THE MOVEMENT SYSTEM: SPECIAL ISSUE

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ABSTRACT

In 2013, the American Physical Therapy Association (APTA) adopted an inspiring new vision, “Transforming society by optimizing movement to improve the human experience.” This new vision for our profession calls us to action as physical therapists to transform society by using our skills, knowledge, and expertise related to the movement system in order to optimize movement, promote health and wellness, mitigate the progression of impairments, and prevent the development of (additional) disability. The guiding principle of the new vision is “identity,” which can be summarized as “The physical therapy profession will define and promote the movement system as the foundation for optimizing movement to improve the health of society.” Recognition and validation of the movement system is essential to understand the structure, function, and potential of the human body. As currently defined, the “movement system” represents the collection of systems (cardiovascular, pulmonary, endocrine, integumentary, nervous, and musculoskeletal) that interact to move the body or its component parts. By better characterizing physical therapists as movement system experts, we seek to solidify our professional identity within the medical community and society. The physical therapist will be responsible for evaluating and managing an individual’s movement system across the lifespan to promote optimal development; diagnose impairments, activity limitations, and participation restrictions; and provide interventions targeted at preventing or ameliorating activity limitations and participation restrictions.

Level of Evidence: 5

Key Words: Movement System, professional identity, physical therapist practice

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BACKGROUND AND INTRODUCTION

The physical therapy profession is often characterized or defined by the treatments we perform. For example, the current Merriam Webster definition of physical therapy is “therapy for the preservation, enhancement, or restoration of movement and physical function impaired or threatened by disease, injury, or disability that utilizes therapeutic exercise, physical modalities (such as massage and electrotherapy), assistive devices, and patient education and training — called also physiotherapy.” The problem with this characterization of our profession is that it places us in the role of technicians who are defined by what we do rather than by our distinct body of knowledge. Such popular mainstream definitions ignore our assessment and clinical reasoning skills that have been refined in order to accurately diagnose and manage our patients. Furthermore, definitions such as this have the potential to mislead the public and other health professionals to underestimate our training, knowledge, and capabilities.

In the new vision statement and associated guiding principles for the profession adopted by the American Physical Therapy Association (APTA) in 2013, there was a conscious effort to promote a more accurate “identity” for the profession. APTA’s vision for the profession is “Transforming society by optimizing movement to improve the human experience.” The first associated principle to accompany this vision was the identity principle which states the following: “The physical therapy profession will define and promote the movement system as the foundation for optimizing movement to improve the health of society. Recognition and validation of the movement system is essential to understanding the structure, function, and potential of the human body. The physical therapist will be responsible for evaluating and managing an individual’s movement system across the lifespan to promote optimal development; diagnose impairments, activity limitations, and participation restrictions; and provide interventions targeted at preventing or ameliorating activity limitations and participation restrictions. The movement system is the core of physical therapist practice, education, and research.”

The concept of the movement system was not new when this vision and identity principle were adopted in 2013. Many clinicians were already using a movement-based approach to the assessment of dysfunction, but the APTA had not promoted the movement system as the foundation or conceptual framework of our practice. At its core, the education of the physical therapist encompasses the study of normal and disordered movement at the molecular, organ, and system levels. We are able to integrate information across multiple existing systems that can influence a patient’s movement and function. It is the integration of this information that the movement system represents and that is reflected in the APTA’s definition of the movement system; “The movement system represents the collection of systems (cardiovascular, pulmonary, endocrine, integumentary, nervous, and musculoskeletal) that interact to move the body or its component parts.” Figure 1 has been adopted as the APTA’s official diagram of the movement system. Unlike other professions that are associated with a single physiological or anatomical system of the body (i.e. urologist), the physical therapist uses their integrative knowledge to maximize physical performance and function and we are the only health care professional trained to systematically evaluate

Figure 1. The Movement System, graphic used with permission of the APTA.
movement at the whole-body level. Therefore, since the term movement system was meant to become a widely-used term not owned by a single discipline, the APTA also adopted a companion definition that was meant to define the physical therapist’s unique role with the movement system.

**PHYSICAL THERAPIST PRACTICE AND THE MOVEMENT SYSTEM**

*Human movement is a complex behavior within a specific context.*

- Physical therapists provide a unique perspective on purposeful, precise and efficient movement across the lifespan based upon the synthesis of their distinctive knowledge of the movement system and expertise in mobility and locomotion.

- Physical therapists examine and evaluate the movement system (including diagnosis and prognosis) to provide a customized and integrated plan of care to achieve the individual’s goal directed outcomes.

- Physical therapists maximize an individual’s ability to engage with and respond to their environment using movement related interventions to optimize functional capacity and performance.

It is important to emphasize that the adoption of the movement system as the foundation of physical therapist practice, education and research was intended to have many more positive benefits for the profession than simply elevating the public’s perception of our role. While the APTA readily acknowledged that many therapists are already practicing as movement system experts who assess movement to identify the root cause of the dysfunction, accurately diagnose the problem, and provide interventions that effectively address the movement disorder and functional limitation, it is widely accepted that there are significant unwarranted variations in the practice of physical therapy that lead to inconsistent quality of the care provided. There are a significant number of therapists whose assessments focus on special tests and impairments rather than movement and function and whose interventions are targeted at treating the symptoms without addressing the root cause of the problem. Specifically, a patient may report to the clinic with patellofemoral pain, and the assessment and treatment is directed toward the knee, when in reality the under-lying problem could well be at the hip. Likewise, a patient may report with low back pain as a primary complaint, when the root cause could be a mobility restriction within the hips. Additionally, both the way students are trained (cardiopulmonary is often a separate and distinct unit separated from musculoskeletal etc.) and the growth of specialization within the profession may have also contributed to the unintended consequence of training therapists to move away from the whole body/ cross systems perspective towards a focus on one particular system. For example, if a neuromuscular physical therapist focuses exclusively on neurological impairments, they may miss critical dysfunction in the musculoskeletal or cardiopulmonary systems that may be significantly contributing to movement dysfunction. An example of this could be seen in a patient with a high risk of falling. Emphasis could be centered upon postural training to control the patient’s center of mass. But if the patient also had a musculoskeletal mobility problem with the spine, reaching overhead would always displace the center of mass in a posterior direction. Putting the emphasis on movement analysis during assessments, targeting interventions at the appropriate movement dysfunction and focusing on the integration of all the systems that interact to produce movement is intended to enhance the consistency of practice and elevate the quality of care provided by all therapists.

Another intended outcome of adopting the movement system is to transition the profession away from a focus on the use of medical diagnoses towards the development and classification of movement system related diagnoses. Most therapists would agree that a medical diagnosis does not guide physical therapy interventions. The APTA has adopted criteria for the development of movement system diagnoses and will be supporting the scientific validation and promotion of these.

To fully promote the movement system, it is anticipated that the professional entry-level curriculum will need to adapt to this new emphasis. At the very least, it is anticipated that there will be an introduction to the term and definition of the movement system in an introductory course combined with
an increased emphasis on movement analysis as an integral part of the assessment process as well as the integration of complex multi-system problems across the curriculum. The intent is not to be prescriptive but to share curricular models and best practices across all entry-level programs and to promote a dialogue within the physical therapy education community.

In summary, adopting the movement system as the core of physical therapist practice, education and research is intended to; 1) elevate the public’s perception of our profession by associating us with our distinct body of knowledge and not just the techniques we use, 2) reduce unwarranted variation in practice and enhance the quality of care, 3) promote new diagnostic labels that will be meaningful to our profession and guide our treatment and 4) to unify educational programs around a common core. The APTA has absolutely no intention of adopting, endorsing or supporting any single therapeutic approach or diagnostic classification system related to the movement system. Scientific discovery related to, and the progression of this concept with input from all stakeholders is welcome and we hope this special edition will help disseminate the concept and engage many more physical therapists from around the world in this vision for the profession.

REFERENCES
ABSTRACT

The Movement System was adopted as the identity of physical therapy as one of the 8 guiding principles accompanying the Vision Statement of 2013. At its inception physical therapy was considered more of a technical field rather than that of a professional field. Physicians were to diagnose the patient's problem and the therapist was to follow the prescription provided by the physician with the primary purpose being to relieve symptoms such as pain or muscle weakness. Even by the 1960's, the prescription became more of a referral and there was recognition that therapists were making decisions about the patient's treatment and discharge disposition. The role of the physical therapist in pathokinesiologic problems has been well accepted over the years but as insights are gained about the role of movement in musculoskeletal pain, the concept of kinesiopathologic problems is being defined. Whether the movement dysfunction is from a pathokinesiologic or a kinesiopathologic mechanisms, the underlying physiologic process is movement which is the composite action of the movement system. This article provides a brief discussion of the steps leading to promotion of the identity and the reasons that further defining and promoting the movement system as the body system for which physical therapists are responsible is necessary for the full recognition of the profession. As suggested by the kinesiopathologic concept of movement inducing pathology, physical therapists can address the cause of musculoskeletal problems and not just symptoms or consequences such as the pathoanatomic problem.

Level of Evidence: 5

Key words: Identity, movement system, pathokinesiologic, kinesiopathologic
THE STEPS LEADING TO AN IDENTITY
More than four years have passed since the American Physical Therapy Association (APTA) designated the Movement System (MS) as the identity of physical therapy. In the process of developing a vision statement that addressed what physical therapy can do for society, the insightful members of the committee enumerated eight principles. The first among these being an identity. The resolution on identity states:

The physical therapy profession will define and promote the movement system as the foundation for optimizing movement. The recognition and validation of the movement system is essential to fully understand the physiological function and potential of the human body. The profession will be responsible for monitoring an individual's movement system across the life span in order to promote optimal development, diagnose dysfunction, and provide interventions targeted at preventing or ameliorating restrictions to activity and participation. The movement system will form the basis of practice, education, and research of the profession.

Amazingly but probably not surprisingly, the issue of an identity had not been specifically addressed in the 96 years of existence of the APTA, though over the years some leaders of the profession have raised the issue. Why the delay? Did the profession already have an identity? If so, what is the identity? From where did it emanate? Is the commonly assumed identity accurate? Was there agreement on the previously assumed identity? A year after the House of Delegates approved the vision statement and the eight guiding principles, an article was published providing an overview of the historical development of the MS and steps by the APTA and by individuals to develop the concept. This article discussed a more general perspective of changes in physical therapy and medicine over the years that lead to the need to develop a clear identity that reflects the extensive changes in the profession over the past 90 years.

IMPLICATIONS OF VISION 2020 AFFECTING IDENTITY
The perspective of the current changes is derived from 60 years in the profession and the opportunity to observe and participate in an amazing transformation of physical therapy. However, this transformation has occurred primarily within the profession and is not widely evident to those on the outside, such as other health professions and the public. The early (but never specifically stated) identity of physical therapy was that of a technical field with clinicians providing physical treatments prescribed by physicians. What a contrast to the goal of the past two vision statements! In Vision 2020 adopted in 2000, the profession's stated lofty goals were consistent with recognition of an autonomous health provider. Vision 2020 stated the goal of the profession to be doctors, diagnosticians, and have direct access to provision of care for patients. That is a marked change from what started as a technical field. Physical therapy is certainly recognized as a profession but at what level? How far has our currently assumed identity progressed? The questions raised by vision 2020 include:

- How does having a doctoral degree differ from having a master's degree?
- What are we going to diagnose?
- What do we offer the public as direct access practitioners?
- What is expected from doctors?

How does having a doctoral degree differ from having a master's degree? The primary rationale at the time of raising entry level to the clinical doctorate was that if patients have direct access to physical therapy, we must be able to recognize conditions that do not “belong” to us. Though certainly a necessary and an admirable role that was always our responsibility. But that rationale does not address what we do for the conditions that do belong to us.

What are we going to diagnose? Just making a statement that we are diagnosticians without providing specific conditions with specific labels makes the claim rather hollow. The lack of diagnostic labels detracts from recognition that we can determine cause or defining characteristics of the conditions we treat. Furthermore, the lack of diagnostic labels fails to convey that movement impairments are not just problems of muscle weakness but can and need to be defined as syndromes. If neurologists or cardiologists claimed to be diagnosticians but did not have specific labels to identify well described pathological
conditions, they would not have the respect of the public or other health practitioners that exists today. The lack of well described diagnostic conditions would also impact treatment and pursuit of underlying pathophysiology. Physical therapy has not followed the pattern of physicians, who classified and described pathophysiological and pathoanatomical conditions, by doing the same with pathokinesiologic and kinesiopathologic conditions.

Why should we have direct access? What do we offer that sends a clear message to the public that they should consult us directly? A common current public belief is that if a health condition, such as a pain problem, is present then a diagnosis is necessary. Are we in any way conveying to the public that a physical therapist can “diagnose” your problem, that there is a label for the condition and a specific method for treating the condition? The prevailing belief is that the doctor diagnoses the problem and if the doctor believes the physical therapist can help relieve the “symptoms” not the problem, the patient will be sent to a therapist. The failure to clearly define what a physical therapist offers, which is directly related to an identity is a major impediment to reaping the benefits of what was implied by vision 2020. Our new vision of how we are going to use our “expertise” to transform society by optimizing movement to enhance the human experience, is going to remain a wishful statement if we do not make the difficult decisions and take the necessary steps to implement all that is implied by designating the movement system as our identity, our expertise, and our responsibility.

TRANSITION FROM TECHNICIAN TO PROFESSIONAL

The status of physical therapy 60 years ago provides some insight into why the transformation of our profession has been so difficult. Entering the field at the end of the polio era, my expectations were that I would help paralyzed children regain their ability to move their limbs and be mobile. My two years of basic college courses were intended to provide enough of a science background to understand anatomy, kinesiology, and physiology. With that information, when the doctor told me what to do, I would understand enough not to be dangerous and maybe even to have some insight into what was happening when stretching muscles to prevent contractures, using muscle re-education to restore muscle function, and practicing basic mobility activities. Of course, manual muscle testing was an important component so that the physician could use the results for identifying what neuronal pathways had been affected by the disease. Manual muscle testing also gave us the information to set expectations for what functional outcome could be expected and what kind of braces and assistive devices would be necessary. During this period, the physical therapist had a clear role with the paralyzed patient of therapeutic exercise to restore muscle function and functional performance. The “prescription” from the physician was very nonspecific, just a diagnosis and therapeutic exercise. In fact, Worthingham indicated that by the 1970’s often the diagnosis was not included in the “prescription” from the physician.

The patient with musculoskeletal pain was a different situation. The “prescription” was usually very specific, detailing the modalities to be used and even some specificity for the exercises. At the time, stretching and strengthening along with modalities were the primary treatments because range of motion and adequate muscle strength seemed to be all that was necessary to restore movement and alleviate pain. Just think how many document systems and insurance companies still require this same information though we know well that this information has little to do with movement performance. We were not expected to figure out the underlying problem, but just implement the prescribed treatments. In fact, Medicare did not pay for physical therapy evaluation until the 1990’s because the physician had performed the examination.

My education really did not address the type of decisions that were necessary for the treatment of the patient with upper motor neuron lesions. The limitation of the physician’s diagnosis became particularly evident when patients with head injury, spinal cord injury, and stroke became the prevailing population in the clinic. What a challenge it was as we tried to understand the difference between treating the patient with upper motor neuron lesions versus those with lower motor neuron lesions. The physician’s diagnosis (or even knowledge) was not much help. In fact, I was part of a study by the Department
of Labor that observed us working with patients and determined we made decisions and therefore could be labeled as professionals rather than technicians. I just wished I had a better understanding of the disordered motor control so the decisions were well founded. The recognition of the expertise of the physical therapist in the treatment of the paralyzed patient is well accepted. But these patients have a diagnosis made by the physician though that diagnosis does not provide useful information regarding the pathokinesiologic condition. The profession did not reinforce the decision-making capabilities of the physical therapist when most forms for referral used by physical therapy services listed the treatment methods and modalities and the physician was to check off what was to be done. Hopefully such forms are no longer used by physical therapy services.

TRANSITION IN PHYSICIAN EDUCATION
In physical therapy, particularly during the 1970’s and 80’s, many things were changing in education and practice as we slowly and subtly began to assume increasing responsibility for making decisions about patient management. Change was also occurring in the education and practice of the physician. In the 1950’s and the early 60’s medical education and practice were anatomically based. The medical student spent extensive hours in the anatomy lab performing dissection of the entire body. Many diagnoses were made based on the physical exam and the location of the pain. Then in the late 60’s, the hours in anatomy were reduced and the increased time was spent in biochemistry courses. Currently in some medical schools only about one week is spent on dissection of the limbs and in others about two weeks. Kinesiology is not part of the course work. Now the educational emphasis for the medical student is cell biology and genetics. In many medical schools, the departments of anatomy have been replaced by neurobiology and physiology by cell biology and physiology. At Washington University School of Medicine St. Louis, anatomy is taught by anthropologist because of the lack of PhDs in anatomy which is reflective of the lack of research related to anatomy. Even systems physiology is not a common focus of research in most basic science departments. As is well known, the physical exam is a small component of the physician’s exam with the primary emphasis being on laboratory and radiological tests. The other major change has been the extensive development of specialists. Though there are many advantages to having specialists in a specific body region, such as the hip reconstruction surgeon, the disadvantage is limited recognition of the interaction of multiple body systems and regional interactions. Thus, a major change over the years is that the physician has minimal knowledge of muscle and movement function. Anatomy and the physical exam are not a major part of practice. Not only is the physician knowledge limited in these areas but there is also limited appreciation for the importance of movement and the role of contributing systems. Recognition of what has changed in physical therapy education and practice is important but so too is recognition of what has changed in the education and practice of the physician.

RECOGNIZING THE ROLE OF MOVEMENT AND THE NEED FOR A PROFESSION-GENERATED IDENTITY
As indicated in the prior information, physical therapists were initially considered to be technicians providing treatment prescribed by the physician. Changing the perception of a health field is more difficult than establishing the desired perception at inception. The earliest definition of physical therapy was treatment by physical means, that included physical agents or modalities and exercise. Of course, the value of this treatment was to restore movement of the limbs and general mobility. So, physical therapy was about movement but on a very simplistic basis of having adequate muscle strength and joint range of motion. The movement disorders of patients with upper motor neuron lesions clearly demonstrated that movement was the result of multiple complex processes. With musculoskeletal pain problems, the development of manipulative and manual therapy reflected the limited effectiveness of strengthening and stretching. The emphasis was then on correcting joint motions rather than limb movements. But the use of movement, even passively applied, was the mode of treatment. What this era did initiate, was the expectation that the therapist should determine the cause of the pain, a relatively new concept.

At the same time, physical therapists were obtaining PhD’s and performing scientific studies. When
physical therapy education was at the baccalaureate level with only two years of basic education, entering a PhD program was not possible without additional education. As more of the physical therapy students had a bachelor's degree before their professional studies, a larger cadre of individuals were qualified and interested in pursuing research degrees. These individuals recognized the need for defining our body of knowledge or underlying science. Helen Hislop identified this need in her 1975 Mary McMillan Lecture and suggested that pathokinesiology is the underlying science. She also stated that the profession suffered from a lack of an identity. Steve Rose, PhD, PT, FAPTA was also an advocate of promoting pathokinesiology as the defining science and even suggested changing the name of the profession. He was also a major promoter of patient classification based on a physical examination that serve as a diagnosis. During a 1984 conference designed to discuss the concept of pathokinesiology, Jules Rothstein stated that 10 years after Hislop reported the problem of the profession's identity the problem is no better. As Dr. Rothstein stated, we are known for what we do and not for what we know. That situation persists today. Several papers were published in the early 1990’s as the outcome of a meeting of academics and clinicians who were interested in furthering the prescient ideas of Dr. Rose. One of the recommendations was to enlarge on the role of physical therapy from just pathokinesiology to include optimization and prevention related to movement. Promoting the concept of movement science was believed to be the optimal way of addressing the comprehensive scope of the body of knowledge of physical therapy. But having a science does not specifically address the clinical application of that science. Just as having neuroscientists does not address the role of neurologists. Describing a movement system, a physiological system of the body, as the focus for clinical practice would be consistent with the pattern used by physicians so successfully.

The evolution in physical therapy education and practice has in many ways paralleled the evolution of understanding movement. Previously adequate interventions targeted at return of muscle strength and range of motion were considered all that were necessary to restore movement and functional performance. The disordered movement resulting from central nervous system lesions demonstrated that the production and regulation of movement is highly complicated. Few physicians were interested in the specifics of the movement disorder and were more interested in the nervous system lesion itself and what type of medication could be used to alleviate symptoms. More recently the role of motor control in patients with musculoskeletal disorders has been the focus of many studies. Only a few orthopaedic surgeons have begun to recognize the role of movement as an important factor in musculoskeletal pain. Beginning in the 1980’s physical therapists were becoming scientists and studying movement disorders as well as aspects of musculoskeletal pain and exercise physiology. An indication of the quality and recognition of research by physical therapists was in the grants provided by the National Center for Medical Rehabilitation and Research (NCMRR). Though designed to promote research by physiatrists, within a few years of its founding, the majority of grants were given to physical therapy based PhD programs. As science was growing, clinical practice remained highly variable in approaches to patient care and was also subjected to demands for productivity. Physicians had minimal background in anatomy and none in kinesiology, so their focus became the underlying pathoanatomical problem now revealed by advances in radiology. Symptom relief became the major emphasis which escalated from anti-inflammatory treatment to forms of opiates for pain relief. The prevailing belief being that if the symptoms subside the condition is resolved, thus movement and activity can be resumed. The inevitability of musculoskeletal pain and osteoarthritis was accepted. What failed to be asked, was how is movement contributing to the problem and how could movement be optimized to slow the process just as activity slows the onset of diabetes and cardiovascular disorders?

Clearly physical therapists were gaining in knowledge about movement-related disorders and ways in which movement could be used for treatment. These gains were reflected in the expansion of the educational content and in the philosophic position adopted by the 1983 House of Delegates.
Physical therapy is a health profession whose primary purpose is the promotion of optimal human health and function through the application of scientific principles to assess, correct, or alleviate acute or prolonged movement dysfunction.

Subsequent modifications of this position in the Guide to Physical Therapist Practice and adopted by the House of Delegates in 1999, expanded the statement of processes used,

“to include examination, evaluation, diagnosis, prognosis and intervention to prevent or remediate impairments in body structures and function, activity limitations, participation restrictions or environmental barriers as related to movement and health”.13

CONSIDERATIONS OF THE PROFESSION’S BUSINESS MODEL AND EFFECT ON THE PRACTICE MODEL

Thus, statements have been made about physical therapy being a doctoring profession but the critical components underlying that status have not been implemented. In part, this can be attributed to the relative business success of physical therapy as indicated by the expansion of educational programs, both for the physical therapist and for the physical therapist assistant, and by profitable practices. When practice is perceived to be good because of profitability, there is little motivation to change or to assess it’s weaknesses. The enactment of Diagnostic Related Groups (DRGS) had a substantial impact on physical therapy in the hospital. No longer was physical therapy a source of substantial revenue. Services moved to outpatient clinics that were not constrained by a fixed amount of money to cover services. So, the effect of DRGs was only temporary but during that time therapists did lose jobs and other sources of revenue had to be found, such as outpatient services and home health. Then the balanced budget act of 1997, which implemented the cap on physical therapy services covered by Medicare had a serious impact on both education and practice. Therapists lost their jobs, salaries went down 20%, applications and enrollment in physical therapy programs were dramatically reduced. Modification of the cap and restructured provision of services restored financial viability mostly by increasing productivity. But there are many reasons to anticipate a not so distant challenge to the business of physical therapy as cost containment becomes a major emphasis by the government and insurance carriers. As the profitability of our previous business model is challenged, there is a necessity to make a strong and vivid case for what physical therapy offers that is not provided by any other profession. Practice based on optimizing movement and the performance of the systems constituting the MS would 1) contribute to maintaining health, and 2) to cost containment by reducing drug and surgical interventions. Recognition of the MS as an important physiological system by the public and other health professions, the use of MS diagnoses, promotion of yearly examinations, lifespan practice, and an emphasis on prevention of movement impairments would provide the specifics for achieving the objectives of vision 2013. Our practice model must change, which requires a clear statement of identity and implementation of all that is implicit in that identity.

WHY THE MOVEMENT SYSTEM AND NOT JUST MOVEMENT?

The group that gathered to further the ideas expressed by Dr. Rose not only suggested the promotion of movement science but were also the first to suggest the idea of the movement system (MS). Over the ensuing 27 years, the concepts have been clarified and developed to varying extents by the approximately 20 individuals in attendance. The Diagnosis Dialog group also reinforced the idea of the movement system. Why use the term MS and not just movement? One reason is that in health care, practice is centered around a body system, which speaks to the expertise of the practitioner. The neurologist is recognized as the expert in the nervous system and the cardiologist as the expert in the cardiovascular system. Though these examples address key anatomical systems and their physiology or their pathophysiology, other physiological processes that involve multiple systems have also been identified as areas of specific practice. For example, the endocrinologist is responsible for the metabolic system, and the immunologist for the immune system. These are systems of systems just as the MS is a system of organ systems as depicted in Figure 1. Movement is a key physiological process
consulted for guidance in development and for prevention. Thousands of dollars are spent to straighten our teeth which is primarily for appearance but no attention is paid to alignment and movement patterns of the body which are essential to all activity.

Movement is key and optimizing the contributions of all the participating organ systems and movement itself can reasonably defer the onset of osteoarthritis as well as other system diseases. In many ways physicians are forced to treat symptoms and consequences while physical therapists can diagnose and treat cause and better yet, play a role in prevention. Conservative treatment, reducing the need for drugs and surgery is cost saving and optimizing the human experience. To be appreciated is that conveying to other health care practitioners and to the public that “therapists” can diagnosis and are responsible for a system of the body is a challenge just based on terminology. As the speech therapists have changed their name to speech pathologists, so should the physical therapy profession consider a change in name that would be in keeping with a change in practice responsibilities.

WHAT IS NEXT?

Upon designating the MS as the identity of physical therapy, the APTA appointed a Board Work Group to develop a definition and a plan to disseminate and implement the MS in practice, education and research. A comprehensive plan was developed as well as a white paper that was published by the APTA and a recommendation for a MS summit. A task force was then appointed to plan and conduct the summit. The task force was to further develop the plan for dissemination and implementation. The summit that was held in December 2016 was considered a success by all those who participated. Three main topics were discussed. The first was terminology, the second was developing a basic movement system exam with a focus on movement, and the third was on diagnosis. The recommendations from the summit were submitted to the APTA Board of Directors. The Board approval for implementation of the recommendations is based on numerous factors including the budget and mandates from the House of Delegates. Though specific steps in enacting the recommendations will be forthcoming, there is no need for physical therapists to wait on promoting the MS. Using the term

Another important aspect of the MS is that guidance for growth and optimal development can become a major responsibility of the physical therapist. Almost daily, evidence is increasing that lifestyle is the major contributor to disease and disability. For example, inactivity has been cited as contributing to a variety of cancers, as well as to the metabolic syndrome a forerunner to diabetes and cardiovascular disease. A recent publication has suggested the major increase in knee joint osteoarthritis is from the reduction in physical activity associated with the post-industrial age. What an irony that as a society we consult our dentist from once to twice a year from a very early age and for the rest of our lives when the major contributions of our oral cavity is for speaking and eating. Yet our body, our MS, is needed for everything and an expert is not

![Figure 1. The movement system adopted by the APTA Board of Directors 2016. Used by permission of the APTA.](image-url)
with patients and in promotional materials is going to be necessary. Implementing practices that provide yearly examinations based on an assessment of the MS would help convey the idea of the importance of optimal movement and that the physical therapist has the expertise that is required. Nothing is more important than movement when considered at all levels of the organism, from ions going through membranes, the flow of synaptic transmitter, how the limbs move, how body segments interact, to how we move in our environment. Just as eating, such an intrinsic part of life, has been taken for granted until recent years, so has movement been taken for granted. As we all know from multiple sources, appropriate nutrition is considered a major factor in health. So must we make the public and other health care practitioners realize that optimal movement is probably even more complicated than optimal nutrition, and that we are the professionals that can provide the guidance that is necessary to be sure exercise and activity contribute to health and not to injury.

CONCLUSION

The APTA has recognized the need for an identity that is commensurate with the extensive changes in the profession that have occurred over the past 30 years. There is little recognition by the public or even by other health professionals that the educational requirement is seven years and that graduates are clinical doctors with extensive knowledge of all the systems that comprise the MS. Promoting the importance of a MS is not only the right thing to do but is also necessary. Knowledge of the movement system can highlight how movement induces pathology, that MS diagnoses can provide labels representing this process, and that a yearly MS exam can contribute to prevention of musculoskeletal problems. Because all indications are that our business model is going to change, physical therapists need to be pro-active and direct change in our practice model.

REFERENCES

ABSTRACT

For at least 40 years, physical therapists have been contemplating the issue of diagnosis. After the profession chose to require completion of doctoral-level training for entry into the profession, making some decisions about diagnosis became essential. In the 2004 Maley Lecture, Cynthia Coffin-Zadai called the profession to action on the question of diagnosis. One response to her call was the formation of a group of physical therapists from across the country to engage in an extended conversation about diagnosis. The Diagnosis Dialog group first met in St. Louis in 2006 and at the end of the meeting they decided to continue the discussion at another meeting. In fact, they met a total of 13 times over 10 years. The purposes of this article are to a) summarize briefly some of the topics that were discussed and b) demonstrate the relevance of those discussions to recent APTA actions regarding the adoption of the movement system as the core of physical therapist practice, education, and research.

**Key Words:** Diagnosis, Movement, Movement System
INTRODUCTION
The overall goals of this special issue of the International Journal of Sports Physical Therapy are to explain the concept of the movement system, and demonstrate how the profession can integrate the concept into physical therapist clinical practice, physical therapist education, and movement system research. The specific purpose of this article is to summarize briefly the work of the Diagnosis Dialog group because of its relevance to recent American Physical Therapy Association (APTA) actions regarding the movement system concept and its relationship to diagnosis.

GETTING STARTED
The multiple reasons for convening the first Diagnosis Dialog meeting were described originally in a Guest Editorial for Physical Therapy.1 What follows here is a brief summary. For over 20 years, many of the faculty at Washington University's Program in Physical Therapy had been interested in the topic of diagnosis and often had considered organizing a gathering of colleagues to talk about diagnosis in physical therapy. Then in the 2004 John H. P. Maley Lecture, entitled “Disabling our Diagnosis Dilemma”,2 Cynthia Coffin-Zadai issued the profession a call to action and the Program decided to respond. The response began by inviting three individuals from other institutions to join us in creating plans for a meeting, namely, Cynthia Coffin-Zadai from the MGH Institute of Health Professions, Barbara Tschoeppe from Regis University, and Ann Van Sant from Temple University. After many months of preparation, the first Diagnosis Dialog meeting was convened in July 2006.

WHAT'S IN A NAME?
The full name of the first meeting was Diagnosis Dialog I: Defining the 'x' in DxPT. We purposefully chose to use the word “Dialog” in the name because we wanted to emphasize the importance of sharing perspectives in a respectful, collegial, and open manner. By intentionally adding an “I” to the name we were hinting that it may take more than one meeting to complete the discussion. Finally, at that time, academic institutions were still in the midst of converting entry-level physical therapist education from the master's level to the clinical doctorate (DPT) level. Ever since the APTA's IMPACT Conferences in the early-1990's, the importance of including diagnosis in post-baccalaureate education had been recognized. However, there was little, if any, agreement on what specific diagnoses physical therapists should be able to make. If diagnosis (Dx) was important for us to practice as DPTs, then the 'x' in the Dx, the missing diagnoses, needed to be defined, made explicit, discussed, tested, validated, revised, and disseminated widely.

DATES AND LOCATIONS OF MEETINGS
The first 2½-day meeting was hosted by the Program in Physical Therapy at Washington University in St. Louis. Dr. Susan Deusinger, Director of the Program at the time, supported the effort by allocating substantial resources to cover the cost of housing and meals for all invited participants, facilities for the meeting, faculty participation, and staff support. For all subsequent meetings, participants covered their own travel expenses but special trips were not required because all of the Diagnosis Dialog meetings were held in conjunction with APTA national meetings. Serendipitously, the next two APTA national meetings after Diagnosis Dialog I happened to be scheduled for Boston and Denver, the home towns of two planning committee members. Thanks to the generosity of those members, Cynthia Zadai, Barbara Tschoeppe, and their institutions, the second and third meetings were held at the MGH Institute of Health Professions and Regis University, respectively. All subsequent meetings were held at APTA National Conference sites prior to the beginning of the conference, most often thanks to assistance from the APTA's Section on Research. Consequently, meetings were held in many cities across the country, including St. Louis (2006), Boston (2007, 2010), Denver (2007), Nashville (2008), Las Vegas (2009, 2014), San Diego (2010, 2013), New Orleans (2011), Chicago (2012), Indianapolis (2015), and Anaheim (2016). The varied locations of the meetings facilitated ongoing participation by members of the original Diagnosis Dialog group and expanded the potential audience for the various educational sessions that the group presented at APTA national meetings.

INVITED PARTICIPANTS
The list of invited participants for the first meeting, Diagnosis Dialog I: Defining the ‘x’ in DxPT, was
designed to include individuals who were known to be interested in the topic of diagnosis, experts in diverse special interest areas, association leaders, researchers, clinicians, educators, and journal editors; see Table 1 for a complete list of original participants. After several meetings, the group decided to expand the Dialog by inviting additional participants and collaborating with them to develop proposals for presentations in educational sessions at CSM.

The expanded list of invited participants included members of the following specialty Sections: Women’s Health, Cardiovascular and Pulmonary, Pediatrics, Oncology, and Orthopaedics. The group also invited individuals functioning in APTA roles that could be influential for expanding the knowledge base of the group and for communicating the current thinking across the profession. For example, a member of the PT Now leadership group at the time, Judy Deutsch, was invited to discuss the concept of using movement-related diagnoses as the major organizing construct for the PT Now topics.

Throughout the years, attendance by members of the group varied based on meeting location, continued interest in discussing the topic, and both personal and professional availability. Whenever the group became aware of new individuals or groups who were interested and willing to contribute constructively to the discussion, they were invited to attend. Table 2 contains the list of everyone who participated in the Dialogs and Diagnosis Dialog-related educational sessions at national meetings. All participants contributed to the richness, breadth, and depth of the wide-ranging discussions throughout the 13 Diagnosis Dialog meetings and enhanced their shared understanding of the issues.

SYNOPSIS OF THE DIALOGS

Diagnosis Dialog I and II: Getting a grip on terminology

A synopsis of the discussions that occurred during the first two meetings was reported in a Guest Editorial for the June 2007 issue of PTJ. To reiterate

<table>
<thead>
<tr>
<th>Table 1. Original Members.</th>
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<tbody>
<tr>
<td>Theresa Bernsen - St. Louis University</td>
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<td>Janel Bezner – APTA Staff</td>
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<tr>
<td>Nancy Byl - University of California at San Francisco</td>
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<tr>
<td>Suzann Campbell - University of Illinois at Chicago</td>
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<tr>
<td>Rebecca Craik - Arcadia University</td>
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<td>Anthony Delitto - University of Pittsburgh</td>
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<tr>
<td>Marti Ferretti - University of Oklahoma</td>
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<td>Edelle Field-Fote - University of Miami</td>
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<tr>
<td>Julie Fritz - University of Utah</td>
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<tr>
<td>Joseph Godges - Kaiser Permanente</td>
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<tr>
<td>Catherine Goodman - Medical Multimedia Group</td>
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<tr>
<td>Jim Gordon - University of Southern California</td>
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<tr>
<td>Andrew Guccione – APTA Staff</td>
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<tr>
<td>Colleen Kigin – Center for Integration of Medicine and Innovative Technology</td>
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<td>Pamela Levangie - Sacred Heart University</td>
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<td>Paula Ludewig - University of Minnesota</td>
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<td>Barbara Norton - Washington University in St. Louis</td>
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<td>Christopher Powers - University of Southern California</td>
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<td>Shirley Sahrmann - Washington University in St. Louis</td>
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<tr>
<td>Patty Scheets - Carle Foundation Hospital</td>
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<tr>
<td>Guy Simoneau - Marquette University</td>
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<td>Barbara Tshoepe - Regis University</td>
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<tr>
<td>Ann VanSant - Temple University</td>
</tr>
<tr>
<td>Cynthia Coffin-Zadai - MGH Institute of Health Professions</td>
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<td>Nancy Zimny - University of Vermont</td>
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Recorders
Jennifer Stith - Washington University in St. Louis
Marcie Harris Hayes - Washington University in St. Louis
briefly, discussions during the first two meetings focused on answering a set of 7 questions (Table 3) that had been derived from a pre-conference survey of the participants and rank-ordered by them based on perceived importance. As you may surmise after reviewing the questions, the group spent a lot of time discussing terminology. Perhaps surprisingly, even in a relatively small group of seasoned professionals, there were many different perspectives on the meanings of words, such as, diagnosis, classification, differential diagnosis, and screening. The group eventually agreed to accept the definition of diagnosis from the Glossary of the 2nd Edition of the Guide to Physical Therapist Practice. The definition refers to diagnosis as being both a process and a label. Two participants wanted to emphasize the process rather than the label form of the word but the majority decided it was time to focus on the labels. The primary point of the discussion regarding classification was whether physical therapists should only classify rather than diagnose; the majority agreed that it is time for physical therapists to make diagnoses not just classify within another practitioner’s diagnosis. Consensus was not clear on the definitions and uses of the words differential diagnosis and screening.

Perhaps one of the most enlightening and entertaining discussions occurred on the topic of how we refer to diagnoses that are made by physical therapists. Historically, we have used a variety of terms, for example, physical therapy diagnosis, diagnosis for physical therapy, and diagnosis by the physical therapist. Because Catherine Goodman had been working on a revision of her textbook, she had called APTA headquarters to ask which version was preferred by APTA. She said that she had received a few different answers depending on who answered the telephone. So, at the Diagnosis Dialog I meeting, she asked Andrew Guccionne, who was then a member of APTA executive staff, to explain the differences and the rationale for a preference. The discussion was lively and culminated in the group’s unanticipated decision to “go naked” on diagnosis. The decision to “go naked” meant that the group thought physical therapists should refer to a diagnosis they make as just a diagnosis without adding any of the

Table 2. Later Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tr>
<td>Karen Abraham</td>
<td>Shenandoah University</td>
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<tr>
<td>Bryon Ballantyne</td>
<td>St. Ambrose University</td>
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<tr>
<td>Jill Boissonnault</td>
<td>University of Wisconsin – Madison</td>
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<tr>
<td>Tamara Burlis</td>
<td>Washington University in St. Louis</td>
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<tr>
<td>Christine Cabelka</td>
<td>Duke University Health System</td>
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<tr>
<td>Susan Clinton</td>
<td>University of Pittsburgh Medical System</td>
</tr>
<tr>
<td>Judy Deutsch</td>
<td>Rutgers School of Health Professions</td>
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<tr>
<td>Ethel Freese</td>
<td>St. Louis University</td>
</tr>
<tr>
<td>Julie Fritz</td>
<td>University of Pittsburgh</td>
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<tr>
<td>Kenneth Harwood</td>
<td>APTA Staff</td>
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<tr>
<td>Lois Hedman</td>
<td>Northwestern University</td>
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<tr>
<td>Kevin Helgeson</td>
<td>Rocky Mountain University of Health Professions</td>
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<tr>
<td>Renee Ivens</td>
<td>Washington University in St. Louis</td>
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<tr>
<td>Aimee Klein</td>
<td>MGH Institute of Health Professions</td>
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<tr>
<td>Stacie Larkin</td>
<td>University of Delaware</td>
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<tr>
<td>Rebecca Lawrence</td>
<td>University of Minnesota</td>
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<tr>
<td>Jennifer Maddocks</td>
<td>Duke University Health System</td>
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<tr>
<td>Murray Maitland</td>
<td>University of Washington</td>
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<tr>
<td>Kathy Martin</td>
<td>University of Indianapolis</td>
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<tr>
<td>Lisa Massa</td>
<td>Duke University Health System</td>
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<tr>
<td>Phil McClure</td>
<td>Arcadia University</td>
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<td>Sally Westcott McCoy</td>
<td>University of Washington</td>
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<tr>
<td>Thomas McPoil</td>
<td>Northern Arizona University</td>
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<tr>
<td>Jean O’Toole</td>
<td>Massachusetts General Hospital</td>
</tr>
<tr>
<td>Nora Riley</td>
<td>St. Ambrose University</td>
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<tr>
<td>Molly Reynolds</td>
<td>Shawnee Mission Center</td>
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<tr>
<td>Natalie Sebba</td>
<td>Duke University Health System</td>
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<tr>
<td>Theresa Spitznagel</td>
<td>Washington University in St. Louis</td>
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<tr>
<td>Justin Staker</td>
<td>University of Minnesota</td>
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<tr>
<td>Michael Voight</td>
<td>Belmont University</td>
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<td>Brian Wrotniak</td>
<td>Daemen College</td>
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Table 3. List of Questions Discussed at Diagnosis Dialog I and II

<table>
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<th>Question</th>
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<tr>
<td>1. What is a diagnosis and what are the ultimate purposes of diagnoses?</td>
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<td>2. What approach(es) should be used to “define” diagnoses for use by physical therapists (e.g., decision trees, Bayesian rules, treatment responsiveness, clinical prediction rules)?</td>
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<td>3. Should diagnoses made by physical therapists be labeled in a particular manner (i.e., diagnosis for PT, diagnosis by PT, physical therapist’s’ diagnosis, physical therapy diagnosis, problem-oriented diagnosis, functional diagnosis)?</td>
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<td>4. How important is it that we establish our professional identity with the movement system?</td>
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<tr>
<td>5. To what extent and how should existing conceptual models (e.g., Nagi, ICIDH, ICF, NCMRR, IOM) be used to inform the development of diagnoses related to physical therapy?</td>
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<tr>
<td>6. How do we define and differentiate between the concepts of diagnosis, differential diagnosis, screening, and classification?</td>
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qualifiers that had been used previously. The one exception they noted was to use the possessive form, “physical therapist’s”, when it was necessary to indicate in clinical documentation which type of clinician had made the diagnosis. The group agreed that “going naked” would make it easier to achieve consistency in communication about diagnosis within the profession and with those in other disciplines. The majority thought it was very important for diagnoses that were made by physical therapists to be viewed in the same light as diagnoses that were made by other health care professionals, for example, physicians. They thought a diagnosis should be descriptive of the patient’s condition within the scope of each clinician’s expertise. The group never retreated from this view and consistently advocated for the profession to “go naked” on diagnosis.

Of particular relevance to recent APTA actions, the group strongly endorsed the notion that it is very important for physical therapists to establish their professional identity with the human movement system; there was no disagreement on this point. Currently, this notion is expressed in the Identity Principle of the APTA’s latest Vision Statement for the profession which was adopted by APTA House of Delegates in 2013. The group also began working on the difficult task of developing criteria for naming diagnoses that are both consistent with the notion of the movement system and within the scope of practice for physical therapists. The group achieved consensus on a proposed set of criteria for diagnostic terms, as follows: “1) use standardized anatomical, physiological, or functional terms that concisely describe the condition or syndrome of the human movement system, 2) use standardized movement-related terms that already exist, 3) include, if deemed necessary for clarity, the name of the pathology, disease, or disorder that is associated with the diagnosis, and 4) be as short as possible to improve clinical usefulness.”

The same set of criteria was used as the starting point for discussion in one of the four major sessions at the APTA’s Movement System Summit in December 2016.

Diagnosis Dialog III: Testing the Criteria and Creating a Framework
The discussions at Diagnosis Dialog III were summarized in a second Guest Editorial for PTJ which was published in October 2007. What follows are some of the highlights. At the end of Diagnosis II, the group had agreed to a revised set of criteria for naming movement system conditions. At Diagnosis Dialog III, the discussion turned away from the exclusive use of existing, primarily pathoanatomically-based, diagnostic terminology and focused on the question of how to develop a diagnostic classification system for movement-related conditions. The participants reflected both on the specific question of what labels to use and on the broad question of how to develop a taxonomic structure for movement-related conditions. The group frequently reiterated the importance of having a set of diagnostic categories defined so they could be recognized easily by PT’s, patients and other health care professionals. The group also often noted that coding for reimbursement purposes is not the same as making a diagnosis and that PTs should not be constrained by existing terminology, for example, the ICF. One of the Diagnosis Dialog members, Theresa Bernstein, was also a member of an ICF work group. She reminded everyone that the terminology in the ICF was being revised constantly. Her main point was that additional terms can be included as part of the revision process. She strongly encouraged the profession to continually work on getting terms included that are relevant to PT instead of just trying to fit their concepts into existing terms.

Prior to Diagnosis Dialog III, the group was assigned the task of generating examples of descriptors that would meet the proposed criteria for naming movement-related conditions. The group generated a list of approximately 70 examples and then discussed many of the examples at the meeting. The following except from PTJ exemplifies some of issues that were considered during discussions of several proposed labels for musculoskeletal conditions:

“Consider 3 descriptors: (1) impairment of glenohumeral mobility associated with adhesive capsulitis, (2) excessive scapular internal rotation associated with rotator cuff disease, and (3) excessive scapular anterior tilting associated with pectoralis minor tightness. One of the group’s first comments was that there might be too much specificity in these descriptors and that the term “scapular dyskinesia” might
suffice; an alternative suggestion was “hypomobility.” One participant drew attention to a subtle difference: descriptor 3 specifies a presumed cause, whereas descriptors 1 and 2 include an associated referral diagnosis. These descriptors also were compared in terms of levels of specificity. For example, a participant who is most familiar with musculoskeletal conditions suggested that terms such as airway clearance dysfunction and cardiovascular pump dysfunction are useful because they paint the “big picture” that is needed to begin planning an intervention strategy. By contrast, the first 3 descriptors for the shoulder problems have a very different level of specificity. This exemplifies the challenge in finding an ideal balance between succinctness and specificity.5

As you may conclude by reviewing the example above and the partial summary in PTJ, this was not an easy task. However, as the discussions proceeded, everyone began to appreciate the insights gained by listening to the perspectives of individuals with expertise in other areas. For example, the issues for a person with expertise in orthopedics became most clear when discussing an example of a movement-related condition in a patient with a primary cardiovascular problem, and vice versa. One of the challenges lies in creating descriptors that are informative yet concise. Another challenge lies in developing a “structure” that accommodates all of the essential components and meshes with existing models, such as, the ICF and the pathoanatomic approach. The multi-axial approach evident in the Diagnostic and Statistics Manual of Mental Disorders, Fourth Edition (DSM-V)7 was viewed as a reasonable model to consider because it allows for description of the patient’s status across a range of dimensions instead of having to represent all of the information about a patient in a single descriptor.

**Diagnosis Dialog IV and V: Developing a structure**

At Diagnosis Dialog IV, the group returned to the examples they had discussed at the previous meeting. A form of card sort process was used in an attempt to identify an underlying structure for the collection of examples. As a starting point, the group tried to sort the examples based on levels of specificity. One recurring struggle was balancing specificity and succinctness in the descriptors. Another struggle was deciding how much needed to be encompassed by the descriptor, everything about the patient or simply the movement problem. What about function, symptoms, environment, etc.? After spending many hours struggling with devising examples of descriptors, the group decided to modify the approach and begin afresh with descriptions of typical patients from which descriptors might arise. As a starting point, the moderator presented a proposed model of the elements that might be encompassed by a diagnostic descriptor related to movement, perhaps referred to as a movement syndrome. As is shown in Figure 1, the model includes five major categories: Client Characteristics, Symptoms, Signs, Contributing Factors, and Structures Affected. Members of the group were asked to think about specific patients and then insert details into the model for that patient. After details had been added to the model for several patients, the group discussed the examples and tried again to devise descriptors. In the course of the discussion, suggestions for revision of the model were suggested. In addition, the group decided a different format would be easier to use than the graphic of the model. The result of the discussion was the template shown in Appendix 1. The template was posted on the Diagnosis Dialog website so members could easily add examples. Thinking about the problem from the perspective of actual patient cases seemed to make the task more manageable but the collection of examples did not grow dramatically.

The relationship of the movement-related diagnosis to existing models was discussed repeatedly. Some of the existing models at the time included the APTA’s patient/client management model,3 the Nagi model,4 the ICDIH,9 the ICF8 and others. The consensus at Diagnosis Dialog I was that we should be informed by existing models but not constrained by them. Everyone understood that many aspects need to be taken into account, for example, signs, symptoms, function, and environment. Everyone also came to understand that clinicians in different areas of practice tend to focus more on some aspects than others. The group discussed the schematics in Figures 3 and 4 as options that might be used to...
represent the relationship between the movement-related diagnosis and two other models. In Figure 2, the published version of the APTA’s patient/client management model is pictured on the left and an adapted version is pictured on the right. Notice that words “movement system” are inserted into the blocks for Examination, Evaluation, and Diagnosis in the adapted version. Doing so, places emphasis on movement-related problems as being the focus of physical therapists. In addition, the representation of the ICF model is inserted between the diagnosis and prognosis blocks. In Figure 3, the movement-related diagnosis is represented as a health condition at the top of the ICF model instead of within the model, just as the health condition determined by a physician is indicated at the top of the model. The figures were intended to invite members to explore new ways of thinking about the concepts. The group did not come to consensus on either of the schematics but did agree that it was important to be able to describe the relationships clearly.

Diagnosis Dialog VI – XII: Expanded engagement and dissemination
The group decided to reach out to colleagues in various specialty sections for added perspective. Thus, we began a series of interactions with new groups of individuals who were interested in sharing ideas about diagnosis in physical therapy. A pattern of interaction evolved around the development of presentations for educational sessions at CSM. The new participants attended a Diagnosis Dialog meeting and shared information about patient cases within their specialty area of practice. Then everyone

**Figure 1. Example of a Model for Diagnosis.**
engaged in discussion about the patient cases to gain a common understanding of the nature of the patient's movement-related problem. The new participants subsequently worked with members of the Diagnosis Dialog group to prepare proposals for educational sessions. Members of the Diagnosis Dialog group also participated in the educational sessions as speakers, panelists, and moderator. The results of the expanded engagement were 12 additional educational sessions that were presented at CSM between 2010 and 2016. The efforts of the section work groups also resulted in at least 3 publications. A list of the tangible outcomes is included in Appendix 2.

A vital component of each educational session was audience participation in the discussion. The presenters invited the audience to explore the possibility of using descriptors of a patient’s movement-related problems as the focus for PTs instead of just using the pathoanatomic descriptors provided by physicians. Everyone recognized the importance of understanding the “medical condition” of the patient and how much clinical specialist know about “medical conditions”. However, the discussions during the presentations gave many members the opportunity to exchange ideas and begin to appreciate the importance of distinguishing the expertise of physical

Figure 2. Example of Representation for Relationship between APTA Patient/Client Management Model, ICF, and Movement-related Diagnosis.

Figure 3. Example of Representation for Relationship between ICF and Movement-related Diagnosis.
therapists from the expertise of physicians by using relevant movement-related diagnoses. Several of the sections are continuing to work on developing terminology consistent with the focus on movement.

**Diagnosis XIII - Passing the Baton**

At the end of their meeting in February 2016, the Diagnosis Dialog group decided to suspend activities in light of two significant actions within the APTA: a) the formation by APTA of a Movement System Task Force, and b) the adoption by APTA House of Delegates of the Position on Management of the Movement System (HOD P06-15-25-24). The final section of the Position statement reads as follows: “Resolved, APTA endorses the development of diagnostic labels and/or classification systems that reflect and contribute to the physical therapists’ ability to properly and effectively manage disorders of the movement system.” With the adoption of this position, the House of Delegates affirmed the need to move forward with the task and the Diagnosis Dialog group did not want to detract from the effort. As noted earlier, the topic of diagnosis was included as one of the major topics at the APTA Movement System Summit in December 2016.

**NEXT STEPS**

One of the major outcomes of the APTA Movement System Summit was a revised version of the criteria for naming movement-related conditions: 1) Use recognized movement-related terms to describe the condition or syndrome of the movement system. Include, if deemed necessary, the name of the pathology, disorder, anatomical or physiological terms, and stage of recovery associated with the diagnosis. 2) Be as succinct and direct as possible to improve clinical usefulness. 3) Strive for movement system diagnoses that span all populations, health conditions, and the lifespan. 4) Whenever possible, use similar movement-related terms to describe similar movements, regardless of pathology or other characteristics of the patient or client. 10

At their April 2017, the APTA Board of Directors adopted the revised set of criteria and the action plan for integrating the movement system concept into practice, education, and research that was generated by participants at the APTA Movement System Summit. One of the items in the action plan for practice is to “Promote the development, implementation and dissemination of diagnostic classification systems/labels that adhere to the established and validated criteria.” The APTA Movement System Task Force has been charged to assemble a work group and move forward with this critical task. Now the fun really begins!

**REFERENCES**

**Appendix 1. Diagnosis Template.**

<table>
<thead>
<tr>
<th>Brief Overview:</th>
<th>Provide a brief overview of the prototypical patient for whom the movement system diagnosis you will describe would be appropriate.</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Demographics:</td>
<td>State the age-range of individuals commonly affected.</td>
</tr>
<tr>
<td>General Demographics:</td>
<td>Indicate the sex of individuals commonly affected.</td>
</tr>
<tr>
<td>General Demographics:</td>
<td>List other key demographic characteristics of individuals commonly affected (e.g., race/ethnicity, primary language, etc).</td>
</tr>
<tr>
<td>History of Current Condition:</td>
<td>List key data from the history of a typical patient that are related to the movement system condition (e.g., patient concerns, mechanism of injury or disease, onset and pattern of symptoms, expectations and goals, etc).</td>
</tr>
<tr>
<td>General History:</td>
<td>List other key data, if any, from the history of a typical patient that are specifically relevant to the movement system condition in individuals commonly affected (e.g., medications, other tests and measures, past history of current condition, previous hospitalizations and surgeries, pre-existing health-related conditions, social history, occupation, growth &amp; development, living environment, family history, social habits).</td>
</tr>
<tr>
<td>Tests &amp; Measurements:</td>
<td>List key tests that should be performed and results expected for individuals commonly affected; if relevant, key negative tests should be included.</td>
</tr>
<tr>
<td>Activity &amp; Participation:</td>
<td>List key activity limitations and participation restrictions that typically are evident in individuals with the condition.</td>
</tr>
<tr>
<td>Key Elements Missing:</td>
<td>If there are any other characteristics that are key elements of this movement system diagnosis and you have not yet had the opportunity to describe them, please list them.</td>
</tr>
<tr>
<td>Diagnoses to Rule Out:</td>
<td>List other conditions with similar presentation that would need to be &quot;ruled out&quot;.</td>
</tr>
<tr>
<td>Diagnosis:</td>
<td>What is the proposed name of the human movement system condition?</td>
</tr>
<tr>
<td>Rationale for Name of Diagnosis:</td>
<td>What is the basis for the name used to identify the movement system condition (e.g., anatomic, physiologic, kinesiologic, response to movement, response to treatment, etc)?</td>
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<tr>
<td>Supporting Evidence:</td>
<td>If the movement system condition that you have described has been reported previously in the literature, please cite reference(s).</td>
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<td>Contributor Information:</td>
<td>What is your name?</td>
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### Appendix 1. Diagnosis Template (continued)

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<thead>
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<th>Contributor Information: In which state are you located?</th>
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</tr>
<tr>
<td>Contributor Information: What is your primary area of practice?</td>
</tr>
<tr>
<td>Contributor Information: Are you an ABPTS-certified specialist?</td>
</tr>
<tr>
<td>Contributor Information: What is your specialty area?</td>
</tr>
<tr>
<td>Contributor Information: How many years have you been a physical therapist?</td>
</tr>
<tr>
<td>Survey Feedback: If the structure provided by the questions in this survey did not allow you to describe the condition adequately, what additional question(s) need to be included?</td>
</tr>
<tr>
<td>Survey Feedback: Please use this space to provide additional suggestions or comments. Thank you for your contribution!</td>
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## Appendix 2. Timeline of Meetings and Tangible Outcomes from Diagnosis Dialog 2006

### 2006

<table>
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<th>Meeting</th>
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<tr>
<td>Diagnosis Dialog I</td>
<td>July 19-21, 2006</td>
<td>Washington University, St. Louis, MO</td>
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<table>
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<tr>
<td>Diagnosis Dialog II</td>
<td>February 13, 2007</td>
<td>MGH Institute of Health Professions, Boston, MA</td>
</tr>
<tr>
<td>Diagnosis Dialog III</td>
<td>June 26-27</td>
<td>Regis University, Denver, CO</td>
</tr>
<tr>
<td>PTJ Symposium</td>
<td>June 30, 2007</td>
<td>PT 2007, Denver, CO</td>
</tr>
<tr>
<td>Poster Presentation – Diagnosis Dialog I &amp; II: Defining the ‘x’ in DxPT; Barbara Norton, Shirley Sahrmann, Jennifer Stith</td>
<td>June 2007</td>
<td>WCPT, Vancouver, BC</td>
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<table>
<thead>
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<th>Publication</th>
<th></th>
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### 2008 – Meeting - Diagnosis Dialog IV – February 5-6; Nashville, TN

<table>
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<th>Event</th>
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<tr>
<td>Educational Session – Diagnosis Dialog: Defining the ‘x’ in DxPT; Cynthia Zadai, Barbara Norton, Anthony Delitto; PT 2008, San Antonio, TX</td>
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<tr>
<td>Educational Session – Diagnosis Dialog: Sharing Perspectives; Panelists: Panel A - Theresa Bernsen, Catherine Goodman, Colleen Kigin, Patty Scheets, Cynthia Zadai, Nancy Zimny; Panel B – Marti Ferretti, Joe Godges, Pam Levangie, Paula Ludewig, Shirley Sahrmann, Ann Van Sant; Panel C – Theresa Bernsen, Rebecca Craik, Edelle Field-Fote, Jim Gordon, Patty Scheets, Ann Van Sant; Panel D – Anthony Delitto, Marti Ferretti, Julie Fritz, Christopher Powers, Barbara Tschoepe, Nancy Zimny; Panel E – Rebecca Craik, Pam Levangie, Paula Ludewig, Christopher Powers, Shirley Sahrmann, Cynthia Zadai; Moderator – Barbara Norton; PT 2008, San Antonio, TX</td>
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</tr>
</tbody>
</table>

### 2009 – Meeting - Diagnosis Dialog V – February 8-9; Las Vegas, NV

| Educational Session - Diagnosis Dialog: Research & Clinical Perspectives on Defining the ‘x’ in DxPT – Part A; Cynthia Zadai, Barbara Norton, Anthony Delitto; CSM 2009, Las Vegas, NV |
Appendix 2. Timeline of Meetings and Tangible Outcomes from Diagnosis Dialog 2006. (continued)

Educational Session – Diagnosis Dialog: Research & Clinical Perspectives on Defining the ‘x’ in DxPT – Part B; Panelists: Panel A - Theresa Bernsen, Catherine Goodman, Colleen Kigin, Patty Scheets, Cynthia Zadai, Nancy Zimny; Panel B – Marti Ferretti, Joe Godes, Pam Levangie, Paula Ludewig, Shirley Sahrmann, Ann Van Sant; Panel C – Theresa Bernsen, Rebecca Craik, Edelle Field-Fote, Jim Gordon, Patty Scheets, Ann Van Sant; Panel D – Anthony Delitto, Marti Ferretti, Julie Fritz, Christopher Powers, Barbara Tschoepe, Nancy Zimny; Panel E – Rebecca Craik, Pam Levangie, Paula Ludewig, Christopher Powers, Shirley Sahrmann, Cynthia Zadai, Barbara Norton (Moderator); CSM 2009, Las Vegas, NV

2010 – Meeting - Diagnosis Dialog VI – February 16-17; San Diego, CA

Educational Session - Diagnosis Dialogs: Defining the ‘x’ in DxPT; Cynthia Zadai, Barbara Norton, Anthony Delitto; CSM, San Diego, CA

Educational Session – Diagnosis Dialog for the Women’s Health Clinical Specialist; Presenters - Barbara Norton, Jill Boissonnault, Karen Abraham, Theresa Spitznagle; Panelists – Theresa Bernsen, Paula Ludewig, Shirley Sahrmann, Barbara Tschoepe, Ann Van Sant, Cynthia Zadai; CSM 2010, San Diego, CA

Vodcast - Norton BJ, Sahrmann SA, Zadai CC: Video on Diagnosis Dialog Initiative. http://ptjournal.apta.org/cgi/content/full/90/6/DC2; June 2010

Meeting - Diagnosis Dialog VII – June 15-16; Boston, MA

2011 – Meeting - Diagnosis Dialog VIII –February 8-9; New Orleans, LA

Educational Session – Diagnosis Dialog for Cardiovascular & Pulmonary Physical Therapists; Ethel Frese, Tamara Burlis, Cynthia Zadai, Barbara Norton (Moderator); CSM 2011, New Orleans, LA

Educational Session – Diagnosis Dialog for the Pediatric Physical Therapist; Presenters - Kathy Martin, Ann Van Sant, Sally Westcott McCoy, Brian Wrotniak, Barbara Norton (Moderator); CSM 2011, New Orleans, LA

Educational Session – Section on Women’s Health Diagnosis Task Force: Membership Forum on Development of Women’s Health PT Diagnosis Language; Presenters – Karen Abraham, Jill Boissonnault, Carrie Pagliano, Theresa Spitznagle, Natalie Sebba, Barbara Norton (Moderator); CSM 2011, New Orleans, LA

2012 – Meeting - Diagnosis Dialog IX – February 7-8; Chicago, IL

Educational Session - Diagnosis Dialog: In patients with multi-system involvement- What "labels" should we use? Karen Abraham, Tamara Burlis, Ethel Frese, Pamela Levangie, Natalie Sebba, Cynthia Zadai, Theresa Spitznagle, Jennifer Maddocks, Barbara Norton (Moderator); CSM 2011, Chicago, IL

Educational Session - Diagnosis Dialog for Oncology Physical Therapists; Catherine Goodman, Lisa Massa, Molly Reynolds, Stacie Larkin, Jean O’Toole, Barbara Norton (Moderator); CSM 2011, Chicago, IL
Appendix 2. Timeline of Meetings and Tangible Outcomes from Diagnosis Dialog 2006. (continued)

Educational Session – Section on Pediatrics Diagnosis Task Force: Member Forum on Development of Pediatric Diagnostic Language; Kathy Martin, Ann Van Sant, Sally Westcott McCoy, Brian Wrotniak; CSM 2011, Chicago, IL

2013 – Meeting - Diagnosis Dialog X – January 20-12; San Diego, CA

Educational Session – Diagnosis Dialog in Orthopedics – Part 1: Shoulder Impingement, Can Therapist and Surgeons Learn to Speak the Same Language? Paula Ludewig, Jonathan Braman; CSM 2013, San Diego, CA

Educational Session – Diagnosis Dialog in Orthopedics – Part 2: What labels should physical therapists use? Paula Ludewig, Tom McPoil, Christopher Powers, Shirley Sahrmann, Barbara Norton (Moderator); CSM 2013, San Diego, CA

Educational Session - The Complicated Patient: In Patients with Multi-system Involvement – How does the diagnoses focus the intervention? Lisa Massa, Christina Holladay, Jennifer Maddocks, Tracy Spitznagle; CSM 2013, San Diego, CA

Educational Session – Diagnosis Dialog for Physical Therapists in the Neurology & Pediatrics Sections; Kathy Martin, Patricia Scheets, Edelle Field-Fote, Sally Westcott McCoy, Barbara Norton (Moderator); CSM 2013, San Diego, CA


2014 – Meeting - Diagnosis Dialog XI – February 2-3; Las Vegas, NV

Educational Session - Diagnosis Dialog: Classification of Shoulder Disorders in the ICF-based Clinical Practice Guideline and Alternative Approaches; Joseph Godges, Paula Ludewig, Aimee Klein, Phillip McClure, Shirley Sahrmann, Barbara Norton (Moderator); CSM 2014, Las Vegas, NV

Educational Session - Diagnosis Dialog: What Do These Patients Have in Common? Kathy Martin, Patricia McGee, Sally Westcott McCoy, Susan Strecker, Barbara Norton (Moderator); proposal submitted but not accepted

2015 – Meeting - Diagnosis Dialog XII – February 2-3; Indianapolis, IN

Educational Session – Movement System Diagnosis and Management of Shoulder Conditions; Joseph Godges, Paula Ludewig, Phillip McClure, Shirley Sahrmann, Barbara Norton (Moderator); CSM 2015, Indianapolis, IN

2016 – Meeting - Diagnosis Dialog XIII – February 16-17; Anaheim, CA

Educational Session – Clinical Examinations Used for Diagnosis of Shoulder Conditions: What Should Be the Focus? Joseph Godges, Paula Ludewig, Shirley Sahrmann, Barbara Norton (Moderator); CSM 2016, Anaheim, CA

ABSTRACT

Proper diagnosis is a first step in applying best available treatments, and prognosticating outcomes for clients. Currently, the majority of musculoskeletal diagnoses are classified according to pathoanatomy. However, the majority of physical therapy treatments are applied toward movement system impairments or pain. While advocated within the physical therapy profession for over thirty years, diagnostic classification within a movement system framework has not been uniformly developed or adopted. We propose a basic framework and rationale for application of a movement system diagnostic classification for atraumatic shoulder pain conditions, as a case for the broader development of movement system diagnostic labels. Shifting our diagnostic paradigm has potential to enhance communication, improve educational efficiency, facilitate research, directly link to function, improve clinical care, and accelerate preventive interventions.

Key words: Diagnosis, Movement System, Physical Therapy
INTRODUCTION
As health care providers, we seek to provide the best possible care to clients who seek our counsel. To do so, we need to provide the “right treatment to the right patient at the right time”.1 Optimally, we evaluate our clients and use “best available evidence”2,3 to determine the “right” intervention. In musculoskeletal care, this process has traditionally relied upon pathoanatomic diagnostic labels. However, as physical therapists, we focus on treating movement impairments, consistent with our professional vision and identity in the movement system.4,5 Subsequently, there is a disconnect between our diagnostic and treatment process.6,7 This manuscript will advocate that in order to advance best possible care and preventive interventions, our diagnostic paradigm needs to shift to a movement system diagnostic classification approach.8 While a uniformly agreed upon and proven movement system diagnostic classification does not currently exist, we present a framework to develop and test such an approach using examples of clients presenting with atraumatic shoulder pain. Our proposal is not presented as the definitive “answer” to our collective diagnostic dilemma.9,9 We firmly believe development of the most effective movement based diagnostic classification will rely upon an interdisciplinary collaborative process, with ongoing refinement. We hope this manuscript will assist in advancing that process.

WHY CLASSIFY?
In considering such a diagnostic paradigm shift, we first must consider why we classify clients in the first place. Why not treat each client individually? There are many benefits to classifying signs and symptoms across individuals. These include best directing our interventions toward common patterns of clinical presentation; understanding the prognosis; communicating with clients, amongst the health care team, and with third parties; influencing reimbursement models; and creating homogenous groups for research investigations and clinical practice guidelines.6-8

There are many potential classification schemes for use in grouping clients. For instance, we can categorize by region of symptoms (e.g. shoulder, low back, or knee), duration of symptoms (acute, subacute, or chronic), or level of tissue irritability (high, moderate, low).10 A diagnostic classification is often presumed to provide utility in determining causation, guiding treatment decisions, and/or prognosticating about a condition.8,11 “Diagnosis may be defined as the determination of the cause or nature of an illness by evaluation of the signs, symptoms and supportive tests in an individual patient.” “Diagnostic criteria are a set of signs, symptoms, and tests for use in routine clinical care to guide the care of individual patients”.12 An ideal diagnostic classification would incorporate adequate, but not excessive specificity. As such, clinical interventions could be tested and clinical practice and prognostic guidelines could be developed and refined within homogenous groups. Some amount of treatment individualization will always need to occur with each unique client, while still allowing an overall treatment approach to be developed and tested from a set of diagnostic labels.

TRADITIONAL PATHOANATOMIC DIAGNOSTIC MODEL
The most common diagnostic labeling for musculoskeletal conditions attempts to identify a specific tissue pathology that is presumed to be the source or cause of the client’s pain or dysfunction (i.e. pathoanatomy). For the shoulder, diagnostic terms such as rotator cuff tendinopathy, full thickness rotator cuff tears, or labral tears are frequently utilized. The gold standard for verifying these conditions is medical imaging (MRI, x-ray, etc.) and/or surgical confirmation.13,14 In typical clinical practice, however, practitioners often rely heavily on “special tests” or “pain provocation tests” to theoretically confirm the underlying presence of a tissue pathology, and that tissue’s role as a pain generator or source of the symptoms. Some immediate challenges with a pathoanatomic model include the high cost of diagnostic imaging, limited validity and reliability of special tests,15-17 and the frequency with which pathoanatomy is found in asymptomatic patients.18-22

As a specific example of the pathoanatomic model, the three most common diagnostic labels for shoulder conditions are depicted in Figure 1. In particular, shoulder impingement or rotator cuff syndrome is the most commonly assigned diagnostic label in individuals presenting with shoulder pain, but may also be termed rotator cuff disease, subacromial...
impingement, or subacromial pain syndrome.\textsuperscript{23–27} The generally accepted clinical confirmation of shoulder impingement syndrome is pain with one or more impingement tests (Hawkins/Kennedy, Neer, etc.), a painful arc of motion when raising the arm, and pain or weakness with resisted external rotation.\textsuperscript{10,28,29} Additional challenges exist within this pathoanatomic diagnostic framework. First, many of the specific pathoanatomical findings co-exist. As such, distinguishing a labral tear from rotator cuff disease, or distinguishing rotator cuff tendinopathy from a partial thickness rotator cuff tear, for example, may not be possible, or even important with regard to treatment planning. Second, even presuming the clinician reaches a valid pathoanatomic diagnostic conclusion, these diagnostic labels have limited ability to direct selection of interventions.\textsuperscript{10} This is in part because rotator cuff disease, for example, is associated with multifactorial etiology and a wide variety of movement system impairments.\textsuperscript{30–32} Further, the presence of tissue pathology is often not the source of the client’s pain. Consequently, it is not beneficial to look to the literature evidence for the “five best exercises” to most effectively treat rotator cuff tendinopathy. As physical therapists, even when we have a pathoanatomic diagnosis in hand, we still need to examine the patient for the associated movement impairments that may contribute to their condition and that are appropriate for physical therapy intervention (Figure 2).\textsuperscript{10,31} For example, one individual might have posterior shoulder tightness as a primary movement impairment leading to their rotator cuff tendinopathy,\textsuperscript{33,34} while another individual might have glenohumeral microinstability as their primary contributing movement impairment.\textsuperscript{35} These differing contributing factors require different treatments. The traditional pathoanatomic approach treats these movement impairments as secondary to the pathoanatomic diagnosis, when in fact the movement factors are most often the primary drivers of treatment decisions.\textsuperscript{31,36} But perhaps an even more important limitation with pathoanatomic diagnoses is that, when present, the pathoanatomy often results from “wear and tear” or “overuse” through repeated exposure to tissue stresses and microtrauma over time. For example, a recent meta-analysis suggests substantially increased incidence of shoulder pain at follow-up in asymptomatic overhead athletes prospectively identified with scapular dyskinesis.\textsuperscript{37} Clinical practitioners aim to target treatments to the cause of a condition as early as possible in its development to facilitate optimal healing and minimize further progression. The pathoanatomic model, which focuses on the effects of stresses on tissues rather than the causative factors, is therefore limited in its power for early detection or ideally prevention of a condition.

Despite these limitations, one of the most common arguments for retaining the pathoanatomic model as the diagnostic framework is that this is the existing physician model. Some argue creating a new and

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**Figure 1.** The three most common diagnostic classifications of shoulder pain in the traditional pathoanatomic model, after ruling out conditions not of shoulder origin (e.g. cervical referred pain).

**Figure 2.** Depiction of the typical flow of the diagnostic process in the traditional pathoanatomic framework. First a pathoanatomic diagnosis would be determined or confirmed using clinical examination findings with or without additional diagnostic imaging. Subsequently, additional examination for associated movement impairments is still needed prior to identifying the best evidence intervention. The three most common pathoanatomic diagnostic categorizations are presented, as well as two examples of potentially related movement impairments.
The unfamiliar diagnostic framework will impair communication with physicians and other healthcare providers. However, in the case of the most common shoulder diagnosis, “impingement”, surgical specialists are advocating for doing away with this diagnostic label. The rationale for this advocacy is that the use of the impingement label has become so broadly applied as to limit its ability to effectively direct treatment. In effect, the impingement diagnosis has become a diagnosis of exclusion of other primary related diagnoses (cervical radiating pain, adhesive capsulitis, glenohumeral instability). Once these other disorders are ruled out, nearly all patients with anterior/lateral shoulder pain complaints are diagnosed with “impingement” or related rotator cuff diagnostic labels. Further, the “impingement” label typically implies anatomic causation to surgeons (specifically anterior acromial), while the same diagnosis typically implies movement causation to physical therapists. (Figure 3). As such, we are using the same label but with different meaning, confounding rather than enhancing communication. We should seize the opportunity the proposed shift in labeling brings in order to also shift the underlying framework from which we make our diagnostic decisions.

**PATHOKINESIOLOGIC OR KINESIOPATHOLOGIC MODEL: MOVEMENT SYSTEM MODEL**

An alternate framework to the pathoanatomic diagnostic classification is a pathokinesiologic or kinesiopathologic model. This model creates a diagnostic classification related to the characteristic movement impairments that are the cause of, or consequence of, the client's pain or dysfunction. This classification then leads directly to the intervention approach (i.e. treating these movement impairments), and can be considered a movement system model. A presumption with this movement system model is that there will be a stronger relationship to function and better integration with the International Classification of Functioning, Disability and Health (ICF) model as compared to the weaker relationships between function and pathoanatomy. This movement system model framework does not presume or preclude any specific tissue pathology. The movement system model continues to recognize the importance of pathoanatomy to our clinical decision-making, but instead treats it as a modifier rather than the overarching categorization of primary interest (Figure 3). The movement system framework also does not preclude psychosocial components to a condition. For example, if a client has reduced scapular upward rotation, glenohumeral subluxation, and shoulder pain secondary to a stroke, we treat the movement impairments, but are informed by the neurophysiologic and psychosocial impacts of the stroke.

When referring back to the three most common shoulder diagnoses (Figure 1), these three categories can be renamed in the movement system framework as depicted in Figure 4. In essence, instability...
was really already a movement system based diagnosis. This category can be thought of as either a hypermobility or a stability deficit. Clients in this category are moving too much at the joint. Secondly, the distinguishing clinical characteristic of adhesive capsulitis is a primary equivalent loss of both active and passive glenohumeral joint motion. This category can be thought of as either a hypomobility, or a mobility deficit. Clients in this category are moving too little at the joint. Within a movement framework, we can also include other pathoanatomic conditions in this hypomobility category with the same characteristic motion loss, including glenohumeral osteoarthritis or post-fracture stiffness. Finally, clients in the “impingement” categorization can be labeled as moving abnormally, with some moving too much, some too little, and others with aberrant or discoordinated movement. As with the hypomobility category, we can expand the pathoanatomic conditions that might present in this motion category beyond just the rotator cuff to include long head biceps tendinopathy, subacromial bursitis, or labral tearing (Figure 4).

At this stage of our classification (three main groups), many clients would end up in the same initial broad categorization based on clinical examination using either the pathoanatomic or the pathokinesiologic framework. However, there are a number of advantages to the movement system based framework. First, the overall treatment goals are derived directly from the diagnostic category: improve functional stability in clients in the hypermobility category; improve functional mobility in clients in the hypomobility category; and improve functional movement coordination or balance of mobility and stability in clients in the aberrant motion category. We would not apply treatments to gain mobility with a client with hypermobility and so forth. This framework further prioritizes the movement in the classification system, and also in the diagnostic process. A movement examination assessing both quality and quantity of movement follows directly from the patient history. Special tests to identify tissue pathology are best used more selectively to potentially modify the intervention approach and inform prognosis and/or coordination of care after identifying a movement classification. Because the movement system is the focus of the diagnosis, there are no issues with scope of practice,5–7 and no over reliance on expensive medical imaging.

PROPOSED SHOULDER MOVEMENT BASED CLASSIFICATION OF GREATER SPECIFICITY

In either model, we still need to drill down from these broad overarching categories to a level of specificity that can more effectively direct treatment. However, doing so from the movement system framework results in a logical and consistent flow starting immediately from the initial diagnostic classification. First, the patient’s chief complaint related to stability, mobility, or pain with movement provides a broad classification that begins to direct our treatment (Figure 4). Subsequently, a movement examination informed by the subjective reports results in pattern recognition related to a primary movement pattern contributing to the client’s pain.
or refuting the suspected diagnosis, and dynamically guiding the clinician’s examination.

With regard to the shoulder, Figure 5 presents common movement patterns recognized in a number of previously described classifications31,42,43 (Joe Godges, DPT, MA, OCS, personal communication). These patterns are not typically present in isolation. For instance, insufficient scapular upward rotation is often associated with glenohumeral hypermobility44,45 and excess scapular internal rotation and insufficient scapular posterior tilt may occur in combination.32 A classification is not determined based on simply the presence of an isolated movement impairment, but instead on the collective history

Figure 5. Proposed classification of primary patterns of movement impairments. Clients may present with shoulder pain of non-mechanical or non-shoulder origin, requiring alternate classification. Within those with symptoms or dysfunction of mechanical origin, glenohumeral or scapulothoracic subtypes are distinguished. Further specificity is provided for the scapulothoracic subtypes. It is recognized that multiple movement impairments may be present and the classification is based on the movement impairment pattern believed most relevant to the client’s presentation.

Figure 6. Additional classification of potential movement impairment contributors to a condition, and subsequent targeted treatment approaches that may follow.
movement system framework, and the necessary associated clinical diagnostic tests and measures. Investigation of utility should be broad ranging, including impact on client short- and long-term outcomes, cost-effectiveness, efficiency of the diagnostic and treatment process, and efficiency of the educational process. There will also need to be additional discussion surrounding the most appropriate labels for each diagnostic category. The American Physical Therapy Association (APTA) has endorsed the following criteria for use with a movement system diagnostic classification.47

1) Use recognized movement-related terms to describe the condition or syndrome of the movement system;

2) Include, if deemed necessary, the name of the pathology, disease, disorder, anatomical or physiological terms, and stage of recovery associated with the diagnosis.

3) Be as succinct and direct as possible to improve clinical usefulness.

4) Strive for movement system diagnoses that span all populations, health conditions, and the lifespan. Whenever possible, use similar movement-related terms to describe similar movements, regardless of pathology or other characteristics of the patient or client.

LIMITATIONS OF THE MOVEMENT SYSTEM FRAMEWORK

The movement system framework is not without limitations that need to be addressed. It will require research investigation to determine and confirm reliable, valid, and useful categorizations within the movement system framework, and the necessary associated clinical diagnostic tests and measures. Investigation of utility should be broad ranging, including impact on client short- and long-term outcomes, cost-effectiveness, efficiency of the diagnostic and treatment process, and efficiency of the educational process. There will also need to be additional discussion surrounding the most appropriate labels for each diagnostic category. The American Physical Therapy Association (APTA) has endorsed the following criteria for use with a movement system diagnostic classification.47

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3) Be as succinct and direct as possible to improve clinical usefulness.

4) Strive for movement system diagnoses that span all populations, health conditions, and the lifespan. Whenever possible, use similar movement-related terms to describe similar movements, regardless of pathology or other characteristics of the patient or client.

Figure 7. Depiction of potential movement system impairments to be assessed following from identification of primary movement pattern abnormalities. These impairments if present would lead directly to treatment planning decisions.
As this framework is developed, this type of nomenclature will require reworking the diagnostic and therapeutic algorithm for clinical practitioners and developing new curricula not only for those in practice, but also for those who educate the next generation of clinicians. However, the direct flow from movement diagnosis, to assessment of movement impairments, to targeted intervention (Figures 5 and 7) can improve the efficiency of the educational process and advancement toward clinical expertise.

This framework is presented with a musculoskeletal shoulder example, but other health conditions can be described in a similar manner. For instance, in a client who has experienced a stroke, classifying the movement presentation will inform the appropriate rehabilitation intervention more directly than classifying the location or size of the brain lesion. Furthermore, there will be a need for linkage to traditional pathoanatomic diagnoses since billing, historical research, and clinician communication are difficult to change. This idea is consistent with criteria #2 listed above. The issue is whether we emphasize the movement system impairments during these communications and how we choose to diagnose and treat our patients.

Lastly, this framework as presented focuses on mechanical pain and dysfunction. As noted in Figure 5, some clients may best fit a biopsychosocial or pain processing classification system in the absence of identifiable mechanical contributors. In addition, it is always important to consider psychosocial and pain processing factors when determining the most appropriate diagnostic classification and treatment approach, even with a primary mechanical contributor. Additional research is required to fully investigate relationships between movement impairments and pain and function.

**IS THERE MULTI-DISCIPLINARY UTILITY IN A MOVEMENT SYSTEM DIAGNOSTIC CLASSIFICATION?**

When originally envisioned, it was thought that a movement system diagnostic framework would be primarily utilized by physical therapists given their movement system identity and expertise. Figure 3 illustrates that in evaluating the same client, a surgeon may focus their exam more on the pathoanatomy, because surgical interventions can modify the pathoanatomy. Physical therapists focus their exam more on the pathokinesiology because rehabilitation interventions can modify the movement system impairments and movement stresses. Both are interested in tissue pathology but from different perspectives. Both are interested in the best functional outcomes for the patients, but each profession has unique treatment “tools”. As such, it might seem that surgeons would continue to use specific pathoanatomic classifications, while therapists might more frequently use a movement system diagnostic classification.

However, at least at the broad categorical level (Figure 4) there is likely substantial multi-disciplinary utility for musculoskeletal conditions. Considering if a condition is predominantly a joint hyper- or hypo-mobility helps to drive appropriate surgical procedure decisions as well as non-surgical rehabilitation. Further, if the origin of the presenting pathoanatomy is based on an abnormal movement causation, a movement classification can be particularly beneficial in treatment planning. Other non-surgical health care providers responsible for first line patient care (physiatrists, family practice physicians, nurse practitioners, physician’s assistants, etc) may also have interest in a movement system diagnostic classification as it relates to appropriate referral and preventive interventions.

As mentioned earlier, clear communication between clinicians is paramount for best patient care. Even so, there remain examples where something as simple as the definition of the same diagnostic label (e.g. “impingement”) differs from profession to profession. Consequently, standardized diagnostic labels would facilitate communication between providers. As a result, we advocate that these movement system diagnostic labels be developed to enhance communication. When developed, they will benefit patients by making communication between all parties easier and more consistent.

**CONCLUSION**

In conclusion, we advocate that development of movement system based diagnostic classifications for health conditions will benefit health care provision, outcomes, education, communication, and
preventive interventions. As a profession, we are slow in advancing the legacy first put forth over 30 years ago.\textsuperscript{6,8,9} With regard to utility of diagnostic classification, we believe improved classifications will evolve from rigorous scientific testing and the test of time - i.e. “the proof of the pudding is in the eating”. As such, it is time to work in earnest toward advancing a movement system diagnostic framework.

REFERENCES


ABSTRACT

Although many physical therapists have begun to focus on movement and function in clinical practice, a significant number continue to focus on impairments or pathoanatomic models to direct interventions. This paradigm may be driven by the current models used to direct and guide curricula used for physical therapist education. The methods by which students are educated may contribute to a focus on independent systems, rather than viewing the body as a functional whole. Students who enter practice must be able to integrate information across multiple systems that affect a patient or client's movement and function. Such integration must be taught to students and it is the responsibility of those in physical therapist education to embrace and teach the next generation of students this identifying professional paradigm of the movement system. The purpose of this clinical commentary is to describe the current state of the movement system in physical therapy education, suggest strategies for enhancing movement system focus in entry level education, and envision the future of physical therapy education related to the movement system. Contributions by a student author offer depth and perspective to the ideas and suggestions presented.

Level of Evidence: 5

Key Words: Physical therapist education, Movement System
INTRODUCTION
When the House of Delegates adopted the new vision statement for the American Physical Therapy Association in 2013, the profession of physical therapy in the United States began a path to change. This professional vision calls upon all physical therapists to utilize our unique body of knowledge, skills, and expertise to transform society. At the core of this evolving journey is The Movement System— affecting all aspects of physical therapist practice. As defined, “The movement system represents the collection of systems (cardiovascular, pulmonary, endocrine, integumentary, nervous, and musculoskeletal) that interact to move the body or its component parts.”

Although many physical therapists have begun to focus on movement and function in clinical practice, a significant number continue to focus on impairments or pathoanatomic models to direct interventions without fully addressing the larger construct of the movement system (as defined). The methods by which students are educated may contribute to this “silo effect”, a focus on independent systems, rather than viewing the body (across systems) as a functional whole. The education of the physical therapist includes the study of both typical and disordered movement at the biochemical (cellular), organ, and system levels. Students who enter practice must be able to integrate information across multiple systems that affect a patient or client's movement and function. Such integration must be taught to students and it is the responsibility of those in physical therapist education to embrace and teach the next generation of students this identifying professional paradigm of the movement system.

The purpose of this clinical commentary is to describe the current state of the movement system in physical therapist education, suggest strategies for enhancing movement system focus in entry level education, and envision the future of physical therapist education related to the movement system. Contributions by a student author offer depth and perspective to the ideas and suggestions presented.

PAST AND PRESENT
Physical therapy curricula are constantly changing, adapting, and growing alongside the rapid changes that occur in the profession of physical therapy. Education of physical therapists in the past was focused on technically based and skill-oriented instruction, strongly related to a biomedical model, and often responding to a provided medical diagnosis. As the profession has matured and physical therapists can provide a primary entry into health care, education has morphed and changed to include a strong focus on differential diagnosis (however, often pathoanatomically related), systems review, with an emphasis on critical thinking and high levels of clinical decision making. Students have been expected to combine aspects of their technical preparation, utilize the patient-client management model, determine a diagnosis and prognosis, and arrive at functionally focused interventions that consider all aspects of the person.

An online assessment of some of the physical therapist educational curricula across the United States (as presented on each school’s website, n = ~40) using the terms “movement”, and “movement system”, was used to explore and draw generalized conclusions regarding inclusion of the movement system by educational programs. Physical therapist educational curricula have great depth and diversity, and most include the assessment of human movement, functional activities, the introduction to movement-based diagnoses, and concepts associated with movement dysfunction, acquisition of movement, control of movement (motor control), and movement disorders. In some curricula, these concepts are linked to specific conditions or pathoanatomical diagnoses. However, in some curricula the focus is broader and more progressive, and includes a pathokinesiologic approach to analysis of functional movement, including movement system disorders and establishment of movement system diagnoses. It appears that education of physical therapists varies widely between curricula, and that the movement system is incorporated differently across programs from no inclusion, to some focusing on the movement system in a single course (often early in the curriculum), while others incorporate movement and the movement system throughout the curriculum. The most common place to include the movement system appears to be in examination and intervention courses. Suggestions for integration into courses and curricula will be provided by the APTA as they are developed.
Varied success to date in widespread and consistent adoption of the movement system into DPT programs may be due to several reasons including but not limited to: lack of agreed upon the necessity for this change, resistance from traditionalists in education (chairs and veteran faculty), and difficulty with logistics including the institutional demands related to and the time constraints of curricular change. It is important to acknowledge that movement system concepts, terminology, and exemplar practices are still being developed, which may also explain the lack of consistent inclusion in curricula. The presence of over 100 clinicians, educators, and researchers from across the country at the APTA Movement System Summit (held in December 2016) was a step toward moving movement systems based thinking forward. As information regarding the movement system continues to be developed and presented, educators need to respond appropriately, with open minds, and the profession's best interests at heart.

THE MOVEMENT SYSTEM: A CURRENT STUDENT'S PERSPECTIVE
From a student's perspective, the process of attempting to retain all the material a physical therapy education has to offer, as well as attending to outside commitments (volunteer work, a leadership role) is difficult. The typical physical therapy student is quick to turn a shoulder to current professional topics, as long as they do not pertain to the next all too quickly approaching exam. One topic that all physical therapy students should be exposed to and embrace is that of the movement system. A common theme that makes students uneasy and frustrated is that identical pathoanatomical diagnoses are often treated with great variability, depending on the clinician. Physical therapy education programs could lead the way to greater clinical consistency by teaching students to choose interventions based on the entirety of the movement system and movement dysfunctions, in contrast with the arbitrary approaches utilized by many clinicians that appear to utilize the practice of “throwing widely used treatments” at a pathoanatomical diagnosis or simply selecting interventions that were emphasized in a particular education program.

When students are taught to choose and justify interventions based upon movement system diagnoses, these interventions will have the same overarching goal(s), leading to greater homogeneity within the practice of physical therapy. For example, utilization of movement system diagnostic classifications as suggested for the shoulder complex in the paper by Ludewig et al would provide insight into greater consistency in interventions. Repeatedly observing and practicing interventions chosen with the goal of addressing movement system impairments will give students confidence and greater certainty in how to select both examination procedures and interventions for their patients and clients. Thus, the concept of the movement system should be on the “radar” of every physical therapy student, as it will improve patient care and provide peace of mind that interventions match a consistent standard of care across the profession.

The many benefits of adopting the concept of the movement system are evident and the groundwork for the movement system has been laid, but physical therapy students possess the vital role of embracing and continuing to develop this concept as it is presented. As students enter practice, they must apply the movement system and not stumble into ruts of treating only one component of the movement system or treating with only the pathoanatomical diagnosis in mind.

FUTURE
What does it mean to embrace the movement system in education? To foster change in practice, the education of students needs to adapt and to lead the way. Ideally, the human movement system should be an integral part (Figure 1) of physical therapist education, alongside traditional components of curricula such as professionalism, clinical decision making, evidence-based practice, and interprofessional collaboration. Rather than dissecting practice into parts of the whole (e.g. classes in each area of practice), focus should remain on the “big picture” or how all areas of practice contribute to management of the movement system.

SUGGESTIONS FOR ENHANCING MOVEMENT SYSTEM INTEGRATION INTO CURRICULA
The introduction of the movement system concept should ideally occur upon entry into a physical therapist educational program. This could occur as part of an orientation to the educational program/
system impairments, but also methods to impact the movement system via skillfully directed interventions. Figures 2-5 present preliminary ideas of how movement observation and possible interventions can be integrated into the curriculum by defining the movement system as critical to the identity of the profession of physical therapy and thereby setting the tone for future inclusion. Clearly, a common identity requires common language and consistent use of accepted terminology. Ideally, an initial professionalism or professional topics course would provide background on the APTA vision statement, the development of the definition of the movement system, and the trajectory of the evolving journey, addressing both where we are as a profession, and where we hope to go. Introduction of common language early in the curriculum is key.

The theme of the movement system should then be woven into all examination and intervention courses, across practice areas including but not limited to musculoskeletal, neuromuscular, cardiopulmonary, and integumentary, across the lifespan. Instruction in each practice area should include not only how to observe and diagnose movement system impairments, but also methods to impact the movement system via skillfully directed interventions.

Figure 1. Example Curricular Threads Model (Used with Permission of MGH Institute of Health Professions, Department of Physical Therapy).

Figure 2. Movement System in Musculoskeletal Practice.
decision-making courses should also emphasize the movement system and provide opportunities for discourse. If possible, there should be less “siloing” of content into practice areas and more integration among/between content areas with examples of how

Figure 3. The Movement System in Cardiopulmonary Practice.

Figure 4. The Movement System in Neuromuscular Practice.

could be conceptualized in the four main areas of practice.

Integration courses, such as graduate seminars, colloquia, and critical thinking and clinical
that need to be emphasized in curricula include the observation of human movement, the knowledge of common movement system impairments across body regions and during functional activities (with diagnostic labels as they are developed), and a wide variety of evidence-based interventions that positively impact the movement system. Such evidence-based interventions are as of yet being researched and reported upon.

Finally, we should promote to current students that they be “ambassadors” of the movement system to not only other physical therapists (clinical instructors, colleagues, etc) within our profession, but also to those outside our profession including other health professionals and the public. Students must be taught to and be able to explain movement system principles to others so that the role and qualifications of physical therapists are well understood. The implementation of the movement system and identifying it as physical therapists’ area of expertise gives current and future physical therapy students an influential and pivotal role in the direction and progression of the physical therapy profession.

CONCLUSIONS

Overall, it will take time, commitment, and diligence on the part of physical therapy educators to accept...
and move forward with the movement system as the core of physical therapy education. This is essential to moving forward toward a unified profession, with a strong professional identity as experts in the movement system.9

To fully promote the movement system, it is anticipated that the professional entry-level curriculum will need to adapt to this new emphasis. At the very least, it is suggested that there be an introduction to movement system terminology and that the movement system is defined in an introductory course. This should be combined with an increased emphasis on movement system analysis as an integral part of the assessment process as well as the integration of complex multi-system movement system problems across the curriculum. Such practices will foster consistency in intervention, and encourage clinicians to consider the whole person from a movement system perspective. The intent of this commentary is not to be prescriptive, rather to share curricular models, ideas for implementation, and encourage best practices across all entry-level programs, in order to promote a dialogue within the physical therapist education community.

REFERENCES:


5. Personal communication, Dr. Barbara Norton, PT, PhD, April 11, 2017.


7. Curricular Strands Cylinder Graphic, used with permission of MGH Institute of Health Professions, Program in Physical Therapy.


ABSTRACT

Treatment plans employed by physical therapists involved in musculoskeletal rehabilitation may follow a conventional medical-model approach, isolating care at the tissue level but neglecting consideration for neurocognitive contributions to recovery. Understanding and integration of motor learning concepts into physical therapy practice is integral for influencing the human movement system in the most effective manner. One such motor learning concept is the use of verbal instruction to influence the attentional focus of the learner. Evidence suggests that encouraging an external focus of attention through verbal instruction promotes superior motor performance, and more lasting effects of a learning experience than an internal focus of attention. Utilizing an external focus of attention when instructing a patient on a motor task may facilitate improved motor performance and improved functional outcomes in treatment plans devised to address musculoskeletal injury and movement disorders. The purpose of this review is to summarize the basic principles of motor learning and available evidence on the influence an external focus of attention has on motor learning and performance, including the benefits of an external focus of attention over an internal focus of attention and how therapists may inadvertently encourage the latter. Furthermore, the benefits of possessing greater awareness of neurocognitive mechanisms are discussed to exhibit how implementing such concepts into musculoskeletal rehabilitation can maximize treatment outcomes.

Level of Evidence: 5

Key Words: Focus of attention, motor learning, movement system, musculoskeletal rehabilitation
INTRODUCTION

One of the foundations of the physical therapy profession is the understanding and rehabilitation of human movement.\textsuperscript{1,2} Over the past several decades, many clinicians and academics have expanded the profession's base of knowledge and understanding of the human movement system and advanced recognition of physical therapists' role as movement impairment specialists of choice.\textsuperscript{2,4} In 1975, Hislop\textsuperscript{5} proposed pathokinesiology, the study of anatomy and physiology pertaining to abnormal human movement, as the foundational science of our profession. In 2014, Sahrmann\textsuperscript{2} broadened this view to involve consideration of conditions caused by "imprecise or insufficient movement" or, kinesiopathology. The Physical Therapy profession's evolving identity is best exemplified by the vision statement adopted by the American Physical Therapy House of Delegates, which has charged the profession with "transforming society by optimizing movement to improve the human experience."\textsuperscript{1}

Given this framework, a paradox arises in clinical practice when a conventional medical-model, focused on the remediation of localized disease and injury, is heavily relied upon during treatment efforts. As a large component of musculoskeletal rehabilitation involves promoting motor control and skill acquisition, this conventional approach may overlook key elements of motor learning. Specifically, less focus may be given to neurocognitive functions, which contribute to the successful teaching and learning of efficient movement.\textsuperscript{6}

A therapist's instructions are a crucial consideration in teaching motor skills and directing a learner's attention of focus. Awareness of the quality of instructions, how they are employed and what significance they have to the learning process, may greatly influence the rate at which a skill is learned and how well the learner retains it. This may also be largely influenced by the individual's attention of focus when learning and performing the task.\textsuperscript{7} Evidence has shown that selecting strategies that incorporate an external focus of attention (EFA), or one which directs an individual's attention to the effect their movement has on the environment, versus an internal focus of attention (IFA), in which attention is drawn to the movement of the individual's body, is optimal in producing superior motor performance and best affecting the motor learning experience. Therapists in musculoskeletal rehabilitation can take advantage of such principles and their effect on the brain in order to achieve greater, more holistic and lasting recovery from movement impairments for their patients.

The purpose of this review is to summarize the basic principles of motor learning and available evidence on the influence an EFA has on motor learning and performance, including the benefits of an EFA over an IFA and how therapists may inadvertently encourage the latter. Furthermore, the benefits of possessing greater awareness of neurocognitive mechanisms are discussed to exhibit how implementing such concepts into musculoskeletal rehabilitation can maximize treatment outcomes.

MOTOR LEARNING

Fostering proficiency of movement is an essential aspect of musculoskeletal clinical practice. While therapists routinely utilize established metrics to quantify treatment gains, measuring and defining the basis of motor learning can be somewhat more challenging. This is primarily because motor learning reflects an internal process of the central nervous system in response to practiced repetition.\textsuperscript{8} Because this phenomena cannot be directly measured, it must be inferred by permanent changes in behavior.\textsuperscript{8} Schmidt and Lee have defined motor learning as "a set of processes associated with practice or experience leading to relatively permanent changes in the capability of movement."\textsuperscript{8, p.327}

One way motor learning is objectified is through the observation of improved motor behavior, or performance. Although practice alone does not always make perfect, it will generally lead to improved sequencing of segmental movement components and greater efficiency in the production of the motor task.\textsuperscript{9} Performance at any given time, however, is highly variable and influenced by many factors. As such, performance in and of itself does not always reflect actual learning,\textsuperscript{8} and further criteria must be demonstrated to distinguish between the two.

Several principles that reflect learning are retention and generalization. Retention represents the ability to demonstrate a skill over time, especially when the
skill persists after a period without practice. Generalization occurs when a learned skill in one setting can be applied to another. Consider a clinical example of a patient receiving treatment after a lower extremity injury. The therapist may initially focus treatment on an isolated task, such as squatting. Sequencing criteria would be established, and the patient's performance would be observed over a set period of time. Once the patient is able to show consistent performance and independence (i.e. without the need of augmented feedback from the therapist), the skill would be considered retained. The next progression for the patient would be to take this foundational movement pattern and utilize it in a different environment than that of the controlled environment provided by the clinic. In this case, the patient could then apply this skill to sitting in a chair at home, demonstrating generalization.

A final component to consider in measuring motor learning is adaptability. Variability is a crucial component in considering dynamic and biological systems. Davids and colleagues stated that "variability in movement systems is omnipresent and unavoidable due to the distinct restraints that shape each individual's behavior". Adaptability accounts for an individual's capacity to accommodate variability and different constraints, whether personal, environmental or task specific. In the previous example, the patient would be demonstrating adaptability if he/she were now able to sit proficiently while riding on a moving team bus, and negotiating around team supplies and equipment laid out around them.

The ability for an individual to transfer a learned motor skill away from the instructional environment of the clinic, in order to maximize their participation in life events, should be a gold standard for the physical therapist. Permanence of skills and their adaptability exemplify true motor learning and highlight the role that cognition and motor learning play in achieving recovery from motor impairment.

**EXTERNAL FOCUS OF ATTENTION**

Attentional focus is an important factor influencing motor performance and skill acquisition. It consists of an individual's ability to control the conscious appreciation of their environment and various elements to a task at hand. It can influence the learner's ability to achieve and retain skilled movement considerably. The Physical Therapist's verbal instructions to the patient, or learner, are an important element in musculoskeletal rehabilitation. They can be used to guide attention, direct the patient to visualize and recall movement, and introduce, correct and refine movement patterns. In an effort to evoke the most effective spatio-temporal components during treatment interventions, these instructions may be communicated to patients in a manner that draws their attention to specific joints, body segments, tissues, etc., producing an IFA. Durham and colleagues described this concept in their study observing the feedback and instructional tendencies of therapists during treatment of individuals with hemiplegic upper extremities. Of the 247 feedback statements identified and assessed in the study, 236 had an internal focus of attention, relating to body movement rather than the effect of the patient's movement on the environment.

Although no evidence exists to explain the reason for the preponderance of IFA in practice, it has been suggested that elements of the physical therapy educational curricula, such as traditional views of muscle function and the primacy of structure over function, or the division of class offerings into independent systems of the body, foster a segmented view of the human movement system. These elements may facilitate clinical practice that minimizes the role of neurological and cognitive aspects of motor control. Clinicians' efforts to further specialize in specific areas of expertise (i.e. orthopedics, or sports medicine) may further compound the problem by narrowing practice preferences.

A caveat to directing a patient's attention internally is that use of an IFA has been shown to be detrimental and degrading to the motor learning process. The constrained action hypothesis has been utilized to explain this occurrence. According to this theory, individuals adopting an IFA will consciously control their movement efforts in learning a motor skill. This action may constrain the more natural or reflexively occurring efforts utilized in the brain during this process. In contrast, an EFA allows for freer, more automatic control of afferent processing, resulting in more effective performance and learning.

Supporting evidence for the use of an EFA has mounted and contributed to the body of evidence.
related to strength and conditioning and sports performance. An EFA has been shown to enhance the accuracy of such sporting skills as golf shots,\(^{21}\) basketball free throws,\(^{20,22}\) sprint performance,\(^{12}\) tennis serves,\(^{23}\) and soccer kicks.\(^{23}\) In the latter example, Wulf and colleagues\(^{23}\) had experienced soccer players perform lofted kicks at a target placed 15 meters away in a net, under two sets of instructional statements worded slightly different from one another (one internal, one external). The internal group had such statements that guided the participant to their own body movements. The external group received wording that minimized body-movement reference, and focused on the movement's effect. The small variation in word choice led to greater accuracy in hitting the target on a one-week, non-feedback retention test for those who received the externally focused instructions.\(^{23}\)

In addition to this pool of literature, attentional focus research has expanded into covering scenarios and demographics commonly represented in musculoskeletal rehabilitation. Welling and colleagues\(^{24}\) studied the effects of different types of instruction on landing technique and jump performance. The study aimed to highlight the potential effect of an EFA in optimizing anterior cruciate ligament injury prevention programs. Ten subjects were randomized across four groups: those receiving verbal instructions directing an EFA towards the effect of the subject's movement, those receiving verbal instructions directing an IFA towards the subject's body during the task, video instruction in which subjects would watch expert demonstration of the task, and a control group which did not receive any specific instructions. Data were gathered and analyzed for all 22 subjects collectively, then analyzed separately for the ten who had suffered a fall. When both groups were considered together, no significant performance advantage was found in utilizing EFA instructions. However, for the ten subjects with a fall history, following EFA instructions were beneficial in reducing postural sway under the sway-referenced condition as compared to IFA instructions, and instructions without attentional focus. Furthermore, when the number of falls occurring during sway-referenced task performance was analyzed in this small group, four falls were recorded under no attentional focus instructions, three falls under IFA instructions, and no falls were found while following EFA instructions.\(^{26}\)

Similar results have been found in other studies. Chiviacowsky and colleagues\(^{27}\) investigated the effects of inducing an EFA versus an IFA during a balance task in older adults (mean age = 69.4 years). Thirty-two participants (24 female and 8 male) were quasi-randomized (it was required that each group contain the same number of male and female participants) into two equal groups: those receiving EFA instructions during balance task, and those receiving IFA instructions. The EFA group was instructed to keep markers on a balance platform horizontal, while the IFA group was instructed to keep their feet hori-
Participants were required to stand on the balance platform, and maintain a horizontal position as best as possible during 30-second trials. The practice phase of the study consisted of ten 30-second trials, with 90-seconds of rest between each trial. The retention phase of the study consisted of non-instructional task performance one day later, of five 30-second trials, again with 90-second intervals between trials. The results of the study demonstrated performance improvements by both groups across retention trials, but the EFA group was more effective in doing so, registering significantly greater time in balance as compared to their counterparts. Gokeler et al.28 examined the effect of attentional focus on distance of, and knee kinematics during single-leg hop jump with patient's status post anterior cruciate ligament reconstruction. Sixteen patients (seven females and nine males) were randomized into two equally sized groups of eight participants, with one group receiving EFA instructions, and the other receiving IFA instructions. Jump distance, knee valgus angle at initial contact, peak knee flexion angle, total range of motion and time to peak angles for the injured and non-injured side were assessed. The EFA group jumped 6-11 cm further than the IFA group, however after statistical analysis, this was deemed to be an insignificant finding. Participants who received the externally directed instructions demonstrated important changes in knee kinematic markers, recording larger peak knee flexion angles at initial contact for the involved side, and greater peak knee flexion angles for both legs. This indicated that participants in the IFA group displayed stiffer landing strategies in the sagittal plane, which studies have associated with greater strain to the anterior cruciate ligament.29

Researchers and clinicians have begun to study the efficacy of gait retraining as an intervention strategy to address some of the common injuries experienced by runners. Crowell and Davis.30 studied the efficacy of a gait retraining program designed to reduce lower extremity loading during running. Ten healthy runners (six female, four males) participated in the study. With use of an accelerometer and force plate, tibial acceleration and ground reaction forces were collected pre-training, post-training and at one month follow up. Loading variables of interest were peak positive tibial acceleration, vertical instantaneous loading rate, vertical average loading rate and vertical impact peak. Participants selected for the study had registered tibial acceleration measurements of over 8g during screening. Gait re-training consisted of eight sessions of treadmill running over a course of two weeks. During each session, tibial acceleration was displayed on a monitor in front of the participant to provide real-time video feedback. The subjects were instructed to “run softer”, make their footfalls quieter and keep the acceleration peak below a set threshold line on the monitor. Running time over the eight sessions increased from 15-30 minutes, while feedback was lessened over the last four sessions. The authors chose this feedback schedule because reduced external feedback requires greater reliance on the processing of inherent information related to the performed task, leading to greater retention of a motor skill and motor learning.31,32 The program resulted in a decrease of all interested loading variables and supports an alternative and potentially promising approach to addressing run-related injury. Although there was no explicit focus on the use of an EFA in this study, subjects were instructed to “run softer” and to make their footfalls quieter. These instructions and wording constitute an EFA, as the learner is instructed to modify the effect of their movement on the environment, rather than the components of the movement itself.

In the early (cognitive) phase of learning, individuals are susceptible to various forms of interference as they begin to process and identify what the specific task is being presented. The conditions of Crowell and Davis’s experiment draw some parallels to that of Welling and colleagues’ previously described in this article, as they both expose participants to some type of visual media and verbal instructions with an EFA. In these cases, positive effects on performance and motor learning were observed. This example highlights the importance of further study of the utilization of an EFA in various treatment scenarios encountered during musculoskeletal rehabilitation.

DISCUSSION
The ultimate goal of musculoskeletal rehabilitation is to address the injury, ameliorate movement impairment, and promote lasting functional movement behaviors that allow patients to fully partici-
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partake in life experiences. Traditional approaches taken to accomplish this may lack consideration of neurocognitive contributions to the motor learning process and may potentially impair them by drawing the attentional focus of the patient internally, to their own body movements, rather than externally, to the effect their movement has on the environment. The results in this review suggest that subtle changes to the wording clinicians utilize during verbal instructions (as seen in Table 1) can have a powerful impact on motor performance and motor learning by directing a learner’s focus externally rather than internally. Such results would be advantageous to efforts in achieving superior functional outcomes for our patients and maximizing the overall success of the rehabilitation process.

It is the opinion of the authors that therapists could benefit from incorporating these principles into daily clinical practice, however, there does seem to be a need for expansion of this research to better guide the integration and practice habits that would most successfully affect movement system changes. This could include expansion of research on the effectiveness of an EFA on motor learning across the lifespan, during different phases of the learning process, with different task complexity levels and between learners of different experience (i.e. novice or expert).

**CONCLUSIONS**

With physical therapy’s nature as an applied science, and the role of physical therapists as the practitioners of choice in the treatment of the human movement system, there is a particular opportunity to use and expand upon this existing body of literature and integrate neuroscientific principles into daily practice. Physical therapists involved in the treatment of the movement system can greatly benefit from promoting an EFA through verbal instructions in order to achieve the most successful and effective movement outcomes for their patients.

**REFERENCES**


**Table 1. Comparison of external focus of attention (EFA) instructions, ones which direct an individual’s attention to the effect their movement has on the environment, vs. internal focus of attention (IFA) instructions, which draw attention to the movement of the individual’s body, during experimental procedures.**

<table>
<thead>
<tr>
<th>Study</th>
<th>Experimental task</th>
<th>EFA Instructions</th>
<th>IFA Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiviacowsky and colleagues27</td>
<td>Horizontal stabilization of a balance platform (stabilometer)</td>
<td>“Look straight ahead. Try to keep the markers in front of your feet horizontal.”</td>
<td>“Look straight ahead. Focus your attention on keeping your feet horizontal.”</td>
</tr>
<tr>
<td>Gokeler et al28</td>
<td>Single leg hop jump for distance</td>
<td>“Jump as far as you can. While you are jumping, I want you to think about pushing yourself off as hard as possible from the floor.”</td>
<td>“Jump as far as you can. While you are jumping, I want you to think about extending your knees as rapidly as possible.”</td>
</tr>
<tr>
<td>Landers and colleagues26</td>
<td>Balance performance on a computerized dynamic posturography *</td>
<td>“Stand quietly with your eyes open and concentrate on putting an equal amount of pressure on the rectangles.”</td>
<td>“Stand quietly with your eyes open and concentrate on putting an equal amount of force on your feet.”</td>
</tr>
<tr>
<td>Welling and colleagues24</td>
<td>Drop vertical jump, followed by maximal vertical jump on landing</td>
<td>“Push yourself as hard as possible off the ground after landing on the force plate.”</td>
<td>“Extend your knees as rapidly as possible after landing on the force plate.”</td>
</tr>
<tr>
<td>Wulf and colleagues23</td>
<td>Lofted soccer kick at a target</td>
<td>“Strike the ball below its midline to lift it; that is, kick underneath it.”</td>
<td>“Position your foot below the ball’s midline to lift the ball.”</td>
</tr>
</tbody>
</table>

* Balance Master · Condition A: eyes open, fixed support surface and surround


ABSTRACT

Background: Retention of movement technique is crucial in anterior cruciate ligament (ACL) injury prevention programs. It is unknown if specific instructions or video instructions result in changes in kinematic and kinetic measures during a relatively short training session, and in a retention test one week later.

Hypothesis/Purpose: The purpose was to determine the effects of verbal external focus (EF), verbal internal focus (IF) and video instructions (VI) on landing technique (i.e. kinematics and kinetics) during training and retention.

Study Design: Randomized Controlled Trial.

Methods: This study compared verbal EF, verbal IF, VI and CTRL group. Forty healthy athletes were assigned to the IF (n=10), EF (n=10), VI (n=10) or CTRL group (n=10). A jump-landing task was performed as a baseline, followed by two training blocks (TR1 and TR2) and a post test. Group specific instructions were offered in TR1 and TR2. In addition, subjects in the IF, EF and VI groups were free to ask for feedback after every jump in TR1 and TR2. One week later, a retention test was conducted without specific instructions or feedback. Kinematics and kinetics were captured using an 8-camera motion analysis system.

Results: Males and females in the EF and VI instruction group showed beneficial results during and after the training session, in terms of improved landing technique. Retention was achieved after only a short training session.

Conclusion: ACL injury prevention programs should include EF and/or VI instructions to improve kinematics and kinetics and achieve retention.

Level of Evidence: 3b

Key words: Injury prevention, motor learning, movement technique, retention
INTRODUCTION
An injury of the ACL is a devastating injury which commonly occurs in sports with a lot of jumping, accelerations and decelerations. Ideally, ACL injury prevention programs achieve long-term effects due to improved movement patterns on the field that translates to reduction of ACL injury incidence. Motor learning is defined as a relative permanent change in movement patterns. The achievement of motor learning effects as relatively permanent changes is defined as retention. For effective ACL injury prevention, learned motor skills needs to become relatively permanent after a certain time interval when no feedback, guidance or instructions are given. Attention of athletes during movement activities can be internally focused (IF) or externally focused (EF). An IF of attention indicates that the athlete’s attention is directed to body movements, (e.g. ‘focus on flexing your knee’), while an EF of attention indicates that the athlete is focused on the environment and the effect of the movement (e.g. ‘focus on landing as soft as possible’). It is suggested that retention of movement technique is superior with an EF compared to an IF.

Using video instructions is a method used to create an EF. When athletes receive video instructions from the example of expert models, they are encouraged to imitate the movements and the mirror neuron system will be triggered. Additionally, the focus of video instructions is more on reviewing whole body movement patterns instead of specific components of a movement. Self or expert videos have both been found to be effective methods to improve landing technique. Furthermore, the fact that retention has been achieved after only one short training session of video instructions indicates that the effects were not only immediate and temporary but also relatively permanent. Therefore, ACL injury prevention programs can be more effective when using video instructions compared to ACL injury prevention programs including only verbal feedback.

Both verbal EF instructions and video instructions result in improved landing technique compared to verbal IF instructions. However, it has not been investigated if verbal EF instructions and video instructions result in permanent better dynamics in terms of improved landings (i.e. kinematics and kinetics). Therefore, the purpose was to determine the effects of verbal EF, verbal IF and video instructions (VI) on landing technique (i.e. kinematics and kinetics) during training and retention. It was hypothesized that the EF and VI groups show improved landing technique in the retention test, compared to the IF and CTRL groups.

METHODS
Participants
A randomized controlled trial was conducted in a controlled laboratory setting. Forty (twenty males, twenty females) subjects were recruited from local ball team sports clubs in Groningen, the Netherlands. Detailed demographics can be found in Table 1. Enrollment, allocation and testing were conducted by the same author (W.W.), who was not blinded. For inclusion, subjects had to be: 1) ≥ 18 years old and 2) physically active in recreational ball team sports for a minimum of four hours per week. Subjects were excluded if they had any lower extremity injury in the prior six months. Subjects were randomly allocated using MATLAB 6.1 (The MathWorks Inc., Natick, MA) to one of the four groups based on sex, age and length: verbal IF group (n=10), verbal EF group (n=10), video group (VI) (n=10) or the control group with no specific instruction (n=10) (Figure 1). Before testing, all subjects signed an informed consent.

Procedures
Collecting expert data
In the current study, expert videos of the jump-landing task of athletes with optimal jump-landing technique were created before the start of data collection and made available for providing instruction to the VI group (expert modelling). The criteria for the expert videos were based on previous research (Table 2). Sex- and size matched expert models were selected for four height ranges (160-170 cm, 170-180 cm, 180-190 cm, 190-200 cm). The expert subjects were all ball team sport players. Before recording the expert jump-landing tasks, general anthropometric measures were taken from the expert subjects. 3D motion capture was used to define the movement of the expert data. Therefore,
expert subjects had twenty-one reflective markers of 14 mm in diameter placed according to the Vicon Plug-in-Gait marker set and model. In addition, trunk markers were added to the sternum, clavicle, C7, T10 and right scapula.

Collecting subject data
The jump-landing test protocol used in the current study is the same as previously reported.13,16 Before testing, anthropometric measures of all subjects were taken followed by the placement of 21 reflective markers of 14 mm (in diameter) placed according to the Vicon Plug-in-Gait marker set with additional trunk markers on the sternum, clavicle, C7, T10 and right scapula. The marker placement was followed by a static calibration. Subjects performed a five-minute warm-up on a stationary bike followed by three squats, three lunges per leg and three vertical jumps. After the warm-up, subjects received a general instruction of the jump-landing.
task and practiced the jump-landing task three times to get familiar with the task. Subjects jumped from a 30-cm high box to a distance of 50% of their height away from the box, down to the two force plates on the ground, and immediately rebounded for a maximal vertical jump on landing as originally described in the Landing Error Scoring System procedures.

3D motion capture was used during a pretest of five jumps (baseline), two training blocks of ten jumps each (TR1 and TR2), a post test of five jumps directly after the training sessions and a retention test of five jumps one week later. Group specific instructions were given after the pretest, and repeated after every five jumps. An overview of the instructions can be found in Table 3. The EF group were instructed to pay attention to the environment and the effect of the movement ("push yourself as hard as possible off the ground after landing on the force plate") while the IF group received instructions related to the subject’s body ("extend your knees as rapidly as possible after the landing on the force plate"). The VI group watched an expert video on a television screen (LG, Flatron 65VS10-BAA) before the two training blocks. Both the EF instructions, IF instructions and expert video instructions were repeated after every five jumps. The goal for the VI group was to imitate the expert video as best they could. Subjects in the CTRL group did not receive any group specific instructions but only received the general instruction before data collection.

Additionally, subjects in the IF, EF and VI group were free to ask feedback during the training blocks (TR1 and TR2) after every jump. This form of feedback is called self-controlled feedback and is suggested to influence the motor learning process because it is more tailored to the subjects’ needs, which results in enhanced intrinsic motivation during the jump-landing task. The feedback consisted of their real time Landing Error Scoring System (LESS) score (range 0-15) of that respective jump. Total LESS scores were provided but no further details were mentioned. Before testing, subjects were told that a lower total LESS score implied an improved landing technique. The CTRL group could not ask for feedback during the measurements. After one week, a retention test was done. No group specific

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**Table 2. Reference scores for the videos of expert jumps used by the VI group.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reference score expert on jump-landing task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee varus/valgus moment (Nm/kg)</td>
<td>&lt;22.25 (females)¹³</td>
</tr>
<tr>
<td>Knee flexion range (°)</td>
<td>&gt;45 (males &amp; females)¹⁷</td>
</tr>
<tr>
<td>Peak vGRF (N/kg)</td>
<td>≤59.15 (males)²⁸ / ≤17.90 (females)¹⁴,¹⁵</td>
</tr>
</tbody>
</table>

Nm = Newton meter; Kg = kilogram; ° = degrees; Peak vGRF = vertical peak ground reaction force; N = Newton.

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**Figure 2.** Subjects jumped from a 30-cm high box to a distance of 50% of their height away from the box, down to the two force plates on the ground, and immediately rebounded for a maximal vertical jump on landing as originally described in the Landing Error Scoring System procedures.
### Table 3. Overview of the instructions given to the different groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>General instruction</th>
<th>Pretest</th>
<th>Instructions</th>
<th>TR1 &amp; TR2</th>
<th>Posttest</th>
<th>Retention test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EF</strong></td>
<td>Jump as high as possible after you have landed off the box</td>
<td>5 DVJ's</td>
<td>Push yourself as hard as possible off the ground after landing on the force plate</td>
<td>2 x 10 DVJ's with self-controlled feedback (LESS score) &amp; group specific instruction after every 5 trials</td>
<td>5 DVJ's</td>
<td>5 DVJ's</td>
</tr>
<tr>
<td><strong>IF</strong></td>
<td>Jump as high as possible after you have landed off the box</td>
<td>5 DVJ's</td>
<td>Extend your knees as rapidly as possible after the landing on the force plate</td>
<td>2 x 10 DVJ's with self-controlled feedback (LESS score) &amp; group specific instruction after every 5 trials</td>
<td>5 DVJ's</td>
<td>5 DVJ's</td>
</tr>
<tr>
<td><strong>VI</strong></td>
<td>Jump as high as possible after you have landed off the box</td>
<td>5 DVJ's</td>
<td>You will see a video of an expert jump. Try to imitate the jump as best you can</td>
<td>2 x 10 DVJ's with self-controlled feedback (LESS score) &amp; group specific instruction after every 5 trials</td>
<td>5 DVJ's</td>
<td>5 DVJ's</td>
</tr>
<tr>
<td><strong>CTRL</strong></td>
<td>Jump as high as possible after you have landed off the box</td>
<td>5 DVJ's</td>
<td>N.A.</td>
<td>2 x 10 DVJ's</td>
<td>5 DVJ's</td>
<td>5 DVJ's</td>
</tr>
</tbody>
</table>

EF = external focus; IF = internal focus; VI = video instruction; CTRL = control group; DVJ = drop vertical jump; TR1 = training block 1; TR2 = training block 2.
instructions or feedback was given during the retention test.

**Data analysis**
Kinematic data were collected using an 8-camera motion analysis system at 200 Hz (Vicon Motion Analysis Systems Inc., Oxford, UK and Vicon Nexus software (version 1.8.3, Oxford, UK)). The 8-camera motion analysis system has shown to be highly reliable (ICC=0.998) with a standard error of measurement (SEM) of 1.83° in the measurement of complex dance movements, making it suitable for use as criterion measure. Furthermore, good measurement accuracy as well as high test and retest repeatability have been previously reported. Ground reaction force (GRF) data was collected using two force plates sampled at 1200 Hz (Bertec Corporation, Columbus, Ohio) and entered in software (Vicon Nexus software). The force plates were located within a custom-built flooring system in which the force plates are flush with the floor.

Primary outcome variables were vertical GRF (vGRF), knee valgus moment, knee flexion moment and maximal knee flexion angles. All variables are expressed at peak external valgus/varus moment. Moments are expressed as external moments normalized to body weight. Jump-landing tasks were analyzed of all included subjects (n = 10 IF, n = 10 EF, n = 10 VI, n = 10 CTRL) for the dominant leg (D) and the non-dominant leg (ND). For the vGRF, only the data of the dominant leg was used. Customized software using MATLAB 6.1 (The MathWorks Inc., 220 Natick, MA) was written and used to compute segmental kinematics and kinetics for both legs. Force plate and kinetic data were filtered using a fourth-order zero-lag Butterworth low-pass filter at 10 Hz.

**Statistical analysis**
With an effect size (ES) of 0.25 (medium effect ANOVA) and an alpha of 0.05, a power of 0.80 was reached with 40 subjects. G*Power for Windows, Version 3.1.7, was used to calculate the required sample size. Hence, 10 subjects were allocated to the EF, IF, VI and CTRL group respectively. Assumptions for normality of distribution for all variables were checked. Assumptions of homogeneity of variance and sphericity were also validated for the use of analysis of variance (ANOVA). To determine differences between groups (EF, IF, VI and CTRL), time (pretest, TR1, TR2, posttest and retention test) and sex (female and male), two 4x5 MANOVA's were used followed by post hoc comparisons (Bonferroni). To determine correlation between the outcome variables, a Pearson correlation analysis was conducted. Based on number of subjects and pooled standard deviation, effect sizes (ES) were calculated for all significant comparisons. Cohen's $d$ values are reported as a measure of ES, where $0.2 \leq d \leq 0.5$, $0.5 \leq d \leq 0.8$ and $d \geq 0.8$ represent a small, moderate and large effect, respectively.

**RESULTS**
No significant differences were found in baseline kinetics and kinematics between groups for both males and females.

**Males**
For males, between group analysis showed significantly greater knee flexion angles in the ND leg at the posttest ($p=0.021$, ES=2.590) and retention ($p=0.019$, ES=2.152) in the VI group, compared to the IF group.

Males in the EF group showed significantly greater knee flexion angles in the ND leg during at the retention trial compared to the posttest ($p=0.048$, ES=0.631) (TABLE 4, FIGURE 3). Furthermore, males in the EF group showed a significantly smaller knee valgus moment in the D leg at the posttest compared to TR1 ($p=0.050$, ES=0.416) and in the ND leg at TR2 compared to the pretest ($p=0.003$, ES=2.629) (FIGURE 7). Males in the IF group showed significantly greater knee flexion angles in the ND leg at the pretest compared to TR2 ($p=0.043$, ES=0.572). Additionally, a significantly greater knee flexion moment was found in the ND leg at the pretest compared to the posttest ($p=0.040$, ES=0.703) and a significant greater knee valgus moment in the ND leg was found at the TR2 compared to the posttest ($p=0.024$, ES=0.788). Furthermore, vGRF analysis showed significantly smaller vGRF at pretest compared to retention ($p=0.007$, ES=1.550) (FIGURE 9). Males in the VI group showed significantly greater knee flexion angles in the D leg at the posttest compared to TR1 ($p=0.008$, ES=1.221) and
showed significantly greater knee flexion angles in the D leg at the posttest compared to TR2 (p=0.030, ES=0.356). Furthermore, a significantly greater knee flexion moment at the pretest in the D leg was found compared to the posttest (p=0.037, ES=0.688) (FIGURE 5). Additionally, a significant smaller knee valgus moment in the D leg was found at the pretest compared to retention (p=0.019, ES=1.508).

No significant differences were found for the males in the CTRL group between the different time point analyses.

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**Table 4. Kinetic and kinematic data per group for males (mean ± SD).**

<table>
<thead>
<tr>
<th></th>
<th>Knee Flexion Angle ND (°)</th>
<th>Knee Flexion Angle D (°)</th>
<th>Knee Flexion Moment ND (Nm)</th>
<th>Knee Flexion Moment D (Nm)</th>
<th>Knee Valgus Moment ND</th>
<th>Knee Valgus Moment D</th>
<th>vGRF (N/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EF</strong></td>
<td></td>
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</tr>
<tr>
<td>Pretest</td>
<td>-65.61 ± 14.60</td>
<td>-63.10 ± 15.06</td>
<td>-2.72 ± 0.84</td>
<td>-2.92 ± 0.88</td>
<td>-0.45 ± 0.20</td>
<td>22.79 ± 9.20</td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>-64.43 ± 16.53</td>
<td>-63.68 ± 16.40</td>
<td>-2.70 ± 1.22</td>
<td>-3.08 ± 1.08</td>
<td>-0.36 ± 0.18</td>
<td>20.03 ± 4.55</td>
<td></td>
</tr>
<tr>
<td>TR2</td>
<td>-67.31 ± 15.99</td>
<td>-67.83 ± 14.73</td>
<td>-2.92 ± 1.44</td>
<td>-3.18 ± 1.20</td>
<td>-0.23 ± 0.08</td>
<td>20.05 ± 4.14</td>
<td></td>
</tr>
<tr>
<td>Posttest</td>
<td>-65.30 ± 13.58</td>
<td>-65.96 ± 12.48</td>
<td>-2.86 ± 1.51</td>
<td>-3.20 ± 1.63</td>
<td>-0.35 ± 0.18</td>
<td>16.74 ± 6.62</td>
<td></td>
</tr>
<tr>
<td>Retention</td>
<td>-71.79 ± 8.96</td>
<td>-71.43 ± 10.40</td>
<td>-2.58 ± 0.94</td>
<td>-2.87 ± 1.22</td>
<td>-0.43 ± 0.12</td>
<td>20.49 ± 8.82</td>
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<tr>
<td><strong>IF</strong></td>
<td></td>
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<tr>
<td>Pretest</td>
<td>-65.69 ± 10.85</td>
<td>-66.98 ± 10.07</td>
<td>-2.57 ± 0.48</td>
<td>-2.84 ± 0.51</td>
<td>-0.41 ± 0.14</td>
<td>19.97 ± 5.24</td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>-61.58 ± 9.31</td>
<td>-64.30 ± 9.61</td>
<td>-2.49 ± 0.40</td>
<td>-2.89 ± 0.44</td>
<td>-0.40 ± 0.10</td>
<td>27.51 ± 11.08</td>
<td></td>
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<tr>
<td>TR2</td>
<td>-59.57 ± 12.97</td>
<td>-62.63 ± 13.93</td>
<td>-2.40 ± 0.63</td>
<td>-2.61 ± 0.72</td>
<td>-0.39 ± 0.08</td>
<td>34.45 ± 11.40</td>
<td></td>
</tr>
<tr>
<td>Posttest</td>
<td>-60.22 ± 11.77</td>
<td>-64.85 ± 9.07</td>
<td>-2.31 ± 0.36</td>
<td>-2.55 ± 0.52</td>
<td>-0.38 ± 0.06</td>
<td>24.15 ± 6.71</td>
<td></td>
</tr>
<tr>
<td>Retention</td>
<td>-53.53 ± 18.71</td>
<td>-58.31 ± 11.36</td>
<td>-2.48 ± 0.63</td>
<td>-2.68 ± 0.72</td>
<td>-0.37 ± 0.10</td>
<td>26.72 ± 4.62</td>
<td></td>
</tr>
<tr>
<td><strong>VI</strong></td>
<td></td>
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</tr>
<tr>
<td>Pretest</td>
<td>-78.44 ± 10.15</td>
<td>-77.90 ± 8.56</td>
<td>-2.25 ± 0.53</td>
<td>-2.31 ± 0.39</td>
<td>-0.43 ± 0.01</td>
<td>23.19 ± 11.58</td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>-75.64 ± 6.19</td>
<td>-76.86 ± 7.06</td>
<td>-1.99 ± 0.44</td>
<td>-2.13 ± 0.27</td>
<td>-0.38 ± 0.06</td>
<td>25.82 ± 11.79</td>
<td></td>
</tr>
<tr>
<td>TR2</td>
<td>-80.68 ± 8.70</td>
<td>-79.52 ± 7.76</td>
<td>-1.94 ± 0.34</td>
<td>-2.12 ± 0.37</td>
<td>-0.38 ± 0.10</td>
<td>22.26 ± 9.31</td>
<td></td>
</tr>
<tr>
<td>Posttest</td>
<td>-83.30 ± 7.75</td>
<td>-83.64 ± 6.43</td>
<td>-1.90 ± 0.38</td>
<td>-2.10 ± 0.31</td>
<td>-0.35 ± 0.08</td>
<td>22.62 ± 11.47</td>
<td></td>
</tr>
<tr>
<td>Retention</td>
<td>-81.90 ± 9.18</td>
<td>-79.24 ± 8.33</td>
<td>-2.16 ± 0.76</td>
<td>-2.22 ± 0.68</td>
<td>-0.36 ± 0.10</td>
<td>24.07 ± 10.08</td>
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<tr>
<td><strong>CTRL</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Pretest</td>
<td>-67.63 ± 8.60</td>
<td>-70.89 ± 7.99</td>
<td>-2.45 ± 0.52</td>
<td>-2.40 ± 0.47</td>
<td>-0.38 ± 0.08</td>
<td>27.25 ± 9.35</td>
<td></td>
</tr>
<tr>
<td>TR1</td>
<td>-68.24 ± 11.22</td>
<td>-70.80 ± 10.79</td>
<td>-2.26 ± 0.88</td>
<td>-2.44 ± 0.70</td>
<td>-0.39 ± 0.12</td>
<td>22.68 ± 7.63</td>
<td></td>
</tr>
<tr>
<td>TR2</td>
<td>-68.82 ± 9.50</td>
<td>-71.04 ± 11.04</td>
<td>-2.33 ± 0.71</td>
<td>-2.37 ± 0.65</td>
<td>-0.39 ± 0.12</td>
<td>21.47 ± 7.61</td>
<td></td>
</tr>
<tr>
<td>Posttest</td>
<td>-71.74 ± 8.39</td>
<td>-74.12 ± 10.13</td>
<td>-2.56 ± 0.63</td>
<td>-2.84 ± 0.77</td>
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<td>26.51 ± 7.94</td>
<td></td>
</tr>
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<td>Retention</td>
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<td>-70.70 ± 14.24</td>
<td>-2.59 ± 0.93</td>
<td>-2.65 ± 0.79</td>
<td>-0.32 ± 0.08</td>
<td>20.70 ± 9.70</td>
<td></td>
</tr>
</tbody>
</table>

EF = external focus group; IF = internal focus group; VI = video group; CTRL = control group; TR1 = training block 1; TR2 = training block 2; ND = non-dominant leg; D = dominant leg; ° = degrees; Nm = Newton meter; vGRF = vertical ground reaction force; N/kg = Newton kilogram. Data are expressed as mean values ± SD. A bracketed connection between sessions indicates a significant difference between these sessions.

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**Figure 3. Graphical representation of knee flexion angles (°) in males.**

° = degrees; D = dominant leg; ND = non-dominant leg; EF = external focus group; IF = internal focus group; VI = video group; CTRL = control group; TR1 = training block 1; TR2 = training block 2.

**Figure 4. Graphical representation of knee flexion angles (°) in females.**

° = degrees; D = dominant leg; ND = non-dominant leg; EF = external focus group; IF = internal focus group; VI = video group; CTRL = control group; TR1 = training block 1; TR2 = training block 2.
Females
For females, no significant difference were found between groups, prior to interventions.

Females in the EF group showed a significantly smaller knee valgus moment in the D leg at retention compared to the posttest (p = 0.034, ES = 1.001) (TABLE 5). Furthermore, females in the EF group showed significant smaller vGRF in TR2 (p = 0.044, ES = 0.692) and the posttest (p = 0.050, ES = 1.167) compared to the pretest. Females in the IF group showed a significant greater knee valgus moment in the ND leg at the posttest compared to retention (p = 0.039, ES = 0.595). Females in the VI group showed significant greater knee flexion angles in the ND leg at retention compared to the posttest (p = 0.008, ES = 1.274) (FIGURE 4). Furthermore, a significant greater knee flexion moment in the D leg at TR2 was found compared to retention (p = 0.023, ES = 0.370) (FIGURE 6) and a significant greater knee valgus moment was found in the ND leg at TR2 compared to the posttest (ND; p = 0.031, ES = 0.460) (FIGURE 8). Additionally, vGRF analysis for females in the VI group showed significant smaller vGRF in the posttest compared to TR1 (p = 0.031, ES = 0.356) (FIGURE 9).

No significant differences were found for the females in the CTRL group between different time point analyses.
Correlations

In the males EF group, high positive correlations were found between knee valgus moment and vGRF in TR2 (D; 0.8, p=0.118). In the males IF group, high negative correlations were found between knee flexion moment and vGRF in TR1 (ND; -0.7, p=0.162). In the males VI group, high positive correlations were found between knee flexion angle and knee valgus moment in posttest (ND; 0.7, p=0.177).

In the females EF group, high negative correlations were found between knee flexion angle and vGRF in TR1 (D; -0.9, p=0.058), TR2 (D; -0.9, p=0.055; ND; -0.7, p=0.154), and posttest (D; -0.8, p=0.133).

Furthermore, in the males EF group high negative correlations were found between knee flexion moment and knee valgus moment in TR2 (ND; -0.9, p=0.037).

DISCUSSION

The main finding in the current study was that both males and females in the EF group showed an improvement in landing technique during training which was maintained after one week. Furthermore, males and females in the VI group show an improvement in some aspects of landing technique in the retention testing conducted after one week.
Movement patterns became more symmetrical over time, especially in the EF and VI group for both males and females. For example, the absolute difference between the ND and D leg in knee flexion angle for the EF group for males decreased from -2.51° in the pretest to -0.36° in retention. Furthermore, the difference in knee flexion angle for the VI group for females decreased from -3.07° in the pretest to -1.03° in retention. Besides more landing symmetry, knee flexion for both legs increased from pretest to retention indicating a softer landing strategy. These findings indicate successful changes in movement technique especially for the EF and VI groups.

Landings with greater knee flexion angles will potentially decrease forces on the ACL and therefore potentially reduce the risk of an ACL injury.26,27 Landing with relatively more extended knees potentially generates greater vGRF than a soft landing, achieved with a more flexed knee. A soft landing with large amounts of knee-joint flexion is more conducive to preventing injury than a stiff-legged landing.26,27 For example, Koga et al analyzed videos of ten ACL injuries and showed that non-contact ACL injuries occurred with a peak knee flexion angle of -47.00°.28 In the current study, males in the VI group showed significant greater knee flexion angles in the posttest (-83.30° ND; -83.64° D) and retention (-81.90° ND; -79.24° D) compared to males in the IF group in the posttest (-60.22° ND; -64.85° D) and retention (-53.53° ND; -58.31° D). Additionally, males in the EF group showed significant greater knee flexion angles in retention (-71.79° ND; -71.43° D) compared to the posttest (-65.30° ND; -65.56° D) which potentially results in decreased forces on the ACL. Future research should focus on the minimal detectable changes of the used kinematics and kinetics to investigate if the differences found are clinically relevant. Furthermore, a high positive correlation between knee valgus moment and vGRF was found in TR2, indicating a smaller knee valgus moment and smaller vGRF in the training session was achieved when adopting EF instructions. Knee valgus is a risk factor for an ACL injury because knee valgus loading increases the load the ACL.14,15 Also, greater vGRF could result in higher forces in the knee and therefore, an increase of the risk of an ACL injury.29 Females in the EF group showed maintenance of a smaller knee valgus moment in the D leg and smaller vGRF in retention. Additionally, high negative correlations were found between knee flexion angle and vGRF in TR1 and in the posttest, indicating greater flexion angles with smaller vGRF in the training session and posttest which implicates an improved landing technique after adopting EF focus instructions. Although this correlation is not significant, it's highly relevant since the correlation is high. The reason for the non-significant correlations can be due the relatively low power (and low n) of the study.

Males in the IF group showed a decrease in knee flexion angles and a smaller knee flexion moment in the training session. These findings are in line with previous research showing smaller knee flexion angles when adopting an IF focus.30,31 Additionally, high negative correlations were found between knee flexion moment and vGRF in TR1, indicating a smaller knee flexion moment was associated with greater vGRF in TR1. These findings implicate a less favorable landing technique when adopting IF focus instructions. Females in the IF group showed a greater knee valgus moment in the posttest compared to the training session. These results indicate that IF focus instructions resulted in a landing technique with greater ACL injury risk. These findings are in line with previous authors who have investigated the effects of an IF focus during landing.31,32,33

Both males and females in the VI group seemed to learn from watching the expert video indicated by maintenance of greater knee flexion angles in retention. Males showed greater knee flexion angles in the D leg in posttest than in the training session, which was maintained in retention. Females showed greater knee flexion angles in the ND leg in retention compared to the training session and posttest one week earlier. Showing a video in training as instruction is used in other studies resulting in improved landing technique.9,10,11,12 Furthermore, another recent study showed retention after one and four weeks of improved sidestep cutting technique in the males receiving video instructions.2 Coaches and medical staff are encouraged to use video instructions in prevention programs. Additionally, research suggests that a combination of feedback and IF instructions are beneficial in the motor
learning process. According to the results of the current study, these prevention programs could be more beneficial by adding EF instructions instead of IF instructions.

Retention is defined as the achievement of learning effects as relatively permanent changes. The findings in the present study indicate that the beneficial effects of EF and VI instructions are still present after one week which is crucial in motor learning and implicates that only two short training sessions result in an improved landing technique as demonstrated with the high retention. Current ACL injury prevention programs often show low compliance due the fact that coaches experience these programs as time-consuming without performance enhancement. Since retention was achieved after relatively short training sessions, the use of EF instructions or VI have potential to improve the longer term effectiveness of ACL injury prevention. Barriers such as ‘the effects are too short lasting for the time spent’ might be countered when implementing EF or VI instructions. Additionally, EF or VI instructions in combination with self-controlled feedback is suggested to increase the intrinsic motivation and therefore, positively influence the motor learning process.

Adopting an EF or VI seems to lead to a potentially greater efficiency in movement patterns. One possibility of the beneficial results of automatic control is that motor unit activation is coordinated more effectively with an EF, including relatively little physical and mental effort compared to an IF. The findings in the present study are in line with the results of research that used the exact same EF and IF instructions. The beneficial effects of EF and VI instructions are best explained by the constrained-action hypothesis, which suggests that an EF of attention decreases the conscious control in a movement and increases automaticity in the motor control system and therefore performance outcomes will increase.

There are some limitations that should be acknowledged. Retention was only measured after one week. Future research should focus on measuring retention after a longer period of time in order to investigate if possible beneficial effects continue to exist over time. Additionally, future research should focus on the effects of a longer training program with EF and VI instructions to investigate beneficial effects of longer and/or more frequent training programs. Subjects included in this study were free from any lower extremity injury in the prior six months and therefore, a limitation could be that subjects could have had a lower extremity injury before the six-month window, which could have affected the results.

CONCLUSION
The current study showed successful retention of some aspects of improved landing technique after a training with EF or VI instructions in recreational athletes. These findings have potential for ACL injury prevention programs. ACL injury prevention programs should include EF and/or VI instructions to enhance motor learning. Future research should focus on the implementation of EF and/or VI instructions in prevention programs and tracking injury to discern the possible effects on decreasing ACL injuries.

REFERENCES


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ABSTRACT

Background: Segmental rolling has been utilized as an assessment and intervention tool to identify and affect dysfunction of the upper quarter, core, and lower quarter. One theory to explain dysfunctional segmental rolling is a lack of segmental spinal control / stabilization. Faulty muscle firing sequencing has been related to poor spinal stability, however to date, no assessment tool exists to evaluate a patient's motor coordination of local and global musculature.

Purpose: The purpose of this study was to assess the temporal sequence of lumbar multifidus activation associated with anterior deltoid activation, and to determine if faulty sequencing was associated with the inability to segmentally roll in subjects without mobility restrictions. The authors hypothesized that in individuals who could not roll, a multifidus muscle onset latency relative to a prime mover activation would be present. In addition, a subset of the individuals with an inability to roll were utilized for a pilot study examining the ability to address the firing pattern with corrective exercise.

Methods: Twenty healthy subjects (13 females, 7 males), ages 19-25, participated in the study. Each subject underwent an upper and lower quarter screen and assessment of thoracic spine mobility. Subjects were excluded from the study if they had previous spine surgery, or were currently experiencing back pain. In addition, subjects who had any disease, disorders, or pathology that would hinder participation in segmental rolling or who had spinal movement contraindications were excluded. Since shoulder flexion is performed during the study, participants who had shoulder pathology or contraindications to upper extremity movement were excluded as well. Subjects with less than 50 degrees of trunk rotation were excluded from the study due to a possible physical mobility limitation that would prevent proficient segmental rolling. Included subjects were assessed on their ability to segmentally roll. Subjects who could complete the rolling task were placed in cohort A (“can roll”), and subjects who could not roll were placed in cohort B (“can’t roll”).

Electromyographic (EMG) activity of the multifidus was recorded adjacent to the lamina of the L4 vertebrae using intramuscular fine-wire electrodes. EMG activity of the anterior deltoid was also recorded with a surface electrode during a single arm movement into shoulder flexion. While in a standing position, subjects were instructed to move their right upper arm into flexion as quickly as possible. Subjects flexed their shoulder to 90 degrees for three trials while muscle activity was recorded. Data were high-pass filtered at 30 Hz to remove baseline artifact, and the onset EMG times was selected as the point at which EMG increased two SD above baseline levels. Onset of the multifidus muscle was reported relative to that of the study due to a possible physical mobility limitation that would prevent proficient segmental rolling. Included subjects were assessed on their ability to segmentally roll. Subjects who could complete the rolling task were placed in cohort A (“can roll”), and subjects who could not roll were placed in cohort B (“can’t roll”).

Results: Nine subjects were placed in cohort A, 11 subjects were placed in cohort B. The mean firing time of the lumbar multifidus for the cohort A was 16.67msec before the anterior deltoid, and the mean firing time of the lumbar multifidus for cohort B was 57.36msec after the anterior deltoid. There was a statistically significant difference (p<0.00) in the firing time between cohorts A and B.

Conclusions: In subjects who could segmentally roll, the multifidus muscle activation always preceded that of the prime mover muscle activation. In subjects who could not segmentally roll, the results of this study confirm that there is a multifidus muscle onset latency relative to the activation of the anterior deltoid. The inability to segmentally roll may be related to faulty sequencing of lumbar multifidus firing.

Key words: Movement system, multifidus muscle, neuromuscular sequencing, segmental rolling

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INTRODUCTION:
The ability to control movement of the core/trunk contributes to all activities of daily living as well as the ability to perform fundamental movement skills including throwing, catching, jumping, striking, running, kicking, and agility, balance, and coordination tasks.\(^1,2\) Several researchers have established that coordination of the local and global stabilizers of the trunk is changed in those with low back pain, with the activity of the multifidi being delayed and reduced during functional tasks.\(^1,3\) Assessment and intervention related to the activation and sequencing of the trunk muscles can be time consuming and challenging for the clinician, therefore the ability to utilize a simple developmental movement pattern such as segmental rolling to accurately evaluate and treat motor coordination of the trunk may be beneficial, especially in orthopedic and sports rehabilitation settings.\(^1,4\) In development, segmental rolling occurs as a response to the body-righting reaction and results in the body reacting to the rotation of the head to one side, creating a segmental and sequential pattern of the trunk, shoulder girdle, and pelvic girdle that follows the head and neck. Segmental rolling requires rotation around the body axis, the vertebral column and is also known as intra-axial rotation.\(^5\)

The multifidi are widely accepted for their role as spinal stabilizers, and have been examined in many studies for their contribution to stabilization of the spine.\(^6,7,8,9\) As defined by Dutton,\(^10\) the role of the multifidi is to stabilize the spine, bilaterally to extend the vertebrae, and unilaterally to rotate vertebral segments to the opposite side, as well as to eccentrically control lateral flexion to the opposite side. Overall, the multifidi work locally to control motion at each vertebral segmental level. This can be differentiated from the actions of global muscles, which work as prime movers. When global muscles take over the role of local stabilizer muscles, there is generally a latency of onset firing time of the local stabilizing muscles.\(^11,13\) The local stabilizer should govern the contraction to stabilize a joint, by contracting independently of the global musculature.\(^11,12\) When this does not occur, it can result in dysfunction and loss of stability, therefore leading to additional restrictions of normal motion secondary to prime mover guarding, as well as the default to compensatory patterns.\(^11\) As these suboptimal compensatory patterns are used, dysfunction can present in the forms of poor posture, poor movement patterns, and eventually, pain.\(^13\)

Many biomechanical studies have demonstrated the importance of the lumbar multifidi in lumbar segmental stability.\(^6,7,8,9,14,15\) Wilke et. al.\(^6\) conducted a study that examined the effects of five muscles on the stability of L4-L5 vertebral motion and determined that the multifidus contributed to two-thirds of the stability provided by all muscle contractions. Other authors have incriminated the lumbar multifidi for their importance in providing spinal stability to diminish low back pain.\(^8,15\) Hebert et al. found that a decrease in lumbar multifidus activation in subjects with low back pain was associated with an increased presence of factors predictive of clinical success with a stabilization exercise program.\(^15\) This supports the importance of restoring activation of the lumbar multifidi (LM) through stabilization exercises for improved lumbar spine stabilization.\(^8\)

When observing people with low back pain, researchers have used imaging to describe impairments of the multifidus based on cross-sectional area.\(^14,15,16\) Poor activation or disuse of the multifidi could result in excessive segmental motion of the lumbar spine, resulting in back pain and changes to the thickness of the muscle. Multifidus fibers have been described as demonstrating alterations in patients after experiencing only three weeks of low back pain.\(^14\) Using real-time ultrasound imaging, the cross-sectional area of the multifidus has been shown to decrease in size in patients with acute low back pain.\(^16\) Reflex inhibition of the multifidi, or activation of global muscles instead of the multifidi, during movement was found to have a direct correlation with the atrophy and fatty infiltration of the multifidi muscles.\(^16\) The significance of lack of multifidus activation has been observed by many authors who conclude that if the functionality of the multifidus is not restored, the patient is more likely to suffer from low back pain.\(^8,14,15,17,18\)

Research has also been performed by Hodges et al.\(^18\) that looked specifically at the onset of activation timing of local spinal stabilizer muscles as compared to global prime movers in patients with low back pain. Subjects in the Hodges et al study performed dynamic shoulder flexion, abduction, and
extension in standing while EMG of local and global muscles was recorded. The onset of activation time was determined for local stabilizers, the transversus abdominus and the lumbar multifidus, through the utilization of fine wire EMG, which was placed into the respective muscle bellies. The needle was inserted into the left transversus abdominis and into the left lumbar multifidus at L4-L5 interspace, 2 cm lateral to the spinous process. The global muscles, obliquus abdominis internus and obliquus abdominis externus were also recorded using fine wire EMG, while additional global muscles including the rectus abdominis and deltoid (anterior, middle, and posterior) were assessed using surface electrodes. Hodges et al found that patients with low back pain had a latency in the onset of firing time of the transversus abdominis and lumbar multifidus compared to that of the deltoid. This study supports the belief that one of the major contributions to low back pain and dysfunction is a loss of neuromuscular control of the local stabilizer muscles of the lumbar segments, not necessarily ligamentous instability. As this study also assessed the onset of firing time between local stabilizers of the lumbar spine to the onset of firing time of global musculature, this study design was utilized as inspiration for the current study design.

Authors who have discussed the importance of lumbar multifidus activation for spinal stabilization, have suggested implementing an exercise program focused on intersegmental training. France et al examined segmental stabilization of the transversus abdominis and lumbar multifidus against superficial strengthening of the rectus abdominis, internal abdominal oblique, external abdominal oblique, and erector spinae muscles. They concluded that segmental stabilization activities were better at improving muscle activation of local stabilizing muscles as well as improving low back pain when compared to prime mover recruitment exercises. In addition, muscular control of the multifidi can be improved through utilization of therapeutic exercises, specifically ones that focus on movements that challenge trunk control through dissociation of the limbs from the trunk. However, utilization of segmental rolling as a local stabilizer recruitment exercise to challenge control of the trunk has yet to be indicated in the literature.

Rolling is a useful tool which is often overlooked due to its simplistic nature. Despite this, rolling is a fundamental movement pattern developed in infancy that sets the foundation for more complex, coordinated movements. During early infancy, children lack the ability to move between postures and spend their time in the relatively static positions including prone, supine, and eventually sidelying. The infant develops head control around four months of age, facilitating the onset of developing transitional movements. The ability to transition through postures via rolling necessitates that an infant moves their shoulder towards the contralateral hip or vice versa in a diagonal manner. Once this occurs, the infant can begin performing log rolls as a means to transition from prone to supine and then supine to prone. As the infant develops better control of weight transfer during transitions and to the ability to dissociate the limbs from the trunk, an infant can begin rolling segmentally by leading with the upper extremities or the lower extremities. The ability to segmentally roll demonstrates necessary trunk control which is needed for dynamic postural control and coordination of the extremities. The spinal control that is developed in infancy continues to develop with age through more complex movements, such as crawling, walking, and running. Unfortunately, these movement patterns have a tendency to become dysfunctional, and at times, even painful, in adults. Dysfunction in general movement tasks such as crossing midline, coordination of the extremities and trunk, as well as weight shifting occur concurrently with a decline in strength and motor control. While movement dysfunctions can increase with age, adults also demonstrate an increase in the variability of how the roll is performed. Adults often exhibit a rolling pattern described as “deliberate”, instead of the “automatic” pattern first developed during infancy. The compensatory patterns that are revealed during segmental rolling can also be seen in compensatory patterns of normal gait and movement. When moving, adults often do not utilize the contralateral movement of the arms and legs. Global muscles and local muscles fire in reverse temporal order, resulting in inappropriate utilization of the global muscles for the role of the stabilization and primary action. Inefficient movement is the consequence.
It has been hypothesized that an inability to roll in a segmental fashion indicates a lack of spinal stabilization.\textsuperscript{13,23,24,25} Spinal stabilization occurs through the activation of local stabilizers muscles, primarily the multifidi. It has also been suggested that rolling can be used as an intervention to improve spinal stabilization through activation of the spinal stabilizer muscles, i.e. the multifidi.\textsuperscript{13,24} Currently, no reported research has identified such a relationship. Therefore, the purpose of this study was to assess the temporal sequence of lumbar multifidus activation associated with anterior deltoid activation, and to determine if faulty sequencing was associated with the inability to segmentally roll in subjects without mobility restrictions. The authors hypothesized that individuals who are not able to perform segmental rolling would exhibit an altered muscle recruitment firing time. Additionally, a small pilot study was conducted with a subset of the experimental group to evaluate whether corrective exercise would change the alterations found in firing time.

**METHODS**

**Subjects**
Following IRB approval by Belmont University, twenty healthy subjects (13 females, 7 males), ages 19-25, were enrolled in the study and informed consent was obtained. Subjects were excluded from the study if they had previous spine surgery, or were currently experiencing back pain. In addition, subjects who had any disease, disorders, or pathology that would hinder participation in segmental rolling or who had spinal movement contraindications were excluded. Since shoulder flexion is performed during experimentation, participants who had shoulder pathology or contraindications to movement were excluded from the study as well. The seated thoracic spine rotation test\textsuperscript{26,27} was performed before testing and any participants with a limitation in thoracic rotation (rotation less than 50 degrees bilaterally) were excluded from the study due to a possible physical mobility limitation that would prevent proficient segmental rolling.

**Instrumentation**
Bi-Polar fine wire electrodes (Motion Lab Systems, Baton Rouge, LA) were utilized to assess activity of the lumbar multifidus adjacent to the left lamina of the L4 vertebrae. The insertion needle had a 50mm, 25-gauge cannula, which held a pair of fine wires. Each wire was 200mm in length, 0.051mm in diameter, and made of 304 series stainless steel with green nylon insulation. The ends of the wires had bare hook sensor ends with 2mm of exposed sensor and a 150mm insulated tail. EMG equipment was attached to the other end of the fine wires, which were clean and free of insulation for 5mm. The subject was placed in the prone position and the needle was inserted at the level of the L4 vertebrae on the left in an inferior and medial direction, aiming for the multifidus adjacent to the left lamina. The cannula was then removed, leaving the hooked sensor fine-wire electrode attached within the muscle. Ambu Blue-Sensor M-00-S ECG surface electrodes were placed on the center of the muscle bellies of the right anterior deltoid. The electrodes were 40.8 x 34 mm in size and were round with an offset snap connector. The backing material was polymer with a conductive wet gel. Utilizing Noraxon MyoResearch XP Master Edition 1.07.64 software, data was collected and band-width filtered at 240 MHz to remove baseline artifact. Data was analyzed utilizing Noraxon software to identity the onset of muscle firing that exceeded mean baseline activity by two standard deviations. The onset firing time of the lumbar multifidus and the anterior deltoid were compared for further analysis. Statistics were performed on SPSS Statistics V18.0.0 software.

**Procedures**
Prior to participation, all subjects completed an informed consent explaining the study as well as a medical history questionnaire. Subjects were then evaluated utilizing an upper quarter screen, lower quarter screen, and seated thoracic rotation test (Figure 1) to identify any exclusion criteria. Subjects were then instructed via a script on how to segmentally roll based on previously published established criteria (Figure 2 & 3).\textsuperscript{24} The rolling ability of the participant was evaluated for proper technique and effort by a single examiner. To be considered able to perform a segmental roll, the subject had to roll from prone to supine and supine to prone without compensation or excessive effort in either direction both by leading with both the upper body and lower body on the left and right sides.\textsuperscript{13,24} Compensation
was defined as utilizing the lower extremities or momentum to assist in rolling, not rolling segmentally (i.e.: log rolling), pushing off the ground with the upper extremities, or lack of motor control demonstrated during the rolling task.\textsuperscript{13,24} If the subject met the criteria for successfully performing a segmental roll, the subject was placed in cohort A. If the subject could not perform a segmental roll, the subject was placed in cohort B. The testing procedures were identical for cohorts A and B. Subjects stood with feet together, hands at their sides, and head facing forward and were then instructed to flex their right shoulder to 90 degrees as quickly as possible. (Figure 4) This was repeated for three trials while muscle activity was recorded.

Pilot Study
Following initial data collection, five subjects who could not roll performed an intervention sequence. The purpose was to identify whether changing segmental rolling ability was related to a change in the onset of firing of the lumbar multifidus activation in relation to the anterior deltoid. Four exercises were utilized – manually cued multifidus activation, prone isometrically resisted opposite shoulder flexion and leg extension, quadruped opposite arm and leg (Figure 5), and assisted segmental rolling.

The manual multifidus activation is performed with the subject lying prone and the experimenter's
fingers placed just lateral to the L4 spinous process. Subjects are instructed to “swell” the muscles under the fingers, thus trying to activate the multifidus at the segmental level. Subjects held the contraction for five seconds and were then instructed to relax. This was performed for five trials. Subjects were then positioned prone for the prone isometric resisted opposite shoulder flexion and opposite leg extension. Manual resistance was provided to the posterior aspect of the right upper arm and the posterior aspect of the mid-thigh while subjects held isometric shoulder and hip extension for five seconds. This was performed for the right shoulder/ left hip and left shoulder/ right hip for five trials each. Quadruped opposite arm and leg were then performed with the participants flexing their right shoulder and extending their left hip so the limbs were straight and parallel to the floor, and then returned to the starting position of quadruped. Ten repetitions were performed with the right arm and left leg, then ten repetitions were performed with the left arm and right leg. Assisted segmental rolling was performed to assist in the neuromuscular reeducation of the segmental rolling pattern. Subjects were supine and the left half of their body was elevated on a 45 degree angle to the floor using a wedge. Five segmental rolls were performed from supine to prone with the left arm leading from the elevated position. Subjects then were placed in the prone position and the left half of the body was again elevated. Five segmental rolls were performed from prone to supine with the left arm leading from the elevated position. This sequence was then repeated with the right side of the body elevated/leading with the right arm. Firing sequencing of the lumbar multifidus and the anterior deltoid was then re-assessed as previously described with three trials of right shoulder flexion while muscle activity was recorded.

RESULTS
Nine subjects (4 males and 5 females) were placed in cohort A (can roll) group and eleven subjects (3 males and 8 females) were placed in cohort B (cannot roll) group. Muscle onset timing data for all subjects in both groups can be found in Table 1. In the cohort A, the mean firing time of the lumbar multifidus was -16.67 milliseconds (+/-14.93) indicating a contraction before the anterior deltoid. In cohort B, the mean firing time of the lumbar multifidus was 57.36 milliseconds (+/-15.33), indicating a contraction after the anterior deltoid. An independent samples t-test was performed and a statistically significant difference was found in the mean firing times between cohort A and B (p = 0.000) with a standard error of difference of 6.812ms.

Table 1. Results for the “can roll” group/cohort A and “cannot roll” group/cohort B demonstrate the tendencies of lumbar multifidus firing time compared to the anterior deltoid. Positive numbers denote a latency in firing time of the lumbar multifidus muscle, and a negative number indicates that the lumbar multifidus firing occurred prior to that of the anterior deltoid. The mean firing time of the lumbar multifidus in comparison to the anterior deltoid for each group can also be compared.

<table>
<thead>
<tr>
<th>Cohort A (Subject Can Roll)</th>
<th>Cohort B (Subject Cannot Roll)</th>
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<tbody>
<tr>
<td>Subject Number</td>
<td>Lumbar Multifidus Firing Time in Relation to Anterior Deltoid (msec)</td>
</tr>
<tr>
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<td>-37</td>
</tr>
<tr>
<td>2</td>
<td>-23</td>
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</tr>
<tr>
<td>10</td>
<td>37</td>
</tr>
<tr>
<td>Mean</td>
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</tr>
<tr>
<td>Standard Deviation</td>
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</table>
Pilot Study Results

Five subjects, who could not segmentally roll and had faulty muscle firing sequences, participated in the intervention. Table 2 shows the firing time of the lumbar multifidus compared to the anterior deltoid. Negative and positive values indicate the same sequencing pattern as previously described. Pre-intervention, the average firing time of the lumbar multifidus was 58.20 milliseconds (+/- 17.60) after the anterior deltoid. Post-intervention, the average firing time of the lumbar multifidus was 16.60 milliseconds (+/- 14.33) before the anterior deltoid. A paired sample t-test of the pre- and post-intervention values determined that there was a statistically significant difference between latency values before and after the intervention (p=0.003).

DISCUSSION

This is the first study to examine segmental rolling and how it relates to motor coordination between spine and the extremity musculature. In this study, the authors found that the ability to segmentally roll without compensation or excessive effort is associated with an earlier onset of multifidus firing as compared to the prime mover activation. In subjects who could segmentally roll, the onset of firing of the lumbar multifidus preceded that of the anterior deltoid by an average of 16.67 milliseconds. The “cannot roll” group demonstrated a faulty firing sequence, in which the onset of firing of the lumbar multifidus always occurred after that of the anterior deltoid by an average of 57.36 milliseconds. Based on the findings of this study, the ability to activate

<table>
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<th>Subject</th>
<th>Pre-Intervention Firing Time (msec)</th>
<th>Post-Intervention Firing Time (msec)</th>
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<tr>
<td>1</td>
<td>68</td>
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</tr>
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<td>2</td>
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</tr>
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<td>5</td>
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<tr>
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<td>-16.60</td>
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<td>17.598</td>
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</tr>
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</table>
the multifidus prior to the activation of the anterior deltoid was associated with the demonstration of successful segmental rolling. Hodges and Richardson found that individuals with low back pain had delayed onset of local stabilizer muscles including the lumbar multifidus and transverse abdominus in an arm raise task. Although the subjects in this study did not have pain, it is possible that a previous episode of pain could have altered their firing patterns. In addition, based on previous research related to back pain and poor motor control of the local and global stabilizers, there is an argument that the individuals in this study with altered rolling patterns and associated multifidi latency may be prone to low back pain in the future due to poor ability to stabilize the spine segmentally.

Five subjects from cohort B who could not segmentally roll received an intervention to retrain lumbar multifidus firing and segmental rolling motor planning. Post-intervention, all subjects were able to segmentally roll without compensation or excessive effort. All subjects also demonstrated a change in firing pattern from pre-intervention to post-intervention, with a faulty firing sequence pre-intervention and an efficient firing sequence post-intervention. These findings suggestive that a change in segmental rolling ability is related to a change in faulty firing sequence to proper firing sequence of the lumbar multifidus and the anterior deltoid.

Clinically, segmental rolling can be utilized to identify the inability to appropriately stabilize the spine, which could be a result of limited spinal motion or inefficient dissociation of the trunk and the extremities. In the case of this study, all subjects with limited spinal motion were excluded, thus, subjects with the inability to roll were unable to do so due to motor sequencing difficulty. Utilizing segmental rolling as an assessment tool for sequencing of local and global musculature, as well as, rotary stability can provide immediate information in how patients are able to perform a functional movement pattern. As indicated in the affiliated pilot study, it appears that the segmental rolling pattern can be refined to meet the standards of a correct, uncompensated segmental roll, as well as restore appropriate onset firing time of the multifidus compared to a global stabilizer. Appropriate timing of multifidus contraction is important when developing appropriate trunk stability to allow for increased freedom of the extremities, and for increased force transfer through the trunk to the limbs. This is significant for sport and for daily life. Utilizing the segmental roll, a clinician has the ability to evaluate and treat motor coordination of local and global stabilizers of the trunk.

One limitation to this study was a bias that may have occurred during convenience sampling through word of mouth and e-mail in the community. The results cannot necessarily be generalized to people...
outside of the current study’s subjects’ age range of 19-25 and outside of the demographics limited in the current study. In addition, this study was limited to subjects who were pain-free and had no reported functional limitations.

Future research beyond this study and pilot study should utilize the findings and develop more direct exploration of rolling with regard to uses in the clinic. This study demonstrated an association between muscle firing times and segmental rolling when looking at a single limb movement in isolation. Future studies should examine the relationships between these firing sequences in functional whole body patterns such as forward and backward bending or multi-segmental rotation in a standing position. The results of this study in combination with that of Hodges and Richardson,18 could be utilized to design a study looking at the use of segmental rolling to decrease pain in subjects with lower back pain. Additional considerations should be made to compare the ability to segmentally roll as well as the latency times of segmental stabilizers in different populations such as gender, age, and activity level. The pilot study identified that a change in segmental rolling ability could be made through intervention, but without incrimination of specific exercises. Further research into what specific interventions should be utilized to modify the lumbar multifidus firing timing should be performed. Based on the findings in this study, the utilization of segmental rolling ability as the indicator for firing time of the lumbar multifidus may be warranted. Utilizing the concept of dissociation and force transfer, further research should evaluate compensatory patterns occurring in segmental rolling as they relate to dysfunction in functional movements, especially in sport. It is possible that the ability to restore the motor sequencing through segmental rolling could improve the ability of an athlete to perform a functional movement or sport skill. In addition, the pilot study demonstrated an ability to change the segmental rolling ability and firing sequence through intervention in a small number of subjects, future research should investigate the duration that the intervention lasts, and the amount of time it takes for the subject to revert to the faulty firing sequence and rolling pattern, if that were to happen. Expanding on this research, the effects of an intervention over a period of time should be examined to see if these changes can be made permanent.

**CONCLUSION**

Segmental rolling ability is associated with the firing sequence of the lumbar multifidus and the anterior deltoid, where subjects with the inability to segmentally roll demonstrated a significantly different firing sequence with a multifidus muscle onset latency relative to the activation of the anterior deltoid, when compared to subjects who could roll. In subjects who could segmentally roll, the multifidus muscle activation consistently preceded that of the prime mover muscle activation. These results suggest that a segmental rolling assessment could be utilized as a method to examine firing sequence of the lumbar multifidus compared to prime movers.

**REFERENCES**


ABSTRACT

Background/Purpose: The Selective Functional Movement Assessment (SFMA) is a clinical model used to assist diagnosis and treatment of musculoskeletal disorders by identifying dysfunctions in movement patterns. Based on the premise that addressing movement dysfunction is associated with an improvement in patient outcomes, the validity of the SFMA would be strengthened by observed improvement in self-reported function being associated with change in movement patterns. The purpose of this study was to explore the validity of the SFMA by determining if a correlation exists between a change in self-reported outcome measures and attributes of the assessment.

Methods: Eighty-five clinical subjects (20.3 ± 1.6 years) were administered the Patient-Specific Functional Scale and one of four region-specific outcome measures followed by the SFMA top-tier movements. When deemed appropriate for discharge or following six weeks of therapy by an independent physical therapist, each subject repeated the outcome measures and was re-evaluated on the top-tier tests by the same initial assessor who was blinded to the subject's self-reported outcomes. Correlations between changes in outcome measures, number of painful movements and measures of movement quality (number of dysfunctional movements and criterion scores) were calculated with Spearman rank correlation coefficients. Subjects were analyzed as a consolidated group and by each region based on primary complaint.

Results: Fair to good positive correlations between improvements in self-reported outcomes and decreases in the number of painful patterns were noted for the complete dataset and for those with shoulder girdle and lumbopelvic complaints (r s = 0.28, 0.52, and 0.41, respectively). Subjects with lumbopelvic complaints demonstrated fair positive correlations with improvements in self-reported outcomes and decreases in the number of dysfunctional patterns (r s = 0.41 and 0.46). No correlations between changes in outcome measures and criterion score were observed.

Conclusion: Improvements in self-reported outcome measures were associated with fewer painful movement patterns of the SFMA. Improvements in self-reported function were not related to changes in movement quality, except for subjects presenting with lumbopelvic complaints.

Level of Evidence: 2b

Key Words: Functional movement, outcome measures, Selective Functional Movement Assessment (SFMA), validity.
INTRODUCTION

Traditional models of physical assessment and treatment in the rehabilitation setting are typically focused on pathoanatomic modes of examination. These models are based upon identifying a structural abnormality or pathology that is the most likely cause of a patient's pain and dysfunction. However, there are many examples in the literature of patients presenting with high levels of pain and disability, but no significant identifiable anatomic pathology. Likewise, multiple authors have demonstrated large numbers of asymptomatic individuals with diagnostically confirmed anatomic abnormalities in the spine, hip, shoulder, and knee. The pathoanatomic model is useful and accurate in many situations, particularly in cases involving acute or traumatic musculoskeletal injury. If a patient presents with recent fracture or muscle strain, the pain being experienced is in large part due to the damaged tissue and inflammatory processes caused by the injury. But when considering the common presence of asymptomatic anatomic abnormalities and the occurrence of pain in the absence of abnormal findings, a case can be made for incorporation of a pathokinesiologic model of evaluation. A pathokinesiologic model refers to an evaluation focused on the identification of movement impairments as potential contributors to a patient's pain and dysfunction. A reliable and valid clinical movement assessment may identify contributing factors to a patient's pain and dysfunction that have not been identified by other regionally-focused means of examination.

Various methods exist for comparing an individual's fundamental movement patterns to established standards. The Functional Movement Screen™ (FMS™; Functional Movement Systems, www.FunctionalMovement.com) is one of these tools, and is designed for use with healthy individuals. The FMS™ has demonstrated acceptable reliability and is often utilized as part of a comprehensive physical performance assessment. However, most patients presenting to a physical therapy clinic are already in pain, and pain has been shown to have deleterious effects on movement patterns. Therefore, movement assessments for healthy subjects may not have the same clinical utility for individuals presenting for evaluation and treatment of pain and dysfunction.

METHODS

This study involved a convenience sample of subjects recruited from patients who reported to a direct-access outpatient physical therapy clinic for evaluation of musculoskeletal pain (United States...
Military Academy, West Point, NY). Eligibility criteria for subjects in the study is presented in Table 1. Following consent, each subject completed an intake data sheet that asked the subject's demographic and injury history information.

Subjects were administered the Patient-Specific Functional Scale (PSFS) and one of four region-specific self-reported outcome measures by the treating physical therapist. The PSFS was the primary patient self-reported outcome of interest, with the region-specific self-reported outcome measure as a secondary patient self-reported outcome of interest.

The PSFS is a self-reported, patient-specific measure designed to assess functional change, primarily in patients presenting with musculoskeletal disorders. Patients are asked to identify up to five important activities they are unable to perform or are having difficulty with as a result of their problem. Each of these activities is then rated by the patient on an 11-point scale to indicate the level of difficulty associated with performing it, where 0 indicates an inability to perform the activity and 10 indicates that there is no difficulty associated with the activity.29 For this study, subjects reported three activities that were impacted as a result of their primary complaint. The PSFS has demonstrated good reliability and validity across multiple body regions with a minimum clinically important difference (MCID) of 1.3 to 2.3 points dependent on the body region being assessed.30,31

Region-specific outcome measures were used in a manner that allocated each subject into one of four groups based on the location of his or her primary area of complaint. Data from subjects presenting with more than one region of pain or dysfunction were collected based on the region he or she chose as the most limiting region. The region-specific outcome measures used were the Neck Disability Index (NDI) for complaints involving the cervical spine and thoracic spine, the Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) for complaints involving the shoulder region, the Oswestry Disability Index (ODI) for complaints involving the lumbo-pelvic region, and the Lower Extremity Functional Scale (LEFS) for complaints involving the hip region and all parts of the lower extremity distal to it. Each of these measures has been described in detail elsewhere, and shown to be reliable and valid.32-39 Table 2 summarizes the region-specific outcome measures used with associated MCIDs.

The intake questionnaire also asked the subject to rate his or her pain in the previous 24 hours at rest

---

Table 1. Eligibility criteria for subjects considered for the study.

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male or female</td>
<td>Musculoskeletal surgery in previous 6 months</td>
</tr>
<tr>
<td>Age 18-40</td>
<td>Self-reported pregnancy</td>
</tr>
<tr>
<td>Musculoskeletal pain ≥ 2 weeks</td>
<td>Participants not fluent in English</td>
</tr>
<tr>
<td>NPRS rating ≤ 4/10 at rest</td>
<td>Condition that resulted in musculoskeletal surgery during the study period</td>
</tr>
<tr>
<td>Active duty military and Department of Defense beneficiaries</td>
<td>Pain found to be due to fracture or non-musculoskeletal cause</td>
</tr>
</tbody>
</table>

Abbreviations: NPRS, numeric pain rating scale.

Table 2. Region-specific outcome measures and associated minimum clinically important differences (MCID).

<table>
<thead>
<tr>
<th>Body Region</th>
<th>Self-Reported Outcome Measure</th>
<th>Scale</th>
<th>MCID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervicothoracic Spine</td>
<td>Neck Disability Index (NDI)</td>
<td>0-100% *</td>
<td>19%</td>
</tr>
<tr>
<td>Shoulder Girdle</td>
<td>Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH)</td>
<td>0-100% *</td>
<td>8%</td>
</tr>
<tr>
<td>Lumbopelvic</td>
<td>Oswestry Disability Index (ODI)</td>
<td>0-100% *</td>
<td>11%</td>
</tr>
<tr>
<td>Lower Extremity</td>
<td>Lower Extremity Functional Scale (LEFS)</td>
<td>0-80 †</td>
<td>9</td>
</tr>
</tbody>
</table>

* higher scores indicate higher levels of disability. † higher scores indicate lower levels of disability.
and at its worst using the Numeric Pain Rating Scale (NPRS). The NPRS is an 11-point scale which measures a subject’s subjective report of pain intensity. The scale has criteria that range from 0 (no pain) to 10 (worst possible pain). This scale has demonstrated good reliability and validity when assessing the intensity of pain, and has a MCID of 2 points.40-42

Following administration of intake paperwork, one of two assessors independently observed each subject perform the top-tier movements of the SFMA. One assessor had received 64 cumulative hours of formal training in administration of the SFMA; the second received 32 cumulative hours of formal training. Both assessors were physical therapists certified in use of the SFMA. SFMA certification requires completion of a 16-hour SFMA didactic and laboratory course and a passing score on the SFMA certification exam.

The top-tier tests consist of 10 movements for the head and neck, the upper extremities, a toe touch pattern, backwards bending, full-body rotation, single leg stance, and deep squatting. In the authors’ experience with SFMA education courses, these movements have been counted as either 7, 10, or 15 patterns depending on how they are grouped. The notation of 10 movements was used throughout this research in order to be consistent with the instructions and scoring sheets provided in the appendices. Examples of each movement with the verbal instructions given to each subject are provided in Appendix A. Subjects were not informed of the grading criteria and were provided with the same verbal instructions for each of the tests. All subjects performed the SFMA in shorts and bare feet. With the exceptions of the single leg stance and deep squatting, all movements were performed with the feet together. Male subjects performed the movements without a shirt. Female subjects performed the movements in a tank top or sports bra, or in the absence of appropriate clothing were asked to adjust their shirts so that the spine and scapulae could be clearly visualized by the observer. The top-tier tests were performed by each subject with no warm-up or preparation beforehand.

Subjects were scored on the SFMA top-tier movements using both a categorical scale and a criterion-based scale (Appendices B and C). Use of the categorical scoring tool requires the observer to assign one of four labels to each movement pattern based on movement quality criteria and whether pain is experienced during the movement. Scoring options are Functional Non-painful (FN), Functional Painful (FP), Dysfunctional Non-painful (DN) and Dysfunctional Painful (DP). The criterion-based checklist scoring tool requires the observer to assign an ordinal scale rating to each top-tier movement based on the same quality criteria as the categorical scoring tool. A score of zero indicates perfect performance without compensation for all movements. A score of 50 indicates failure of all criteria. To demonstrate an example of differences in pattern performance, the multisegmental flexion component of the top-tier tests with associated scoring of the pattern is presented in Figure 1.

Following intake data collection, the subjects were independently evaluated by a treating physical therapist who was not present for the assessment of the SFMA top-tier performance. The assessors provided results of the assessment to the treating physical therapist. The final assessment was conducted after six weeks of physical therapy or when the treating physical therapist deemed the patient to be appropriate for discharge, whichever occurred sooner. At the final data collection visit, the treating physical therapist...
therapist administered the PSFS using the same three activities identified at intake and the region-specific outcome measure. The same assessor who performed the initial SFMA observed the subject perform the top-tier tests of the SFMA for the final assessment. The assessor was blinded to the results of patient self-reported data and specific course of treatment administered by the treating physical therapist. Subjects who required treatment beyond six weeks of rehabilitation continued to receive the standard of care until deemed appropriate for discharge.

DATA ANALYSIS
From previous research on correlation sample size estimates, a sample of 79 subjects was needed to determine a correlation coefficient of 0.75 with a 95% confidence interval half width of 0.10. To account for potential drop-outs, the intent was to recruit a sample of 100 subjects.

Data analysis was completed using R statistical software package “Rcmdr” version 2.2-5 (R Foundation; Vienna, Austria). The total number of dysfunctional patterns and the total number of painful patterns observed in the SFMA at both intake and final assessment were calculated. Comparisons of intake to final assessment values of PSFS, regional outcome measures, number of dysfunctional and painful patterns, and SFMA criterion scores were conducted using Wilcoxon signed-ranks tests. These comparisons were calculated for the consolidated dataset and for each of the four body regions examined. Ninety-five percent confidence intervals for Spearman rank correlation coefficients were calculated in Microsoft Excel 2016 using the Fisher transformation (Microsoft Corporation; Redmond, WA). Interpretation of the Spearman rank correlation coefficient has been described as: 0.00 – 0.25 = little or no relationship, 0.25 – 0.50 = fair relationship, 0.50 – 0.75 = moderate to good relationship, >0.75 = good to excellent relationship. Statistical significance was set at p < 0.05 for all analyses.

RESULTS
A cohort of 89 subjects consented to participate in the study. From the initial cohort, four subjects were dropped from the study following consent. Reasons for exclusion included two subjects who received surgery for their injuries during the study period, one subject who reported a higher level of resting pain than allowed by the intake criteria following consent, and one subject who moved away from the geographic area before final assessment data were collected. This resulted in a total of 85 subjects (68 male, 17 female) available for analysis. Of those subjects included in the study, 28 (33%) reported a previous injury of similar nature, 34 (40%) reported a time-loss injury of at least two weeks within the previous five years, and nine (11%) reported a previous musculoskeletal surgery secondary to injury. Demographic data for subjects at intake are summarized in Table 3.

Comparisons of intake to final assessment values of self-reported outcome measures showed statistically and clinically meaningful improvements for the consolidated dataset and for subjects with a primary complaint of shoulder girdle, lumbopelvic, and lower extremity complaints. A significant decrease in the number of painful patterns from intake to final assessment was detected for the consolidated dataset and for subjects with a primary complaint of shoulder girdle, lumbopelvic, and lower extremity complaints. A significant decrease in the number of painful patterns from intake to final assessment was detected for the consolidated dataset and for subjects with a primary complaint of shoulder girdle, lumbopelvic, and lower extremity complaints (mean decrease of 1.1, 1.1, 1.8 and 0.5 patterns, respectively). Subjects with a primary complaint of lumbopelvic pain demonstrated a significant mean decrease of 1.8 dysfunctional patterns and a significant mean decrease of 1.8 points on the criterion scale from intake to final assessment. No
other significant changes to the number of dysfunctional patterns or the criterion scores were demonstrated. For subjects presenting with a primary complaint involving the cervical spine or thoracic spine there were no statistically significant differences in self-reported outcome measures, presence of pain during movement, or measures of movement quality between intake and final assessment. These results are summarized in Table 4.

Fair, positive correlations were demonstrated between change in PSFS and change in the number of painful patterns for the consolidated dataset ($r_s = 0.28, p = 0.01$) and for those subjects with a primary complaint of lumbo-pelvic pain ($r_s = 0.41, p = 0.049$). Fair, positive correlations were noted for both change in PSFS ($r_s = 0.41, p = 0.049$) and change in ODI ($r_s = 0.46, p = 0.03$) with a change in the number of dysfunctional movement patterns for those subjects with a primary complaint of lumbo-pelvic pain. A moderate to good positive correlation was also demonstrated for change in QuickDASH and change in the number of painful patterns ($r_s = 0.52, p = 0.04$). No other significant correlations were demonstrated. These results are summarized in Table 5.

Post-hoc analysis using R statistical software package “pwr” version 1.2-1 demonstrated that observed statistical power for the dataset ranged from 0.04 to 0.41.
DISCUSSION

The purpose of this study was to explore the relationship between patient self-reported measures of function and objective measures of movement quality as defined in the top-tier movements of the SFMA. For the consolidated data set of this cohort, there was a statistically significant, positive correlation across all body regions between a change in self-reported function and change in the number of painful movement patterns a patient experienced when performing the SFMA. As a patient’s perception of function improved, he or she was likely to experience a decrease in the number of painful patterns performed. Analyzing the consolidated dataset across all body regions, an improvement in self-reported function was not related to a change in movement quality as defined by the SFMA.

From a regional perspective, patients presenting with shoulder girdle or lumbopelvic complaints demonstrated a positive correlation between a change in the number of painful movement patterns and a change in self-reported outcome measures. The only regional subgroup that demonstrated an improvement in movement quality when an improvement in self-reported function occurred was that of patients with a primary complaint of lumbopelvic issues.

The results observed in this study indicate that improvement in self-reported function is more strongly related to a decrease in pain during movement than it is to quality of movement. It is important to note that the design of this study was not to investigate if movement quality in the SFMA could be altered with intervention but just to examine if a relationship between self-reported function and movement exists. It is possible that in this group of subjects, quality of movement may be a characteristic that is independent of, or at least not heavily influenced by, self-reported functional outcome measures.

As shown in Table 4, subjects in this study demonstrated clinically important improvements in self-reported measures of function across all regions except for those with primary complaint of cervicothoracic pain. It is believed that the magnitude of these improvements in self-reported function was sufficient to show a clinically meaningful change in movement quality if the two attributes were related. Dolbeer et al. determined a minimum detectable difference of 5.41 points on the criterion score of the SFMA, so it may be that the changes observed in this study were too small to support detection of a significant correlation with self-reported outcomes (Tables 4 and 5). However, it must be noted that no minimum clinically important difference for a change in movement quality has been established and a decrease of just one

<table>
<thead>
<tr>
<th>Self-Reported Outcome of Interest</th>
<th>Movement-Related Outcome of Interest</th>
<th>Complete Dataset</th>
<th>Cervicothoracic</th>
<th>Shoulder Girdle</th>
<th>Lumbopelvic</th>
<th>Lower Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSFS Number of Dysfunctional Patterns</td>
<td>&lt;0.001 (-0.21, 0.21)</td>
<td>0.58 (-0.62, 0.97)</td>
<td>0.14 (-0.38, 0.59)</td>
<td>0.41* (0.00, 0.70)</td>
<td>-0.20 (-0.48, 0.11)</td>
<td></td>
</tr>
<tr>
<td>Number of Painful Patterns</td>
<td>0.28* (0.07, 0.47)</td>
<td>-0.05 (-0.89, 0.87)</td>
<td>0.27 (-0.26, 0.68)</td>
<td>0.41* (0.00, 0.70)</td>
<td>0.20 (-0.11, 0.48)</td>
<td></td>
</tr>
<tr>
<td>SFMA Criterion Score</td>
<td>0.03 (-0.18, 0.24)</td>
<td>0.20 (-0.83, 0.92)</td>
<td>0.14 (-0.38, 0.59)</td>
<td>0.22 (-0.21, 0.58)</td>
<td>-0.02 (-0.33, 0.29)</td>
<td></td>
</tr>
<tr>
<td>Region-Specific Questionnaire</td>
<td>Number of Dysfunctional Patterns</td>
<td>-</td>
<td>0.58 (-0.62, 0.97)</td>
<td>0.13 (-0.39, 0.59)</td>
<td>0.46* (0.06, 0.73)</td>
<td>-0.02 (-0.33, 0.29)</td>
</tr>
<tr>
<td>Number of Painful Patterns</td>
<td>-</td>
<td>0.56 (-0.64, 0.97)</td>
<td>0.52* (0.03, 0.81)</td>
<td>0.36 (-0.06, 0.67)</td>
<td>0.19 (-0.12, 0.47)</td>
<td></td>
</tr>
<tr>
<td>SFMA Criterion Score</td>
<td>-</td>
<td>0.40 (-0.75, 0.95)</td>
<td>0.05 (-0.46, 0.53)</td>
<td>0.27 (-0.16, 0.61)</td>
<td>0.09 (-0.22, 0.39)</td>
<td></td>
</tr>
</tbody>
</table>

Values reported are correlation coefficients (95% confidence interval). Region-specific questionnaires used were Neck Disability Index, Quick Disabilities of the Arm, Shoulder, and Hand, Oswestry Disability Index, and Lower Extremity Functional Scale. * indicates a statistically significant correlation (p <0.05).

Abbreviations: SFMA, Selective Functional Movement Assessment.
painful or dysfunctional pattern may be considered important to a patient.

It is important to note that many self-reported outcome measures are more strongly weighted in a patient's experience of pain than his or her objective levels of function. This may explain some of the reason that improvements in perceived function and decreases in the number of painful patterns were generally observed, but limited improvements in quality of motion were seen (Table 4). As noted previously, the criterion score is not affected by pain. When taking these two factors into account, these results indicate that the categorical scoring method may have more practical usefulness for movement assessment than the criterion scoring method.

One should also consider the wide variations in movement that may be observed in different populations exposed to different activities. Most notably in some throwing athletes, relatively large asymmetries in range of motion and movement may be of athletic advantage and therefore considered advantageous to the sport in question. It is likely that with such adaptive asymmetries, a patient may not be able to achieve what is deemed a functional pattern on the SFMA and yet be asymptomatic with all activities. It may be useful to consider instead the concept that there is some range of movement quality (a "standard deviation" of movement) that is acceptable for activity and function rather than just one ideal way for all patients to move.

The relatively small changes in movement quality parameters observed may have been due to several factors. Treating therapists had the results of the top-tier SFMA available to them, but it is unknown to what extent each therapist attempted to influence movement quality of the patient as opposed to a treatment plan focused primarily on addressing the patient's chief complaint through other methods. Though grading standards of the SFMA are objective, some amount of subjectivity and error with grading of any movement system will be present which may result in variation to observed changes in movement quality from intake to final assessment. Finally, the criterion scoring method weights each pattern differently based on the number of quality criteria for each pattern (Appendix C). Functional improvement noted by a patient with lumbopelvic complaints could potentially change his or her criterion score far more than a patient with unilateral shoulder pain based on the greater number of associated quality criteria and movement patterns that may be influenced by a lumbopelvic complaint. This may also offer some explanation as to why some body regions demonstrated stronger relationships between movement quality and self-reported outcome measures.

This study was conducted on a convenience sample at a direct-access physical therapy clinic. Therefore, the number of subjects in each region varied considerably. The relatively small numbers of subjects in each region may have reduced power sufficiently to not detect any significant changes. The observed power calculations listed above indicate that the regional analyses may have benefitted from a greater number of subjects in each group to minimize a risk of Type II error. However, the utility of post-hoc power testing has been questioned and it is believed that it may not be of particular use. Rather, a more accurate way of stating the issue is that this study was appropriately powered for the consolidated dataset, but the a priori estimate of the correlation coefficient $r$ value of 0.75 was an overestimation of the correlation between movement and self-reported function, if a correlation truly exists. Thus, it is not believed that this study was underpowered, particularly when noting that significant differences were found, an occurrence that necessitates sufficient power.

For those subjects presenting with lower extremity complaints, running and ruck marching were common aggravating activities. These two activities are frequently required by the subjects involved in this study. Due to the dynamic nature of these actions and other high-level sporting activities, the ability to perform them may not be reflected well by the SFMA. It may be expected that a smaller magnitude of change in observed movement quality would result from a treatment plan designed to facilitate return to these activities.

Future research should examine the potential for improving movement quality as measured by the SFMA when treatment plans are specifically designed to do so. This approach could also address
the question of whether an improvement in movement quality would lead to a subsequent change in self-reported outcome measures. As mentioned earlier, because self-reported outcome measures may be more heavily weighted to a patient's experience of pain, future research might explore the relationship between the SFMA and other objective physical performance outcome measures such as the upper and lower quarter Y-Balance Tests or hop testing. It is of note that this study population consisted of young and generally physically fit individuals at a military academy, and the results of this study may not apply to the general population. Future research should examine a more diverse range of subjects.

CONCLUSION

Significant improvements in patient self-reported functional outcome measures were associated with a decrease in the number of painful patterns experienced during the SFMA. Improvements in self-reported function were not related to a change in the observed movement quality of the assessment, except for those patients presenting with lumbopelvic pain. Movement quality as evaluated by the SFMA may be an independent attribute of patient presentation that is not strongly influenced by changes in patient self-reported function alone. Future research should investigate if specific interventions can change the quality of movement in the SFMA, and to what extent this change may affect self-reported outcome measures.

REFERENCES


34. Gummesson C, Ward MM, Atroshi I. The shortened disabilities of the arm, shoulder and hand questionnaire (QuickDASH): validity and reliability based on responses within the full-length DASH. *BMC Musculoskel Disord.* 2006;7:44.


Appendix A. Demonstration of each pattern of the Selective Functional Movement Assessment with the verbal instructions provided to each subject. With the exceptions of Single Leg Stance and Overhead Deep Squat, all movements were performed standing upright with both feet together.

Cervical Flexion

“Keeping your mouth closed and tongue resting lightly on the roof of your mouth, bring your chin down to your chest or as close as you can.”

Cervical Extension

“Please look up to the ceiling as high as you can.”

Cervical Rotation

“Turn your head as far as you can to the right.”

This movement is performed bilaterally.

Upper Extremity Pattern One – Medial Rotation and Extension

“Using your left arm in one movement, reach behind your back and try to touch the bottom of your opposite shoulder blade.”

This movement is performed bilaterally.
Appendix A. Demonstration of each pattern of the Selective Functional Movement Assessment with the verbal instructions provided to each subject. With the exceptions of Single Leg Stance and Overhead Deep Squat, all movements were performed standing upright with both feet together. (continued)

Upper Extremity Pattern Two – Lateral Rotation and Flexion

“Using your left arm in one movement, reach behind your head and try to touch the top of your opposite shoulder blade.”

This movement is performed bilaterally.

Multi-Segmental Flexion

“Bend down and try to touch your toes.”

Multi-Segmental Extension

“Raise your arms above your head and lean back as far as you can.”
Appendix A. Demonstration of each pattern of the Selective Functional Movement Assessment with the verbal instructions provided to each subject. With the exceptions of Single Leg Stance and Overhead Deep Squat, all movements were performed standing upright with both feet together. (continued)

Multi-Segmental Rotation

“Place your hands by your sides with palms facing forward and rotate your entire body as far as you can to the left.”

This movement is performed bilaterally.

Single Leg Stance

“With your hands by your sides and palms facing forward, raise your right thigh so it is parallel with the floor.”

This position is held for 10 seconds with the eyes open, and then for 10 seconds with the eyes closed.

This movement is performed bilaterally.

Overhead Deep Squat

“Standing with your feet shoulder width apart and pointed straight forward, raise your arms in a Y position with your elbows straight. Squat as low as you can.”

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### Appendix C.

#### THE SELECTIVE FUNCTIONAL MOVEMENT ASSESSMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Date:</th>
<th>Total Score:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cervical Flexion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Can’t touch Sternum to Chin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Excessive effort and/or lack of motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cervical Extension</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Not within 10 degrees of parallel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Excessive effort and/or lack of motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cervical Rotation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Nose not in line with mid-clavicle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Excessive effort and/or appreciable asymmetry or lack of motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pattern #1 – MRE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Does not reach inferior angle of scapula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Excessive effort and/or appreciable asymmetry or lack of motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pattern #2 – LRE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Does not reach spine of scapula</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Excessive effort and/or appreciable asymmetry or lack of motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multi-Segmental Flexion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Cannot touch toes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Sacral angle &lt;70 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Non-uniform spinal curve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Lack of posterior weight shift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Excessive effort and/or appreciable asymmetry or lack of motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multi-Segmental Extension</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ UE does not achieve or maintain 170</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ ASIS does not clear toes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Spine of scapula does not clear heels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Non-Uniform spinal curve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Excessive effort and/or lack motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multi-Segmental Rotation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Pelvis Rotation &lt;50 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Shoulders rotation &lt;50 degrees</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Spine/pelvic deviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Excessive Knee flexion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Excessive effort and/or lack of symmetry or motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Single Leg Stance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Eyes open &lt;10 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Eyes closed &lt; 10 seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Loss of Height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Right □ Left Excessive effort or lack of symmetry or motor control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overhead Deep Squat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Loss of UE start position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Tibia and Torso are not parallel or better</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Thighs do not break parallel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>□ Loss of sagittal plane alignment: Right</td>
<td></td>
<td>Left</td>
</tr>
<tr>
<td>□ Excessive effort, weight shift, or motor control</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Appendix D.

The Patient-Specific Functional Scale

This useful questionnaire can be used to quantify activity limitation and measure functional outcome for patients with any orthopaedic condition.

Clinician to read and fill in below: Complete at the end of the history and prior to physical examination.

Initial Assessment:

I am going to ask you to identify up to three important activities that you are unable to do or are having difficulty with as a result of your ________ problem. Today, are there any activities that you are unable to do or having difficulty with because of your ________ problem? (Clinician: show scale to patient and have the patient rate each activity).

Follow-up Assessments:

When I assessed you on (state previous assessment date), you told me that you had difficulty with (read all activities from list at a time). Today, do you still have difficulty with: (read and have patient score each item in the list)?

Patient-specific activity scoring scheme (Point to one number):

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unable to perform activity

Able to perform activity at the same level as before injury or problem

(Date and Score)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Initial</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average score</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total score = sum of the activity scores/number of activities
Minimum detectable change (90%CI) for average score = 2 points
Minimum detectable change (90%CI) for single activity score = 3 points


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ABSTRACT

Background: Lower quarter injuries account for more than 50% of all injuries in collegiate athletics. Neuromuscular screening tests could potentially identify athletes who are at risk for sustaining an injury. While previous research has studied individual tests, the authors of this paper are unaware of any study that has compared diagnostic accuracy of multiple neuromuscular screening tests within one study cohort.

Hypothesis/Purpose: The purpose of this study was to examine the accuracy of three common neuromuscular screening tests to predict the occurrence of a lower quarter injury in female collegiate volleyball and basketball players.

Study Design: Prospective Cohort

Methods: Thirty-five subjects underwent a pre-season screening by performing the Y-balance test, the Functional Movement Screen™, and Single Leg Hop test. Data were collected on lower quarter injury incidence, lost practice time, and lost competition time among subjects throughout the course of one season. Receiver operating characteristics curves were plotted and area under the curve was calculated to assess the relationship between lower extremity injury incidence and the scores of the functional tests.

Results: Lost-time injuries occurred in 11 athletes (31.4%), of whom, six athletes (17.1%) lost 50 hours or greater. There were no significant relationships between occurrence of a lost-time lower extremity injury and scores on any of the three tests. Positive and negative likelihood ratios all included the value of 1.0.

Conclusions: Although reliable, the screening tests under study did not appear to retain adequate validity to predict lower quarter injury risk within these female collegiate athletes.

Level of Evidence: Level 2b

Key words: Ankle, hip, injury prediction, knee, lower quarter, lumbar, movement system, relative risk, sports
INTRODUCTION
Lower extremity injuries present a considerable burden to athletes’ team performance and lost playing time, with potential economic effects on the conference, University, and intercollegiate athletics as a whole. Data from the National Collegiate Athletic Association (NCAA) Injury Surveillance System indicate women’s basketball athletes to have an injury rate of 6.54 injuries per 1,000 exposures, with 59% of these injuries occurring in the lower extremity.1 Women’s collegiate volleyball injury incidence has been reported at 40.6 injuries per 1,000 exposures, with 65.5% occurring in the lower extremity.2 Additionally, descriptive epidemiological data shows that both women’s collegiate volleyball and basketball players are at higher risk of injury in the preseason compared to regular and postseason.3,4 Based on the analysis of risk factors in these epidemiological studies, it is clear that athletic injuries are always ‘unintentional’ but not always ‘accidental,’ and that at least some risks may be modified or mitigated.

Given the prevalence and severity of lower extremity injuries in intercollegiate athletics, there may be special interest in assessing injury risk profiles in athletes in order to create individualized plans to manage modifiable risks. The prerequisite for validity is reliability; screening tests must be highly reliable in order to be valid to predict lower quarter injuries. Three common screening tools demonstrate good interrater reliability, including the Y-balance test (YBT) (ICC 0.85-0.93 +/- 2.0-3.5 cm)5 the Functional Movement Screen™ (FMS™) (ICC 0.843),6 and the Single Leg Hop (SLH) test (ICC 0.97 +/- 5.0-5.3 cm).7 The Y-balance test involves standing on one leg and reaching three directions with the non-stance leg. Of the three measured directions, a left to right difference of >4 cm with the anterior reach has demonstrated 59% sensitivity and 72% specificity values for injury occurrence in a prospective study design.8 The FMS™ ranks seven fundamental movement patterns, incorporates three clearing tests, and is designed to screen for major movement limitations and asymmetries to determine potential injury risk.9 Recently, Garrison et al studied the FMS™ predictive ability of injury in 160 collegiate men’s and women’s athletes and found a positive likelihood ratio of 5.8 for a FMS™ composite score of 14 or less being predictive of injury during sport.10 A component of the YBT and FMS™ that may be potentially missing is the assessment of higher-impact dynamic aspects of sports, often performed in basketball and volleyball, such as landing from a jump.11-13 A third screening test, the Single Leg Hop (SLH) test, assesses a single limb hop jump distance on one leg compared to the other. A study completed on 193 Division III athletes showed that a difference of >10% between sides on the SLH test correlated to a four fold increase in ankle or foot injury occurrence.14

Despite a growing body of evidence suggesting these screening tools may be predictive of lower quarter injury, there are various gaps in the existing literature. Studies have investigated single screening tools but have not yet studied several screening tools within one study. Also, studies have found these tests are valid screening tools in large cohorts,8,10-12,14,15 but there is a lack of investigation into the ability of the YBT, FMS™, and SLH tests to predict injury occurrence within single team cohorts. This is important since one purpose of these tests is to use them as part of a screening process to predict lower quarter injury risk in individual team cohorts, smaller than the typical sample sizes analyzed in research articles. Thus, the purpose of this study was to examine the accuracy of the YBT, FMS™, and SLH tests to predict the occurrence of a lower quarter injury in female collegiate volleyball and basketball players. The authors of this study hypothesized that the results of one or more of these screening tools studied would accurately predict lower quarter injury occurrence in this population.

METHODS
Subjects
The study was approved by the institutional review board prior to beginning the pre-testing. Inclusion criteria utilized were 1) subjects had to be a member of Hillsdale College’s women’s basketball or women’s volleyball team and 2) they had to have currently been practicing and participating in competition without injury. The rationale for these criteria are that the authors sought to examine injury prediction in a smaller cohort, thus other sports and other genders were excluded. It was also important that subjects were uninjured as the study aimed to follow healthy athletes and their risk for developing
injury. All subjects provided informed consent prior to participation in the study.

**Pre-testing Procedure**
Prior to beginning the study, all tests were performed by a physical therapist on six random test subjects, outside the target subject pool. These six subjects were tested following the same protocol later described in the methods section for the YBT, FMS™ and SLH. The same tester was used for this pre-testing procedure in order to gain experience and refine study method protocols. The results were analyzed to determine intra-rater reliability of the tester performing the screening tests.

**Screening Tests Procedures**
An investigator who is a physical therapist performed the formal screening tests. This investigator had three years of experience using each of these tests in the clinical setting and was certified in the FMS™ prior to start of this study. Protocol for this study required subjects to first receive an explanation and demonstration of each screening test. For all included subjects, the same investigator (author 1) provided the explanations and demonstrations of each test. Each of the three screening tests and methods are listed below.

*The Y-Balance Test:* Testing protocol for the YBT was similar to previous testing on the Star Excursion Balance Test. Subjects took position with their toes at the center of a grid that had measuring tape marked off in three different directions- anterior, posteromedial, and posterolateral (Figure 1). The subjects performed each direction with six practice trials and then three measured trials with the best score for each direction being used. These scores were normalized to limb length for statistical analysis. Subjects performed anterior, posteromedial, and posterolateral reach with the right foot prior to reaching each direction with the left foot. Scores were not used if subjects were unable to return their reach leg back to the center of the grid while maintaining single leg balance on the contralateral side.

*Functional Movement Screen™ (FMS™):* Subjects performed each segment using FMS™ certified equipment (Figure 2). The study investigator assessing the subjects was an FMS™ certified examiner. Component tests of the FMS™ were rated by a standardized examiner on a 3-point scale. Pain during the movement was scored as 0. A composite score for the FMS™ was calculated by summing the item scores.
subject data sheet was filled out after consulting coaching staff and athletic training staff for official counts of each variable. Weekly observations were made for 33 weeks. Data forms were assessed for predictive ability of pre-screening tests to injury incidence. Lower quarter injury incidence was defined as an injury to the low back, hip, knee, ankle, or foot regions, during participation in athletic team activities that resulted in a minimum of one lost day of practice or the inability to participate in at least one full competition.

Statistical Methods
Sample Size Considerations: A Receiver Operating Characteristic (ROC) curve is a graphical representation of the trade-off between the false negative and false positive rates for every possible cut off of a diagnostic test. The accuracy of a diagnostic test (i.e. the ability of the test to correctly classify those athletes that may get injured vs. those who do not) is measured by the area under the ROC curve. An area of 1.0 represents a perfect diagnostic test, while an area of 0.50 represents an inaccurate test or essentially one that is comparable to flipping a coin. Statistically, more area under the curve means that the test is identifying more true positives while minimizing the number/percent of false positives. Although there is limited published data to determine power for this study's sample size, the authors of this study found results from Plisky et al, 2006 to be adequate to base a current power analysis from.12 Assuming an injury rate of 25% (based on Table 5 in Plisky et al., 2006) a sample of seven injured athletes and 28 non-injured will provide 80% power to detect a difference of 0.324 between the area under the ROC curve (AUC) under the null hypothesis of 0.50 and an AUC under the alternative hypothesis using a two-sided z-test at a significance level of 0.05. If injury rate in this study is ≥25%, this study would have adequate power to detect a difference. The above calculations apply to each of the three diagnostic tests separately. In addition, the authors also tested for differences in AUC between the three diagnostic tests with alpha adjusted for inflation to 0.0167.

Statistical/Power Analysis Plan: Intra-rater reliability analysis was conducted in order to confirm high intrarater reliability for all preseason screening tests (FMS™ subscale score, FMSTM™ total score, SLH, and

Figure 3. Performance of the Single Leg hop test.

Single Leg Hop (SLH): Each subject stood barefoot with her toes on a designated starting marker and jumped for distance off of one foot while landing on the same foot and maintaining single leg balance after landing (Figure 3). Single leg balance was to be maintained for at least one second, with this time being estimated by the investigator. Each subject went through six practice trials on each limb and then had three test attempts for their furthest distance. Distance was measured by marking where the posterior edge of the heel landed and the longest distance for each limb was recorded.

Data Collection
Observational data collection began following completion of the pre-testing procedure. Data were collected and recorded for thirty-five subjects on a standard data collection form. This form included weekly sport practice hours, strength and conditioning hours, injuries sustained during activity, and hours missed due to injury. A weekly observational

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*The International Journal of Sports Physical Therapy | Volume 12, Number 6 | November 2017 | Page 951*
Intraclass correlation coefficient (formula 2,1) and Cohen’s Kappa were used to assess intrarater reliability for continuous and categorical variables, respectively. Incidence of lost-time injury was the basic unit of analysis for this study. Differences in demographics between injured and non-injured players were analyzed with Student’s t-test and chi-square tests for continuous and categorical variables, respectively. Continuous variables were represented as mean ± SD or median (range) and categorical variables were reported as a percentage. All hop distances and YBT reach distances were standardized to the athlete’s limb length. Receiver operating characteristics (ROC) curve analysis and area under the curve (AUC) calculation was used to determine the association between screening test result and incidence of lost-time injury. Alpha was set at 0.05 and all analyses were conducted with SAS v. 9.3 (SAS Institute Inc., Cary, NC) and/or SPSS v. 21, (IBM Corp).

RESULTS

Pre-testing results
Intrarater reliability measures from the pre-testing procedure revealed that Cohen’s K values ranged from .700 +/- .241 to 1.00 for the FMS™ composite and its individual components. P-values for all functional tests included values from <.001 to .165 (Table 1). All reliability measures reflect adequate reliability except for YBT Posteromedial Left measurement, which had a measure of .435 ± .000-.992. The authors are unsure as to why the posteromedial left measurement was not reliable. It can be surmised that a motor learning effect may have accounted for the variability that was observed in this particular measurement for the six random subjects used for pilot testing. Perhaps the reliability could have been studied further if more test subjects were used for the pre-testing procedure. At any rate, the detailed protocol for this study was performed carefully and consistently to decrease chances of test results being affected by variables such as motor learning.

Main study results
Thirty-six Division I female athletes were screened for study participation, consented to participate, and met inclusion criteria. One subject was excluded due to an injury preventing her from practicing or participating in competition. Therefore, data were collected on thirty-five female subjects, of whom seventeen were basketball team members and eighteen were volleyball team members. Eleven of these athletes (31.4%) sustained a time-loss injury. Of these, six subjects (17.1%) sustained an injury resulting in >50 hours of lost-time (practice, competition, or strength and conditioning time loss) due to a lower quarter injury. The mean number of hours lost due to injury was 20.6 ± 47.4 hours. Competition exposure time mean values were 326.8 ± 293.7 minutes and 62.6 ± 34.4 minutes for basketball and volleyball players, respectively (Table 2).

Descriptive Statistics for the Functional Screening Tests
The mean composite YBT scores, adjusted for limb length, were 2.471 ± .164 for the right and 2.503 ± .167 for the left lower extremity. Those who experienced lower quarter injury (LQI) scored 2.501 ± .148 and 2.463 ± .148 for their left composite YBT and right composite YBT, respectively, while those who did not experience LQI scored 2.493 ± .210 for the left and 2.488 ± .202 for the right.

Mean score for all subjects’ FMS™ test was 14.9 ± 1.7, with the mean for those with LQI being 14.6 ± 1.6 and those without LQI being 15.4 ± 1.9. Mean scores for the SLH were 50.7 ± 7.7 inches on the left and 50.5 ± 7.7 inches on right. Those who experienced LQI scored 50.8 ± 6.3 inches on the left and 50.8 ± 7.1 inches on the right, while those who did not experience LQI scored 50.8 ± 10.4 inches on the left and 49.8 ± 9.3 inches on the right (Table 3).

P-values used to test statistical significance of differences in test scores amongst those with and without LQI ranged from .030 to .981. The only p-value that allowed the authors to reject the null hypothesis was the hurdle step component of the FMS™ test. The hurdle step component’s p-value was 0.030. In this case, a higher score on the hurdle step test was more predictive of injury. Raw individual scores of those athletes who were injured are listed along with their injury diagnosis as reported by the college’s sports medicine staff (Table 4).

Predictive validity of FMS™ components
High true positive rates were observed for Squat, Hurdle Step, Inline Lunge, and Rotary Stability
to predict the incidence of a lost-time injury. There was a significant association between Hurdle Step score and hours lost due to injury (p<.05), but not other FMS™ components.

Table 1. Pre-testing data: p-values in the “Reliability” column of table 1.1 assess the null hypothesis that the intraclass correlation coefficient (formula 2.1; ICC2.1) is 0.

<table>
<thead>
<tr>
<th>Reliability</th>
<th>Cohen’s K +/- Standard Error</th>
<th>ICC2,1</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>.739 +/- .212</td>
<td>N/A</td>
<td>.007</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>N/A</td>
<td>.014</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>N/A</td>
<td>.014</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>N/A</td>
<td>.014</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>N/A</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>.700 +/- .241</td>
<td>N/A</td>
<td>.024</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>N/A</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>.760 +/- .203</td>
<td>N/A</td>
<td>.002</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.963 (.763-.995)</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.967 (.784-.995)</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.878 (.368-.982)</td>
<td>.005</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.945 (.662-.992)</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.950 (.692-.993)</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.435 (.000-.992)</td>
<td>.165</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.948 (.682-.993)</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.820 (.172-.973)</td>
<td>.012</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.976 (.843-.997)</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td>.971 (.811-.996)</td>
<td>&lt;.001</td>
<td></td>
</tr>
</tbody>
</table>

(Table 5). A high true negative rate was observed for Straight Leg Raise. However, positive and negative likelihood ratios all included 1.0, suggesting lack of predictive value for any FMS™ component.
DISCUSSION

The purpose of this study was to investigate the efficacy of three commonly used neuromuscular screening tests to predict lower quarter injury in a homogenous population of female collegiate basketball and volleyball athletes. Although the authors hypothesized that one or more single tests or a cluster of these test would accurately predict occurrence of these lower quarter injuries, there were no significant relationships between occurrence of a lost-time LQI and YBT, FMS™ composite/component, or SLHT scores. This finding suggests that none of these tests showed strong predictive ability in this cohort of women's collegiate volleyball and basketball players.

Initial research published prior to conducting the study reported that these screening tests were accurate in predicting lumbar, hip, knee or ankle injuries. However, since this study was

Table 2. Subject demographics, injury incidence, and competition exposure.

<table>
<thead>
<tr>
<th>Gender</th>
<th>35 female (100.0%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sport</td>
<td>17 basketball (48.6%)</td>
</tr>
<tr>
<td></td>
<td>18 volleyball (51.4%)</td>
</tr>
<tr>
<td>Incidence of lost time injury</td>
<td>11 (31.3%)</td>
</tr>
<tr>
<td>Lost time due to injury (hours)</td>
<td>20.6 ± 47.4</td>
</tr>
<tr>
<td>Mean competition exposure time (minutes)</td>
<td>Basketball: 326.8 ± 293.7 Volleyball: 62.6 ± 34.4</td>
</tr>
</tbody>
</table>

Table 3. Descriptive statistics: Functional Movement Screen™ (FMS™) total score, Y Balance Test (YBT), and Single Leg Hop Test are expressed as mean ± standard deviation. Functional Movement Screen™ component scores are expressed as median (interquartile range). p-values in the “Functional Screening Performance” column are the result of Pearson Chi-square (categorical variables) or one-way ANOVA (continuous variables) to test the null hypothesis that screening measurements are the same between subjects with and without any lost-time lower quarter injury (LQI).

<table>
<thead>
<tr>
<th>Functional Test</th>
<th>All (n=35)</th>
<th>LQI (n=11)</th>
<th>No LQI (n=24)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td></td>
<td></td>
<td></td>
<td>.832</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td></td>
<td></td>
<td></td>
<td>.030*</td>
</tr>
<tr>
<td>Inline Lunge</td>
<td></td>
<td></td>
<td></td>
<td>.729</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td></td>
<td></td>
<td></td>
<td>.554</td>
</tr>
<tr>
<td>Straight Leg Raise</td>
<td></td>
<td></td>
<td></td>
<td>.656</td>
</tr>
<tr>
<td>Push-up</td>
<td></td>
<td></td>
<td></td>
<td>.594</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td></td>
<td></td>
<td></td>
<td>.220</td>
</tr>
<tr>
<td>FMS Total</td>
<td>14.9 ± 1.7</td>
<td>15.4 ± 1.9</td>
<td>14.6 ± 1.6</td>
<td>.243</td>
</tr>
<tr>
<td>YBT Anterior (Adjusted)</td>
<td></td>
<td></td>
<td></td>
<td>.589</td>
</tr>
<tr>
<td>L</td>
<td>.504 ± .067</td>
<td>.513 ± .063</td>
<td>.500 ± .069</td>
<td>.467</td>
</tr>
<tr>
<td>R</td>
<td>.504 ± .067</td>
<td>.513 ± .063</td>
<td>.500 ± .069</td>
<td>.467</td>
</tr>
<tr>
<td>YBT Posterolateral (Adjusted)</td>
<td></td>
<td></td>
<td></td>
<td>.922</td>
</tr>
<tr>
<td>L</td>
<td>1.02 ± .076</td>
<td>1.02 ± .076</td>
<td>1.02 ± .069</td>
<td>.317</td>
</tr>
<tr>
<td>R</td>
<td>1.03 ± .077</td>
<td>1.01 ± .092</td>
<td>1.04 ± .069</td>
<td>.749</td>
</tr>
<tr>
<td>YBT Posteromedial (Adjusted)</td>
<td></td>
<td></td>
<td></td>
<td>.872</td>
</tr>
<tr>
<td>L</td>
<td>.949 ± .081</td>
<td>.956 ± .101</td>
<td>.946 ± .072</td>
<td>.872</td>
</tr>
<tr>
<td>R</td>
<td>.967 ± .079</td>
<td>.966 ± .093</td>
<td>.968 ± .074</td>
<td>.872</td>
</tr>
</tbody>
</table>
In the current study, qualitative factors for the FMS™ screening tests were analyzed. Poor movement quality as defined by a lower score on the FMS™, did not show increased risk of injury in this cohort of basketball and volleyball players. The second of the previously mentioned studies investigated the YBT and the authors reported that composite reach score was not associated with non-contact injury in Division I collegiate athletes. The current study also examined the relationship between YBT composite scores and injury occurrence and found the YBT was not able to predict lower quarter injury. Lastly, the authors of this study found that differences between limbs during the SLH test were not associated with lower quarter injury occurrence. This study's findings are paralleled by a recent article, where Brumitt et al found a lack of association between the SLH test and lower quadrant noncontact injury in a population of male collegiate basketball players.21

The results from this study, and other published research, suggest that physical functional screening tools may have limited utility in identifying women's collegiate basketball and volleyball athletes who are at increased risk of lower quarter injury. It is possible that these tests, when used in conjunction with history findings such as previous history of injury, or other psychosocial variables, such as reports of increased stress, may more accurately predict injury in athletes who participate in these sports. Teyhen et al performed a study with 320 subjects all of whom were US Army Rangers. Interestingly, they found that smoking, prior surgery, recurrent prior musculoskeletal injury, limited-duty days in the prior year for musculoskeletal injury, asymmetrical ankle dorsiflexion, pain with FMS clearing tests, and decreased performance on the two-mile run and two-minute sit-up test were associated with increased injury risk. Though the population in their study is distinct from those subjects included in the current study, it highlights the potential that other factors could have similar or stronger predictive value in predicting lower quarter injury when compared with neuromuscular screening tests. Bahr, et al has suggested that sports injury screening tests have the tendency to provide limited predictive ability due to a number of factors. One of such factors is that sports injury screening tests are scored...
on a continuous scale. A continuous scale and the inherent nature of athlete scoring on these tests create overlap between those who do not get injured and those who do. So while there could be some associations between a screening test and injury occurrence, athlete-screening tests typically are not able to identify those who are likely to get injured from those who are not. Perhaps this notion explains the low predictive ability of these tests in this study’s cohort.

Strengths of this study include that the tests used can be easily reproduced in clinical practice. The YBT was purposefully performed without the YBT kit. This variation can cause considerable differences in the measurements obtained for the anterior reach part of the test; however, it was purposefully performed without using the kit to improve the external validity of study results (typically performed without the kit in clinical practice). Another strength of this study was that each of the functional tests were reliable, similar to findings of previous authors.14,17,27-29

The main limitation of this study was the number of subjects included, increasing potential for a type II error, though the sample demonstrated adequate power, indicating sufficient number of subjects and a large percentage in this study who sustained

<table>
<thead>
<tr>
<th>Subject Identification Number</th>
<th>YBT Adjusted Composite L</th>
<th>YBT Adjusted Anterior Reach L</th>
<th>FMS Composite L</th>
<th>SLH L</th>
<th>SLH R</th>
<th>Injury Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.487</td>
<td>2.521</td>
<td>0.387</td>
<td>0.411</td>
<td>17</td>
<td>59</td>
</tr>
<tr>
<td>10</td>
<td>2.253</td>
<td>2.318</td>
<td>0.46</td>
<td>0.444</td>
<td>14</td>
<td>43.5</td>
</tr>
<tr>
<td>19</td>
<td>2.19</td>
<td>2.222</td>
<td>0.492</td>
<td>0.522</td>
<td>13</td>
<td>41.5</td>
</tr>
<tr>
<td>21</td>
<td>2.213</td>
<td>2.157</td>
<td>0.438</td>
<td>0.41</td>
<td>16</td>
<td>43</td>
</tr>
<tr>
<td>22</td>
<td>2.766</td>
<td>2.729</td>
<td>0.614</td>
<td>0.573</td>
<td>18</td>
<td>63.5</td>
</tr>
<tr>
<td>25</td>
<td>2.503</td>
<td>2.471</td>
<td>0.591</td>
<td>0.555</td>
<td>15</td>
<td>46</td>
</tr>
<tr>
<td>27</td>
<td>2.411</td>
<td>2.426</td>
<td>0.547</td>
<td>0.537</td>
<td>16</td>
<td>35.5</td>
</tr>
<tr>
<td>30</td>
<td>2.523</td>
<td>2.443</td>
<td>0.523</td>
<td>0.531</td>
<td>17</td>
<td>52</td>
</tr>
<tr>
<td>32</td>
<td>2.757</td>
<td>2.746</td>
<td>0.582</td>
<td>0.548</td>
<td>17</td>
<td>49</td>
</tr>
<tr>
<td>33</td>
<td>2.602</td>
<td>2.648</td>
<td>0.52</td>
<td>0.515</td>
<td>14</td>
<td>68.5</td>
</tr>
<tr>
<td>34</td>
<td>2.718</td>
<td>2.691</td>
<td>0.536</td>
<td>0.596</td>
<td>14</td>
<td>58</td>
</tr>
</tbody>
</table>
The underlying goal of all injury screening is to reduce the occurrence of injury. Being able to detect those at increased risk of injury would theoretically help clinicians target interventions to prevent injury in those at risk individuals. Future research should continue to investigate whether physical tests, for instance landing mechanics, or other factors such as joint laxity, and hamstring to quadriceps strength ratios, may help predict lower quarter injury in this population. Additional studies should investigate whether personal factors, (such as previous injury history and psychosocial factors) have predictive ability for lower quarter injury.

**CONCLUSION**

The results of this study indicate that the FMS™, SLH, and YBT were not predictive of lower quarter injury occurrence in a group of female collegiate volleyball and basketball players. Clinicians

<table>
<thead>
<tr>
<th>FMS Component</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive Likelihood Ratio</th>
<th>Negative Likelihood Ratio</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>90.9%</td>
<td>4.2%</td>
<td>0.95 (0.77-1.16)</td>
<td>2.18 (0.15-31.77)</td>
<td>30.3% (15.6-48.7%)</td>
<td>50.0% (1.3-98.8%)</td>
</tr>
<tr>
<td>Hurdle Step</td>
<td>81.8%</td>
<td>0.0%</td>
<td>0.82 (0.62-1.08)</td>
<td>---</td>
<td>27.3% (13.3-45.5%)</td>
<td>0.0% (0-84.2%)</td>
</tr>
<tr>
<td>Inline Lunge</td>
<td>81.8%</td>
<td>12.5%</td>
<td>0.94 (0.68-1.28)</td>
<td>1.45 (0.28-7.50)</td>
<td>60.0% (14.7-94.7%)</td>
<td>60.0% (14.7-94.7%)</td>
</tr>
<tr>
<td>Shoulder Mobility</td>
<td>27.3%</td>
<td>62.5%</td>
<td>0.73 (0.24-2.17)</td>
<td>1.16 (0.72-1.87)</td>
<td>25.0% (5.5-57.2%)</td>
<td>65.2% (42.7-83.6%)</td>
</tr>
<tr>
<td>Straight Leg Raise</td>
<td>18.2%</td>
<td>87.5%</td>
<td>1.45 (0.28-7.50)</td>
<td>0.94 (0.68-1.28)</td>
<td>40.0% (5.3-85.3%)</td>
<td>70.0% (50.6-85.3%)</td>
</tr>
<tr>
<td>Push Up</td>
<td>63.6%</td>
<td>29.2%</td>
<td>0.90 (0.54-1.50)</td>
<td>1.25 (0.46-3.39)</td>
<td>29.2% (12.6-51.1%)</td>
<td>63.6% (30.8-89.1%)</td>
</tr>
<tr>
<td>Rotary Stability</td>
<td>100.0%</td>
<td>0.0%</td>
<td>1.00</td>
<td>---</td>
<td>31.4% (16.9-49.3%)</td>
<td>---</td>
</tr>
</tbody>
</table>

**Table 5. Clinometric properties of Functional Movement Screen (FMS™) components to predict lost-time injury incidence in intercollegiate female basketball and volleyball players if FMS™ score < 3. Parenthetical values are 95% confidence intervals.**
who are attempting to identify who within a group of physically active people are at increased risk of injury should consider that the performance on the YBT, FMS™, and SLH alone might not accurately identify at risk individuals in female basketball and volleyball players. Clinicians should also consider that information from physical tests, in combination with other variables, such as personal factors, might have added predictive ability for injury occurrence. Clinicians using injury screening tools should consider the available evidence on validity of such tools. Future research should compare a wider range of physical variables, as well as non-physical factors that may be able to more accurately identify those at increased risk for injury.

REFERENCES


ABSTRACT

Background: The shoulder mobility screen of the Functional Movement Screen™ (FMS™) and the upper extremity patterns of the Selective Functional Movement Assessment (SFMA) assess global, multi-joint movement capabilities in the upper-extremities. Identifying which assessment can most accurately determine if baseball players are at an increased risk of experiencing overuse symptoms in the shoulder or elbow throughout a competitive season may reduce throwing-related injuries requiring medical attention.

Purpose: The purpose of this study was to determine if preseason FMS™ or SFMA scores were related to overuse severity scores in the shoulder or elbow during the preseason and competitive season.

Study design: Cohort study.

Methods: Sixty healthy, male, Division III collegiate baseball players (mean age = 20.1 ± 2.0 years) underwent preseason testing using the FMS™ shoulder mobility screen, and SFMA upper extremity patterns. Their scores were dichotomized into good and bad movement scores, and were compared to weekly questionnaires registering overuse symptoms and pain severity in the shoulder or elbow during the season.

Results: Poor FMS™ performance was associated with an increased likelihood of experiencing at least one overuse symptom during the preseason independent of grade and position (adjusted odds ratio [OR] = 5.14, p = 0.03). Poor SFMA performance was associated with an increased likelihood of experiencing at least one overuse symptom during the preseason (adjusted OR = 6.10, p = 0.03) and during the competitive season (adjusted OR = 17.07, p = 0.03) independent of grade and position.

Conclusion: FMS™ shoulder mobility and SFMA upper extremity pattern performance were related to the likelihood of experiencing overuse symptoms during a baseball season. Participants with poor FMSTM performances may be more likely to experience at least one overuse symptom in their shoulder or elbow during the preseason. Additionally, individuals with poor SFMA performances may be more likely to report overuse symptoms during the preseason or competitive season.

Level of evidence: Level 3

Key words: Functional Movement Screen™, movement dysfunctions, movement system, prevention, risk factors, sports injury.
INTRODUCTION
Throwing a baseball is one of the most dynamic movements in all of sports. During the throwing motion, large forces are repetitively generated as the arm moves through vulnerable end-range positions.1 Due to the nature of the overhead throwing motion, baseball players are susceptible to microtrauma in the soft tissue structures that can eventually result in chronic injury.2,3,4 Many high school and collegiate level injuries receiving medical attention do not occur as a result of one particular pitch, but rather through cumulative micro-trauma.5 Pitchers have been identified as the primary position to experience shoulder injuries when compared to other positions, resulting in greater time loss and surgical interventions.6 However several throwing-related risk factors exist for all players including: sport specific adaptations,7,8,9,10 throwing velocity,11 overuse,12 muscle imbalances,2,13,14,15,16,17,18,19 and previous injuries.14,20

A pre-participation physical exam should provide the athlete and sports medicine professionals with information that might prohibit/alter sport participation, along with information meant to improve performance and/or prevent injury from the musculoskeletal exam.21 However traditional pre-participation physical exams have only proven effective at identifying current injuries as opposed to predicting future injuries.22 A standard musculoskeletal screen that correlates to future injuries should be incorporated into the pre-participation exam process for grouping and classifying individuals to forecast injury risks.23

The assessment of full body, multi-joint movements that gauge the quality of human movement have gained in popularity among sports medicine professionals.24 The Functional Movement Screen™ (FMS™) and Selective Functional Movement Assessment (SFMA) are two commonly used screening tools, which have both demonstrated high inter- and intra-rater reliability in individuals who are certified and have greater experience administering the screens.25,26 They are both time-efficient, and are used to identify potential dysfunction within different movement patterns.27 While the FMS™ is often used to determine asymmetries, imbalances, and injury risk, the SFMA is a clinical model often used as a diagnostic tool designed to identify musculoskeletal dysfunction in patients with pain.

To date there are no studies comparing both the FMS™ and SFMA upper extremity screens as tools to find relationships with overuse symptoms in baseball players. The purpose of this study was to determine if preseason FMS™ shoulder mobility scores or SFMA upper extremity pattern scores could accurately identify players at increased risk for in-season overuse symptoms that may contribute to more significant time-loss injuries. Poor FMS™ and SFMA scores were hypothesized to increase the likelihood of reporting at least one overuse symptom in the preseason or competitive season.

METHODS
Participants
For this study, 135 male NCAA Division III collegiate baseball players (mean age = 20.1 ± 2.0 years) were recruited from four local universities. Among those recruited were 31 seniors, 25 juniors, 35 sophomores, and 44 freshmen. Participants were included if they were actively participating in all team activities on the date of testing. Participants were excluded if; (1) they were being treated for a shoulder or elbow injury or (2) they reported upper extremity injuries at the time of testing. This study was approved by a university institutional review board and written informed consent was obtained from all participants before beginning the study.

Data Collection
The screening dates, for each university, took place during the two-week period in the beginning of Spring 2016 before the start of official team practices. The examiner for all subject data collection was a certified FMS™ and SFMA practitioner, with over 5 years of experience screening individuals. All participants completed a questionnaire on position and grade in school. All participants were individually screened in random order with the FMS™ shoulder mobility and both upper extremity patterns of the SFMA, while including the clearing tests for rotator cuff impingement and for acromioclavicular (AC) joint impingement as described by Cook, et al.27 Total FMS™ scores were dichotomized into “good” and “poor” groups (good = 2 or 3, poor = 0 or 1).
SFMA scores were dichotomized into “good” and “poor” (good = functional non-painful (FN), poor = dysfunctional painful (DP), dysfunctional non-painful (DN), and functional painful (FP)).

Throughout the preseason and competitive season, overuse symptom surveillance was tracked for each participant using a weekly questionnaire to register any shoulder/elbow complaints and/or time loss from practice or competitions. The four-question questionnaire was a modified version of the Oslo Sports Trauma Research Centre (OSTRC) Overuse Injury Questionnaire (Table 1). The questionnaires were completed over four preseason weeks (in which only indoor practices occurred), and eight competitive-season weeks (in which both games and practices occurred). Based on each subject's answers, they were given a symptom-severity score. The higher the total severity score, the more overuse symptoms existed for each given week. Participants with a severity score of 0 meant they were asymptomatic, and were fully healthy for that given week. This was used as an objective measure to determine overuse problems for the shoulder or
elbow, and was used to create dichotomous overuse symptom scores (i.e. score of “0” or “1”) for both preseason and the competitive season time periods. Individuals were identified as having preseason overuse symptoms (i.e. score of “1”) if they reported any overuse symptom during the 4 weeklong preseason. Individuals were identified as having competitive season overuse symptoms (i.e. score of “1”) if they reported any overuse symptom during the eight week competitive season time period.

Statistical Analysis
Data analyses were conducted using the Statistical Package for the Social Sciences version 23.0 (SPSS, Inc., Chicago, IL). Initial chi-square analyses were performed to assess relationships between FMS™ or SFMA performance category and presence of any overuse symptom during the preseason or competitive season. Logistic regression analyses assessed relationships between FMS™ or SFMA performance category and presence of any overuse symptom during the preseason or competitive season, while controlling for effects of grade and position. Statistical significance was determined a priori at p<0.05. Power analyses revealed that for the chi-square analyses 88 subjects were needed to identify a moderate effect size of 0.30 at an alpha level of 0.05 and an achieved power of 0.80. For logistic regression analyses 113 subjects were needed to achieve an odds ratio of 2.0 at an alpha level of 0.05 and an achieved power of 0.80.

RESULTS
The primary positions of the 135 participants initially enrolled in this study were: pitchers (n=60), catchers (n=16), middle infielders (n=31), corner infielders (n=34), and outfielders (n=29) (several participants documented splitting time played between multiple positions). Although 135 participants were initially enrolled in the study, not all submitted complete responses to the questionnaires. As a result of missing data, 60 participants were included in the chi-square and logistic regression analyses assessing relationships between FMS™ performance category and presence of any overuse symptom during the preseason. Chi-square and logistic regression analyses assessing relationships between FMS™ performance category and presence of any overuse symptom during the competitive season were performed on data from 36 subjects. Similarly, 60 and 36 participants were included in the chi-square and logistic regression analyses assessing relationships between SFMA performance category and presence of any overuse symptom during the preseason and competitive season, respectively.

FMS™ Score
Poor FMS™ performance was associated with an increased likelihood of experiencing at least one overuse symptom during the preseason both with (adjusted odds ratio [OR] = 5.14, p = 0.03) and without (unadjusted OR = 3.73, p = 0.03) controlling for the effect of grade and position (Table 2). FMS™ performance was not associated with experiencing at least one overuse symptom during the competitive season in either chi-square or logistic regression analysis.

SFMA Score
Poor SFMA performance was only associated with an increased likelihood of experiencing at least one overuse symptom during the preseason when controlling for the effect of grade and position (adjusted OR = 6.10, p = 0.03) (Table 2). Poor SFMA performance was associated with an increased likelihood of experiencing at least one overuse symptom during the competitive season both with (adjusted OR = 17.07, p = 0.03) and without (unadjusted OR = 5.71, p = 0.046) controlling for the effect of grade and position.

DISCUSSION
There were several primary findings in this research. Participants with poor FMS™ scores (scores of 0 or 1) were more likely to experience at least one overuse symptom in their shoulder or elbow during the preseason when compared to participants with good FMS™ scores (scores of 2 or 3), independent of grade or position; the same was true of SFMA performance. There was no association between FMS™ performance and overuse symptoms during the competitive season. SFMA performance however, was related to overuse symptoms during the competitive season independent of grade or position.

These findings suggest upper extremity movement screens may help identify players at an increased risk of developing overuse symptoms during the
preseason. These findings are similar to those previously published on FMS™ shoulder mobility scores and shoulder injuries. Poor performance on the FMS™ shoulder mobility has been previously demonstrated in collegiate athletes who self-report prior shoulder injuries or shoulder surgeries.29 These potential relationships may be explained by sport-specific adaptations that typically occur in the dominant arms of baseball players, particularly glenohumeral internal rotation deficits (GIRD). GIRD is a condition resulting in the loss of internal rotation of the glenohumeral joint as compared to the contralateral side.9,14,30,31 This altered range of motion is likely due to a combination of soft-tissue and structural changes in anatomy. The stress of throwing may create a chronic stretching of the anterior capsule and tightening of the posterior capsule; leading to changes in soft-tissue creating instability and impingement.32

It is unclear why SFMA scores were related to overuse symptoms during the competitive season, whereas FMS™ scores were only found to be significant during the preseason. It could be due to differences in scoring criteria. There is a margin for asymmetry to exist on either arm with the FMS™, since the arms are reciprocally being tested. The cutoff range to score (3, 2, or 1) has a distinct benchmark for allowable distance between the fists as the subject attempts to concurrently reach behind their back. The SFMA however, only has the criteria to touch a landmark of either the inferior angle of the opposite scapula in pattern one, or the spine of the opposite scapula in pattern two. An inability to reach the landmark could occur with as little as a half-inch distance, or six inches of distance, with both resulting in the score of DN if no pain was present. An inability to touch such landmarks may be the threshold of minimum mobility that is necessary to reduce the chances of overuse.

Knowledge gained through this research suggest that the FMS™ shoulder mobility and SFMA upper extremity patterns may provide value in a pre-season screen for collegiate baseball players. These screens quickly and accurately identify individuals who have limited or painful mobility, and poor performance on both screens increased the likelihood of overuse severity symptoms in the preseason, while the SFMA performance was also associated with increased likelihood of overuse severity symptoms in the competitive season. However due to the wide confidence intervals surrounding the odds ratios the true extent to which FMSTM and SFMA scores are related to increased risk of experiencing overuse symptoms is uncertain.

This study is not without limitations when interpreting the data. The sample included in this study was a convenience sample of four area colleges. Overuse symptoms were self-reported by the athletes and therefore may be underreported. Due to subject attrition with questionnaire responses, this study ended up being underpowered, possibly explaining some of the insignificant findings. Fatigue, conditioning levels, pitch counts, and throwing velocities were not included in this study and so we were unable to assess the relationship between FMS™ or SFMA performance and overuse symptoms independent of these other proposed injury risk factors. The total volume
of throwing each subject encountered throughout the 2015 summer and fall seasons and 2016 spring season was not controlled for, nor could the amount of outside physical activity that may contribute to shoulder or elbow related injuries (i.e. strength and conditioning programs, physical labor jobs, etc.). The questionnaire used in this study was a modified version of the OSTRC overuse questionnaire which has currently only been validated for knee injuries.

Future research should investigate other sports with repetitive overhead motions such as tennis, swimming, volleyball, javelin, football quarterbacks, etc. It may also prove valuable to quantify movement competency in other regions of the body, along with the shoulder and elbow because dysfunctional movement in the upper extremities may influence dysfunctional movement elsewhere in the kinetic chain, possibly increasing both the acute and chronic stress on the shoulder or elbow. Lastly, an intervention study aimed at improving participants’ movement scores through various strategies (e.g. static stretching, dynamic movements, shoulder stability exercises) is necessary to develop rehabilitation protocols that improve scores and subsequently reduce the risk of overuse symptoms.

CONCLUSIONS

This study identified relationships between FMS™ performance, SFMA performance, and overuse symptoms in DIII collegiate baseball players. Specifically, participants with poor FMS™ performances may be more likely to experience at least one overuse symptom in their shoulder or elbow during the preseason. Additionally, individuals with poor SFMA performances may be more likely to report overuse symptoms during the preseason or competitive season. Implementing the FMS™ shoulder mobility screen and SFMA upper extremity patterns into baseball pre-participation screens may help identify individuals most likely to experience overuse symptoms over the course of a season.

REFERENCES


ABSTRACT

Background: The Functional Movement Screen™ (FMS™) has been the focus of recent research related to movement profiling and injury prediction. However, there is a paucity of studies examining the associations between physical performance tasks such as balance and the FMS™ screening system.

Purpose: The purpose of this study was to compare measures of static balance in stable and unstable conditions between different groups divided by FMS™ scores. A secondary purpose was to discern if balance indices discriminate the groups divided by FMS™ scores.

Study Design: Cross-sectional study.

Methods: Fifty-seven physically active subjects (25 men and 32 women; mean age of 22.9 ± 3.1 yrs) participated. The outcome was unilateral stance balance indices, composed by: Anteroposterior Index; Medial-lateral Index, and Overall Balance Index in stable and unstable conditions, as provided by the Biodex balance platform. Subjects were dichotomized into two groups, according to a FMS™ cut-off score of 14: FMS1 (score >14) and FMS2 (score ≤14). The independent Students t-test was used to verify differences in balance indices between FMS1 and FMS2 groups. A discriminant analysis was applied in order to identify which of the balance indices would adequately discriminate the FMS™ groups.

Results: Comparisons between FMS1 and FMS2 groups in the stable and unstable conditions demonstrated a higher unstable Anteroposterior index for FMS2 (p=0.017). No significant differences were found for other comparisons (p>0.05). The indices did not discriminate the FMS™ groups (p>0.05).

Conclusions: The balance indices adopted in this study were not useful as a parameter for identification and discrimination of healthy subjects assessed by the FMS™.

Level of evidence: 2c.

Key words: Postural balance; Movement System; Physical Function; Physical Therapy Modalities.

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4 Rehabilitation Sciences Graduate Program (PPGCR), Universidade de Brasília (UnB), Campus UnB Ceilândia, Brasilia/DF, Brazil.
INTRODUCTION
Human posture is characterized by the biomechanical alignment of different joints and their relative orientation to the environment.\(^1,2\) The postural control system is responsible for controlling body position in space, with the goal of providing both stability and alignment. The balance of an individual requires the ability to maintain the center of mass within the base of support, determining the stability limits of the individual.\(^2\) Research on balance and its impacts on musculoskeletal injuries and dysfunctions has evolved in the last few years.\(^3\) For instance, lower limb asymmetries, poor postural control\(^4\) and decreased single-leg static and dynamic balance have been associated with the prediction of musculoskeletal injuries\(^3,5\) and have been used to discriminate healthy adults with functionally stable and unstable ankle joints.\(^6\)

The efficiency of the postural control has been also associated with the ability to properly perceive the daily-life environment.\(^7\) Consequently, the maintenance of the body balance is an essential functional task that relies on complex systems, which could be used, for example, to monitor neurological disorders or aging effects.\(^8\) In this context, contemporary evaluation methods such as the Functional Movement Screen\(^9\) (FMS\(^{TM}\)) have focused on a broader understanding of functional movement competency.\(^3,10,11\)

The FMS\(^{TM}\) is a reliable assessment screening method composed of seven movement patterns, performed using a dynamic and functional approach.\(^12\) Furthermore, the method can identify mobility and stability deficits, even in healthy and asymptomatic individuals.\(^8\) Research on the FMS\(^{TM}\) has grown, and studies addressing sports injuries are a recurring topic.\(^10,13\) Previous systematic reviews\(^14,15\) have addressed the injury predictive capacity of the FMS\(^{TM}\), and concluded that the strength of association between FMS\(^{TM}\) composite scores and subsequent injury was moderate or low, owing to methodological problems of the included studies. Nevertheless, it is worth noting that the previous systematic reviews focused on military personnel, police and firefighters, and athletes. According to Engquist, Smith, Chimera, Warren,\(^16\) even though a non-athlete population may never be screened before participation in activity, they still engage in recreational sport activities. This raises an important question regarding the study of functional measurements such as balance, and the association between the performance of the FMS\(^{TM}\) in healthy non-athlete participants.

In this context, discriminant analyses are important as they allow the detection of variables that may discriminate between groups of individuals.\(^17\) Balance is an important functional construct and has previously been used to discriminate better performance in Tai-Chi practitioners.\(^18\) Mak and Ng\(^18\) found that more experienced Tai-Chi practitioners presented a longer functional reach and less sway in the single-leg medial-lateral plane, indicating better stability and a lower susceptibility to falling during practice. Accordingly, balance might also influence the overall movement assessment proposed by the creators of the FMS\(^{TM}\),\(^3\) which is provided by continuous adjustments and muscle contractions\(^19\) during five of the seven movement patterns that also require strength, joint flexibility and motor coordination.\(^20\) It is important to note that all of these variables are essential for an adequate joint mobility and postural control.\(^9,13\)

Notwithstanding, Kazman, et al\(^21\) demonstrated that evidence regarding the weight of different constructs and/or variables that could influence and/or explain the composite FMS\(^{TM}\) score is still lacking. Similarly, Teyhen, et al\(^22\) observed that there is a paucity of studies associating physical performance measures, such as balance, and the FMS\(^{TM}\). Additionally, studies with the FMS\(^{TM}\) and balance assessments in the general population are limited.\(^16\) Thus, further research is warranted considering the importance of balance, commonly used in clinical settings to assess aspects of neuromuscular function.\(^3,18,23\)

Therefore, the aim of the present study was to compare measures of static balance in stable and unstable conditions between different groups divided by FMS\(^{TM}\) scores. A secondary purpose was to discern if balance indices discriminate the groups divided by FMS\(^{TM}\) scores. It was hypothesized that static balance deficits could influence the overall performance of the FMS\(^{TM}\) movement patterns. Moreover, as static balance indices are commonly used in the clinical practice, they could be adopted to easily discriminate subjects with either poor or excellent
movement profiles based on the FMS™ composite score, if a relationship exists.

METHODS

Study design
This is a cross-sectional study with analytical components, characterized by the assessment of static balance and functional movement screening in healthy young individuals in a movement analysis laboratory setting.

Subjects
A convenience sample of fifty-seven subjects (25 men and 32 women) with a mean age of 22.9 ± 3.1 years, 1.7 ± 0.9 m, 63.7 ± 12.6 kg and 22.0 ± 3.1 kg/m² participated. All participants were classified as moderate or highly physically active, by responding the IPAQ Questionnaire (International Physical Activity Questionnaire). All participants were invited to participate by signing the Informed Consent, approved by the Institutional Research Ethics Committee (protocol CAAE n. 31873814.4.0000.0030).

Procedures
Participants underwent an evaluation process in the Laboratory of Human Functional Performance Analysis, at two different occasions. In the first visit, each volunteer was asked to answer a questionnaire with personal information, dominance of the lower limbs (leg used to kick a ball) and health related information (musculoskeletal injuries, cardiovascular diseases), followed by anthropometric measurements (weight, height and body mass index - BMI). Subsequent to the evaluation, all participants performed a familiarization with the balance platform, consisting of a practice session using the same testing protocol.

At the second visit, each volunteer completed an assessment in the balance platform, in stable and unstable conditions. After a 10-minute rest interval, all subjects were assessed using the Functional Movement Screen™. The assessor was certified in the method (Level 1).

Balance evaluation
For the present study, the Balance System platform was used (Biodex Medical Systems, Shirley, New York, USA). The calibration was performed according to the manufacturer's specifications manual. The platform consists of a circular base with a surface inclination mobility up to 20° in a range of 360° movements. The platform is able to move in the anteroposterior (AP) and mediolateral (ML) axes and allows the assessment of postural balance in stable and unstable conditions. The Athlete Single Leg Stability Testing (ASL) protocol was adopted. The assumption of this test is to challenge the proprioceptive system, which is commonly used in clinical settings (such as the Romberg test). Thus, the ASL test was adopted to challenge the participants pertaining the ability to maintain single limb stance. The ASL was performed under two conditions: stable and unstable, characterized by two sets of 20 seconds for both lower limbs (dominant and non-dominant), with five minutes rest between each limb and each condition.
For unstable conditions, the platform provides degrees of instability ranging from 1 to 8, in which higher degrees of instability impose greater challenge and instability. Based on a pilot study, the level 4 was determined as a suitable challenge and sufficient instability, allowing the participants to complete the protocol. Thus, the level 4 was adopted for the unstable condition in the present study.

Subjects were instructed to adopt a position with the supporting leg in a semi-flexed position and the contralateral limb with the knee flexed at 90º, arms crossed and hands resting on the shoulders (Figure 1). Based on the ASL test, the following indexes were obtained: 1) Anteroposterior (AP): represents the variation of the platform displacement in the sagittal plane; 2) Medium-lateral (ML): represents the variation of the platform displacement in the frontal plane; and 3) Overall Balance Index (OBI): represents the overall displacement. For all the indices, higher values represent a high amount of platform displacement, thus indicating a poorer balance.

The Functional Movement Screen™ (FMS™)

The FMS™ is comprised of seven movement patterns (Figure 2): Deep Squat (multisegmental and functional movement that evaluates hip, knee, ankle and torso); Hurdle Step (assess the stride mechanics and trunk stability during a unilateral stance); In line Lunge (evaluates the mobility of the hip and trunk, ankle and knee stability, and hamstring flexibility); Shoulder Mobility; Active Straight-Leg Raise (hamstring flexibility and pelvic stability); Trunk Stability Push-up (trunk and pelvic stability); and Rotary Stability (assesses the stability of the trunk while the upper and lower limbs are in a combined motion). The score of each movement ranges from ‘1’ to ‘3’, and is based on the movement quality, presence of asymmetries and difficulties in completing the test. The score ‘3’ represents an ideal movement and the score ‘1’ represents a movement with deficits based on the method’s recommendations, described elsewhere. The score ‘0’ is applied in painful movements, and the test is interrupted. The maximum score of the FMS™ is 21. The FMS™ measurements were taken in real-time and the participants were allowed to perform three attempts for each movement pattern.

Previous studies demonstrated that athletes with scores equal to and lower than 14 were associated with a higher risk of injury compared to those with the highest scores ( >14). According to Kiesel et al, the cut-off with score of 14 was sensitive to the detection and prediction of musculoskeletal injuries. Moreover, scores > 14 were related to a better functional status of subjects assessed by the FMS™. Hence, the present study adopted the score of 14 as a criterion for group division: FMS₁ (individuals classified with score >14) and FMS₂ (individuals classified with scores ≤14). Even though the composite cut-off score was established in athletes, a previous study demonstrated that student-athletes and general college students presented no significant differences on the performance of all movement patterns of the FMS™. Therefore, the authors determined that the group division would be suitable for the purpose of the present study.

Figure 1. Subject's position on the balance platform.
Statistical analysis

Data normality assumptions were confirmed by the Shapiro-Wilk test. The paired Students t-test was applied to compare the dominant and non-dominant limbs. As significant differences between the lower limbs were not found in any balance index (OBI, AP and ML) for both stable and unstable conditions, data from the dominant limb are presented.

The independent Students t-test was used to verify differences between the FMS₁ and FMS₂ groups regarding dependent variables OBI, ML and AP and participants’ demographic data.

A discriminant analysis was applied in order to identify which of the balance indices (AP, ML or OBI) would adequately discriminate the FMS™ groups (FMS₁ and FMS₂). For the discriminant analysis, the homogeneity of variance-covariance matrices was tested by the Box’s M test. Two discriminant analyses were performed to identify which of the balance indexes, in stable and unstable conditions, would significantly discriminate the FMS₁ and FMS₂ groups (Wilk’s Lambda - λ). The canonical correlation was used to measure the association between the discriminant scores and the group of individuals classified by the FMS™. Subsequently, the classification analysis was applied to demonstrate the accuracy of participant’s allocation in the groups and was confirmed by a cross-validation.

SPSS (Statistical Package for Social Sciences) version 22.0 was used for all analyses, and the significance was set at 5% (p≤0.05).

RESULTS

There were no significant differences between FMS₁ and FMS₂ groups regarding demographic characteristics (Table 1). Values of the overall balance index (OBI), anteroposterior (AP) and mediolateral (ML) indexes, in stable and unstable conditions, are shown in Figures 3, 4 and 5, respectively, for both groups.

The comparison between FMS₁ and FMS₂ groups in the stable and unstable conditions demonstrated a significantly higher unstable AP index for the FMS₂ (p = 0.017). No significant differences were found for the other comparisons (p > 0.05).

The balance indexes in the stable condition did not discriminate between the groups of subjects.
allocated to the FMS\textsubscript{1} and FMS\textsubscript{2} ($\lambda = 0.92; \chi^2 = 4.17; p = 0.24$). Likewise, the balance indexes in unstable condition did not discriminate the groups ($\lambda = 0.86; \chi^2 = 7.33; p = 0.06$).

**DISCUSSION**

The purpose of the present study was to compare balance indexes between two groups of subjects assessed by the FMS\textsuperscript{TM} method. The study also attempted to verify whether the balance indexes in stable and unstable conditions discriminated the FMS\textsubscript{1} and FMS\textsubscript{2} groups. A statistically significant difference was found in the unstable AP index, however, the other balance indices did not discriminate between the groups based on the composite FMS\textsuperscript{TM} score (cut-off score of 14).

The present study results demonstrated that balance indexes in stable and unstable conditions were not significantly different between FMS\textsubscript{1} and FMS\textsubscript{2} groups, except the unstable AP index condition, which was significantly higher for the FMS\textsubscript{2} group. This is an interesting finding, considering that the balance is a key component for different movement patterns used daily and sport movements.\textsuperscript{35} Additionally, the FMS\textsubscript{2} subjects (score ≤14) presented lower scores on the Deep Squat, Trunk Push-Up, and Leg Raise compared to the FMS\textsubscript{1} (based on a descriptive mode analysis). It is speculated that a higher AP instable index in this group might be related to worse performances on those FMS\textsuperscript{TM} movement patterns in which sagittal plane movements...
and consequently muscle actions are major components. This corroborates the FMS™ requirements for a stable support base and an adequate body stability. The stable OBI, AP and ML indices present no significant differences between groups. This may be explained by the fact that a static one-leg balance test was adopted. According to Blackburn et al, balance tests under static and minor instability conditions offer only small challenges for healthy individuals with preserved vestibular, visual and somatosensory systems. Also, Clifton et al evaluated the effects of a fatiguing exercise protocol on postural balance measurements in healthy subjects, and demonstrated that the sum scores of the FMS™ were not different when individuals were compared before and after performing the exercise protocol. The study's assumption was that after the completion of the fatiguing exercises, the postural control would be deleteriously affected and, consequently, the FMS™ would be able to detect balance deficits as a result of a worse performance in the movement patterns. However, the authors found that the sum score had no relationship to the balance measurements, though individual movements such as the Hurdle Step and In Line Lunge required greater postural control. Those movements were the only ones associated to the identification of balance deficits before and after the fatiguing exercise protocol.

The present study partially contradicts the results from Clifton et al, as the FMS₂ group presented a significantly higher unstable AP index when compared to the FMS₁. This indicates that the FMS group had anteroposterior balance deficits, in agreement with Teyhen et al. Those authors found that a better FMS™ performance was associated with a greater anterior reach in the Y-Balance test, combined with other components such as greater hamstring muscle flexibility and greater lower limb functional status. It is important to note that the body stability is a dynamic process involving an equilibrium between stabilizing and destabilizing components and coordinated muscular responses. Moreover, AP balance refers to the ability to maintain a stable vertical alignment, associated with minimum body movements forward and back. Specifically, AP balance is dependent on synergistic muscles that act as a unit, characterized by strategies involving the muscles of the ankle, knee and hip. Thus, as expected, the ASL performed in unstable condition challenged the subjects' postural control and synergist muscles to a greater extent than static.

It is possible that individuals with lower total scores (≤14) had muscle strength deficits, especially in muscles such as the gastrocnemius and quadriceps. This hypothesis could explain the differences for the AP index in unstable condition among the FMS₁ and FMS₂ groups. This is also supported by the medial-lateral index findings, in which no significant differences were found between groups and this index seems to be dependent on the position of the hip and trunk and the use of their respective muscles. Therefore, one limitation to the current study was not having evaluated the participants' muscle strength. Thus, it is suggested that future studies measure both muscle strength and dynamic balance measurements for this purpose.

Regarding the discriminant analysis, the current study demonstrated that the balance indices in stable and unstable conditions (OBI, AP and ML) did not discriminate between the FMS₁ and FMS₂ groups. According to Marôco, the discriminant analysis is a multivariate statistical technique that identifies which variables can distinguish different groups of individuals. Furthermore, this statistical technique generates a discriminant function that represents the differences between groups and classifies new individuals correctly. Thus, the technique provides a classification method used to assess how the discriminant function is able to correctly classify individuals in their groups, specifically, FMS₁ or FMS₂. The balance indexes utilized in the present study were not able to identify groups of subjects based on the FMS™ composite cut-off score ≤14 and >14, corroborating a previous systematic review. The review demonstrated that the adoption of a FMS™ composite score is not adequate for the purpose of injury prediction, as the screen construct is unlikely to be unidimensional and involve different physical skills on each movement.

The present findings could be explained by Sefton et al who reported that balance variables are numerous and there is no consensus on which one provides more detailed information regarding functional assessments. They performed a discriminant analysis to determine which sensorimotor variable (static
and dynamic balance, motoneuron pool excitability, and joint kinesthesia) would be more suitable to differentiate individuals with and without chronic ankle instability. Their findings demonstrated that a combination of seven variables comprising static balance and motoneuron pool excitability classified 86% of the participants.

Previous authors have reported that only two FMS™ movements were strongly dependent on key components of the balance, the in line lunge and the hurdle step. Even though the other FMS™ movements have balance components in their construct, it is possible that they would be more influenced by a multivariable discriminant analysis composed by variables such as muscle extensibility, joint mobility, and muscle strength, corroborating the suggestions of Ross, Guskiewicz, Gross, Yu. The study by Lockie et al demonstrated that a dynamic Y-Balance test was not associated with the FMS™ movements and might also explain why the groups in the present study were not discriminated by static balance indices. It is speculated that the FMS™ detected only general movement deficits of the participants, based on the composite FMS™ score. Thus, another limitation was the recruitment of healthy volunteers with no neuromuscular diseases or significant postural control dysfunctions. Moreover, the current findings can be explained by the fact that most of the participants presented hurdle step and in line lunge scores ranging from 2 to 3, indicative of a good functional status.

Future studies should evaluate subjects affected by musculoskeletal disorders that impose balance or neuromuscular control deficits, as well as to adopt healthy individuals as matched controls. This would help to better understand the discriminant potential of the indexes adopted in the present study. The inclusion of muscle strength and biopsychosocial factors in the discriminant analysis is recommended, in order to elucidate if other variables could influence and/or determine the classification of the functional movement. The association between physical measures such as the static balance, with each one of the seven FMS™ movements is also warranted.

CONCLUSION
The findings of the current study demonstrated that healthy subjects assessed by the FMS™ presented no differences in the balance indices applied in stable and unstable conditions, though subjects with a lesser movement profile (score < 14) presented a higher degree of anteroposterior balance instability. Additionally, the static balance did not discriminate groups of healthy individuals based on the FMS™ composite score (and a cut-off score of 14). From a practical standpoint, the current study demonstrated that the adoption of static balance measurements, which are commonly used to assess neuromuscular function, has limited contributions to the FMS™ composite score of healthy and physically active young adults.

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ABSTRACT

Background: The Functional Movement Screen (FMS™) is a widely used seven-test battery used by practitioners working in sport medicine. The FMS™ composite score (sum of seven tests) in soccer athletes from different competitive levels has been well explored in literature, but the specific movement deficits presented by young high competitive level players remains unclear.

Purpose: The aim of the present study was to provide a detailed description of the performance of elite young soccer players (age 14-20 years) on the FMS™ testing battery.

Study design: Cross-sectional observational study.

Methods: One-hundred and three young soccer players (14-20 years) from a premier league club were assessed by two experienced raters using the FMS™ testing battery. FMS™ composite score, individual-test scores and asymmetries were considered for analysis, and comparisons between age categories were performed.

Results: FMS™ composite scores ranged from 9 to 16 points (median = 13 points). 82% of the athletes had a composite score ≤14 points, and 91% were classified into the “Fail” group (score 0 or 1 in at least one test). Almost half of athletes (48%) had poor performance (i.e., individual score <2) in “deep squat” test. Most of athletes in the younger categories (under-15 and under-16) had poor performance in the “trunk stability push-up” test (70%) and in the “rotary stability” test (74%). Asymmetry in at least one of five unilateral FMS™ tests was found in 65% of athletes.

Conclusion: High-performance young soccer players have important functional deficits, especially in tasks involving deep squat and trunk stability, as well as high prevalence of asymmetry between right and left body side.

Level of evidence: 3a.

Key words: Athletic performance, FMS™, human movement, injury prevention, movement system, soccer.

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INTRODUCTION
The Functional Movement Screen (FMS™) is a movement-competency-based test battery aimed to provide a clinically interpretable measure of “movement quality”. For a comprehensive review of the screening test battery and it’s scoring see Cook et al.1,2 Despite the subjectivity on the visual assessment of human movement, the FMS™ presents acceptable levels of inter-rater and intra-rater reliability.3 Therefore, the FMS™ has been used as a screening tool for developing exercise programs focused on injury prevention, rehabilitation, and performance enhancement in sports. Kiesel et al.4 first examined the ability of the FMS™ to predict injury in American football players. Thereafter, the use of the FMS™ has spread to a range of sports, and athletes with a FMS™ composite score ≤14 points are usually classified as those with high injury risk. However, systematic reviews have provided conflicting conclusions on this cut-point.5,6

The FMS™ has also attracted considerable attention by researchers as evidenced by the increasing number of publications involving recreational,7 college,8 and Olympic9 athletes from different sports. Regarding soccer, McCall et al.10 investigated strategies related to injury prevention adopted by premier league teams in different countries of Europe, America and Oceania; and results indicated that FMS™ is the most commonly used method to identify risk factors for non-contact injuries. In addition, there are studies describing the FMS™ composite score of male soccer players in different competitive levels, such as professionals,11 semi-professionals,12 veterans,13 college,14 and adolescent15,16 athletes.

Portas et al.16 performed a cross-sectional study with 1,163 young soccer players (age 8-18 years) and demonstrated that most athletes presented composite scores ≤14 points. However, since the injury predictive value of the FMS™ composite score is inconsistent,5,6 more attention should be paid to individual athlete performance in each task rather than the simple sum of scores. Coaches, conditioning trainers, athletic trainers, physiotherapists and other practitioners of the coaching/medical staff are increasingly interested in identifying specific deficits of athletes, aiming to plan and implement corrective programs to improve movement quality. In this way, scores in each one of the seven FMS™ tests (i.e., individual scores) and different scores between right and left side in the unilateral FMS™ tests (i.e., asymmetries) may provide more accurate information about the functional deficits of the evaluated athletes.17

The aim of the present study was to provide a detailed description on the performance of elite young soccer players (age 14-20 years) on FMS™ testing battery. FMS™ composite score, individual-test scores and asymmetries were addressed to provide relevant deficits observed in soccer athletes engaged in the highest competitive level of their age category.

METHODS
Study Design
Young soccer players from a Brazilian Series A professional club were invited to participate in this cross-sectional observational study. The study was approved by the institutional ethics committee (#1.196.139), and all volunteers (subjects ≥18 years old) or their legal representatives (subjects <18 years old) provided informed consent before starting study participation. Each athlete performed the full battery of FMS™ in a single day. Tests were performed in their own training center and always before practice sessions. All evaluations were carried out between August and October (Brazilian season starts at February and ends at December).

Participants
One-hundred and three male soccer athletes, 14 to 20 years old, with experience in national and international competitions participated in this study. All athletes played in the youth categories of an elite Brazilian soccer club, recognized by the Brazilian Football Confederation as one of the main player development programs in Brazil. According to the organizational structure of the club, these athletes were divided into four competitive categories: U-15 (age ≤15 years, n = 28), U-16 (age ≤16 years, n = 26), U-17 (age ≤17 years, n = 24) and U-20 (age ≤20 years, n = 25). The U-15 and U-16 athletes trained once a day, six days a week, with each training session lasting approximately two hours (approximately 12 hours of on-field training per week). The U-17 and U-20 athletes trained in two additional shifts,
completing about 16 hours of on-field training per week. All athletes performed gym training two to three times per week.

Participants with the following conditions were excluded from the study: (1) athletes with less than two years of competitive sport practice; (2) athletes currently undergoing rehabilitation of musculoskeletal injuries; or (3) athletes away from the team’s training routine for >30 days within the six-month period prior to the study due to musculoskeletal injuries or any other health conditions.

Procedures
Anthropometric data from each participant was completed by the coaching staff that regularly performed these measurements as part of their evaluation routine. Body mass and height were respectively obtained from a calibrated scale (Urano, Brazil) and a stadiometer (Sanny, Brazil). Information regarding tactical position were also provided by the coaching staff. When the athlete played in more than one tactical position, the most frequently position was considered for analysis.

Participants were previously informed about the day and time they would be evaluated, and received the following recommendations: (1) not to perform high-intensity physical activities in the 24 hours prior to the tests; (2) not to drink alcohol within 48 hours prior to testing; (3) not to take any kind of analgesic and/or anti-inflammatory drugs within 48 hours prior to testing; (4) not to consume stimulant substances (e.g., caffeine) within 12 hours prior to testing; and (5) wear adequate clothing to perform the tests (shorts, t-shirt and sneakers).

Athletes were assessed using the full FMS™ protocol, comprised by seven movement patterns, following the order described by the creators of the method: (1) “Deep squat”; (2) “Hurdle step”; (3) “In-line lunge”; (4) “Shoulder mobility”; (5) “Active straight-leg raise”; (6) “Trunk stability push-up”; And (7) “Rotary stability”. The specific clearing tests were performed after tests #4, #6 and #7. Detailed explanation regarding each test and scoring procedures can be found in Cook et al. Evaluations were conducted by two experienced raters and carried out with an official FMS™ kit (Sanny, Brazil).

The raters explained each movement pattern in a standard way to the participants. Athletes performed three trials of each movement, and the best performance was considered for analysis. The ability to perform the movement pattern was observed by the two raters, who independently scored the task performance in a 4-point scale (0, 1, 2 or 3 points). The highest score from three trials was recorded in a specific worksheet. At the end of the test battery, both raters verified the agreement of the given scores for each pattern of movement performed. When there was disagreement in any scored test, player was asked to repeat the movement pattern.

Statistical Analyses
Descriptive statistics (mean, standard deviation, median, interquartile range, minimum and maximum values) were performed for the FMS™ composite scores. Participants who scored a 0 in the FMS™ (indicating pain) or a 1 (indicating dysfunction) in any test movement were classified into a “Fail” group; while athletes who scored only 2 or 3’s were classified into a “Pass” group. Percentage distribution of individual scores (each one of the seven tests) and the presence of asymmetries in unilateral tests were also calculated. Categories (U-15, U-16, U-17 and U-20) were compared using one-way ANOVA followed by post-hoc Least Significant Difference (LSD) test for the following variables: body mass, height, FMS™ total score and the individual scores. All analyses were computed via SPSS® 17.0, and the level of significance for all tests was set at p<0.05.

RESULTS
As shown on Table 1, no significant differences in height between age categories were observed (p=0.902). However, the U-20 athletes had greater body mass compared to U-15 (p=0.001) and U-16 (p=0.001) athletes. The distribution in the tactical positions of players was similar among the categories.

Eighty-two percent of the athletes had a FMS™ composite score ≤14 points (89% of U-15; 92% of U-16; 75% of U-17; and 72% of U-20). Ninety-one percent of players were classified into the “Fail” group (96% of U-15; 96% of U-16; 83% of U-17; and 88% of U-20). As observed in Figure 1, both U-15 and U-16 athletes presented lower values of composite score than...
the U-17 (p=0.007; p=0.005) and U-20 (p=0.035; p=0.025) players. Additional information regarding the FMS™ composite score are presented in Figure 1.

Distribution of the individual scores in each of the seven tests of FMS™ is presented in Figures 2 to 4. There were no significant differences between the categories considering the movement tests (Figure 2): “deep squat” (p=0.314), “hurdle step” (p=0.183), “in-line lunge” (p=0.900). On the mobility tests (Figure 3): U-15 and U-16 players had higher scores compared to U-20 category on “shoulder mobility” test (p=0.001; p=0.027); and the U-15 players had lower scores compared to any other categories in the active “straight-leg raise” test (p=0.040; p=0.002; p=0.013). Regarding the stability tests (Figure 4): U-20 athletes presented superior values compared to both U-15 (p=0.019) and U-16 (p=0.007) players on “trunk stability push-up” test; and the U-17 and U-20 athletes had higher individual scores compared to the U-15 and U-16 players in the “rotary stability” test (p<0.001 for all comparisons).

The absolute number and percentage of athletes from each category presenting asymmetries can be observed in Table 2. A total of 65% of the participants presented asymmetry between right and left side in at least one of the five unilateral FMS™ tests.

**DISCUSSION**

The objective of the present study was to describe the functional movement performance of high competitive level youth soccer players using the FMS™ test battery. The main findings of the current study were: (1) the athletes achieved composite scores ranging from 9 to 16 points; (2) most of athletes had a composite score ≤14 points; (3) almost half of athletes presented a poor performance (i.e., individual score <2) on the “deep squat” test; (4) most of athletes in the younger categories (U-15 and U-16) had a poor performance on “trunk stability push-up” and on “rotary stability” tests; and (5) most of athletes presented asymmetry in at least one of the five unilateral tests.

Similarly to the present study, Portas et al.16 described an age-related effect on FMS™ composite scores in youth players of English Football League
(from 11 to 14 points); while mean composite scores reported in adult players ranged between 15.11 and 16.12 points. A similar age-related performance seems to occur among female athletes, since collegiate18 and professional19 players obtained mean FMS™ composite scores of 13 and 16 points, respectively. Taken together, these findings suggest that younger athletes show greater deficits in functional movement patterns compared to older adolescent or adult players.

Of interest is the high percentage of athletes with total score ≤14 points in the present study. This cut-point was firstly proposed by Kiesel et al.4 in 2007, and a systematic review from Bonazza et al.5 also suggested a higher incidence of injuries in individuals with FMS™ composite scores ≤14 points. On the other hand, a recent systematic review by Moran et al.6 found a “moderate” evidence to recommend against the use of FMS™ total score as an injury prediction test in soccer, while the evidence was “limited” or “conflicting” for other sport populations (including American football, college athletes,
than those with higher scores, but athletes with an asymmetry or a score ≤1 on any individual test of the FMS™ were at 2.73 times greater risk of a musculoskeletal injury than others. Thus, the high incidence of players into the “Fail” group (91%) and with bilateral asymmetries (65%) found in the current study could present a real concern for the coaching/medical staff. The results reported here and in other studies with young male and female soccer athletes suggest that adaptations promoted by the specific training required by this sport does not lead players to adequate levels of functional movement. This hypothesis is strengthened by findings indicating that FMS™ composite scores are unaffected throughout the competitive soccer season at the university competitive level. In other words, a specific intervention program (in addition to the usual training performed in soccer) seems necessary to increase the FMS™ scores, as already demonstrated in American football players.

The analysis of individual scores provides a deeper understanding on the movement deficits of athletes. Almost half of athletes did not reach satisfactory levels in the “deep squat” test, which can be explained by limitation of ankle dorsiflexion in most cases. Moreover, it seemed that the highest composite scores observed in the oldest athletes (U-17 and U-20) may be partially explained by the better performance of these players in the stability tests (trunk stability push-up and rotary stability). While 84% of the athletes of the two most advanced categories scored 2 points in rotary stability, only 26% of youngest athletes (U-15 and U-16) achieved this score. A similar pattern occurred in the “trunk stability push-up” test, although with a less expressive difference (59% vs. 30%). Considering that all four age categories investigated in the present study basketball, ice hockey and running). Therefore, the current literature does not consistently support the injury predictive value of the FMS™ composite score.

According the cohort study of Mocka et al., college athletes with FMS™ composite scores ≤14 points were not at greater risk of musculoskeletal injury.

| Table 2. Athletes with asymmetry in the FMS™ tests that are performed bilaterally |
|---------------------------------|---|---|---|---|---|
|                               | U-15 (n=28) | U-16 (n=26) | U-17 (n=24) | U-20 (n=25) | All (n=103) |
| **Hurdle step**                | 2 (7%)      | 2 (8%)      | 0 (0%)      | 1 (4%)      | 5 (5%)       |
| **In-line lunge**              | 2 (7%)      | 1 (4%)      | 2 (8%)      | 1 (4%)      | 6 (6%)       |
| **Shoulder mobility**          | 5 (18%)     | 5 (19%)     | 8 (33%)     | 10 (40%)    | 28 (27%)     |
| **Active straight-leg raise**  | 9 (32%)     | 1 (4%)      | 4 (17%)     | 3 (12%)     | 17 (17%)     |
| **Rotary Stability**           | 4 (14%)     | 3 (12%)     | 2 (8%)      | 1 (4%)      | 10 (10%)     |
Injury rate, which may contribute to the more dramatic losses of range of motion in shoulders than legs observed in U-17 and U-20 categories. In addition, the resistance exercises for upper trunk (e.g., bench press, lat pull down) may also contribute to diminished shoulder mobility in these athletes.

Kiesel et al. demonstrated that asymmetries in the unilateral tests of FMS™ could be an injury predictive factor. Although these asymmetries have already been shown in elite and semi-professional soccer players, the present study seems to be the first to report asymmetries in young soccer players and to discriminate which of the tests present these asymmetries. The high percentage of athletes presenting asymmetry in at least one of the five unilateral tests (65%) suggests that coaching/medical staff should pay attention to the imbalances generated by soccer practice, which is characterized by the predominance of motor gestures with a preferred lower limb (e.g., pass and kick). Surprisingly, the “shoulder mobility” test presented the highest number of asymmetries among the athletes, which can be considered the least representative movement demand on soccer practice (excepted for goalkeepers). The asymmetries on functional movement patterns induced by soccer training and its repercussions on sports performance and injuries should be further investigated.

One limitation of the present study is that the authors were not able to access the full history of athletes’ injuries, which is a possible confounding factor for FMS™ results. However, all athletes were deemed healthy during data collection and had no periods of absence ≥30 days in the previous six months, which gave confidence regarding the conditions in which each athlete performed the tests during the study.

**CONCLUSION**

In summary, most elite young soccer players (age 14-20 years) have important functional deficits, especially in tasks involving deep squat and trunk stability, as well as high prevalence of asymmetry between right and left sides of the body. The present study provides reference values on the FMS™ performance of high-level competitive soccer players in their respective age categories. Coaches, conditioning trainers, athletic trainers, physiotherapists, and
other practitioners involved with soccer should be aware that young athletes seem to have greater functional deficits compared to adults,\textsuperscript{11,12,19} which may lead to a reduced technical capacity and increased injury risk. As a practical application, the authors recommend coaching/medical staff apply collective training programs with emphasis on trunk stabilization improvement (especially in younger players), while other specific deficits evidenced by FMS\textsuperscript{TM} may be worked individually or in sub-groups.

REFERENCES


ABSTRACT

Background: Pre-operative quadriceps strength may have a positive influence on post-operative function and outcomes at time of return to sport. Little consideration has been given to quadriceps strength during the early post-operative timeframes. Twelve-week post-operative anterior cruciate ligament reconstruction (ACL-R) is considered a critical time point for progression in the rehabilitation process. There is currently limited research looking at the relationship between clinical measurements pre-operatively and at 12-weeks following ACL-R.

Purpose/Hypothesis: The primary purpose of this study was to examine the differences between Y-Balance Test Lower Quarter (YBT-LQ) and isokinetic quadriceps strength tested pre-operatively and post-operatively following ACL-R (12-weeks).

Study Design: Within subject, repeated measures

Methods: Thirty-nine participants (15.6±1.5 y/o) were diagnosed with an ACL tear and were undergoing rehabilitation to return to a sport requiring cutting and pivoting were included. YBT-LQ and isokinetic quadriceps strength were assessed pre-operatively and at 12-weeks after ACL-R. YBT-LQ composite scores were calculated bilaterally and isokinetic quadriceps strength was tested using the Biodex Multi-Joint Testing and Rehabilitation System. Paired T-tests were used to determine mean group differences between YBT-LQ and isokinetic quadriceps strength scores pre-operatively and at 12-weeks post-operative. A Pearson Correlation was performed to determine relationships between variables at both time points.

Results: There was a significant improvement in YBT-LQ composite scores from pre-operative to 12-weeks post-operative on both the involved (Pre-operative: 89.0 ± 7.7; 12-weeks: 94.1 ± 7.1, p<0.001) and uninvolved (Pre-operative: 92.6 ± 6.2; 12-weeks: 97.6 ± 6.8, p<0.001) limbs. Quadriceps strength decreased significantly from pre-operative to 12-weeks on the involved limb (Pre-operative: 82.3 ftlbs ± 38.6; 12-weeks: 67.9 ftlbs ± 27.4, p<0.01), but no differences were found on the uninvolved limb (Pre-operative: 117.3ftlbs ± 42.0; 12-weeks: 121.7ftlbs ± 41.5, p = 0.226).

Conclusions: Involved limb quadriceps strength decreases from time of pre-operative to 12-weeks following ACL-R.

Level of Evidence: 3

Key words: Anterior cruciate ligament reconstruction, pre-operative, quadriceps strength, Y-balance test

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INTRODUCTION

With the ever increasing prevalence of anterior cruciate ligament (ACL) tears and subsequent re-tears, there is a need to improve return to sport outcomes. Extensive research has been performed to examine the relationship between quadriceps strength and function at the pre-operative time point and time of return to sport (RTS) in patients who have undergone anterior cruciate ligament reconstruction (ACL-R). Greater quadriceps strength pre-operatively has been correlated to increased quadriceps strength post-operatively. However, it is well documented that quadriceps strength deficits may remain for two years and beyond, following ACL-R.1-5 Multiple authors have shown that those individuals with greater quadriceps strength pre-operatively have significantly greater quadriceps strength at RTS, and those with lower quadriceps strength pre-operatively have lower functional scores on single and triple hop tests (time and distance) at time of RTS and may take longer to RTS after ACL-R.1,2,6 Quadriceps strength is important as it relates to outcomes and performance at time of RTS.2,7 Recently, researchers have found that decreased quadriceps strength, and larger asymmetries between limbs, lead to shorter distances on hop tests.1,8 This suggests that strength deficits and side to side symmetry are important to consider when looking at readiness to RTS. Limb asymmetry following ACL-R has been found to negatively affect return to sport time and these asymmetries may persist even past RTS. Despite the variability in study design and methodology, it has been consistently demonstrated that pre-operative quadriceps strength is important in the rehabilitation process.

The Y-Balance Test – Lower Quarter (YBT-LQ) is one of the functional tools used to measure single limb performance and neuromuscular control and has been studied in individuals with ACL-R.9,10 The YBT-LQ requires an individual to load on a single leg and squat while reaching with the contralateral limb. This test not only measures neuromuscular control but has also been correlated to quadriceps and hip strength.9,10 Particularly the anterior reach portion demonstrates high activation of the vastus medialis and lateralis.11 The YBT-LQ has not been studied pre-operatively in an ACL-R population to date. Garrison et al.12 found a relationship between the YBT-LQ performance at 12-weeks post-operatively (12-weeks) and at time of RTS. Participants who demonstrated a greater than 4 cm YBT-LQ anterior reach (ANT) difference between sides at 12-weeks did not meet criteria to RTS for the single and triple hop tests for distance.12 This 12-week mark may be an important indicator of performance and affect outcomes at time of RTS, however the value of the YBT-LQ in the pre-operative time frame is still unclear.

There is currently limited research looking at the relationship between pre-operative measurements and outcomes at 12-weeks following ACL-R. Although research shows that quadriceps strength is not restored until well after 12-weeks, it is important to track improvements throughout the rehabilitation process in order to make modifications based on patient performance.5 If patients reach a specific threshold on the YBT-LQ at 12-weeks they may be more likely to pass functional testing at time of return to sport. Likewise, if patients have more quadriceps strength and better YBT-LQ scores pre-operatively, this could have a positive effect on outcomes at 12-weeks. The primary purpose of this study was to examine the differences between YBT-LQ and isokinetic quadriceps strength pre-operatively and at 12-weeks following ACL-R. The secondary purpose was to examine relationships between these same variables, at both time points. The authors hypothesized that there would be a statistically significant improvement in both quadriceps strength and YBT-LQ scores from pre-operative to 12-weeks post ACL-R. In addition, it was hypothesized that there would be a statistically significant relationship between all variables at both time points.

PARTICIPANTS

This study was a within subjects, repeated measures design. Thirty-nine participants (21 males, 18 females) with an average age of 15.6±1.5 years volunteered for this study. Each participant was diagnosed with an ACL tear by a fellowship trained, board certified, orthopedic surgeon which was confirmed by MRI. Participants were enrolled prior to ACL-R with an average starting date of five days pre-operatively. All participants had an ACL reconstruction using patellar tendon autograft performed by the same surgeon. Demographics for the participants are listed in Table 1. Testing was conducted on
each participant pre-operatively, within one week of ACL reconstruction and within one week of their 12-week post-operative time point. While each individual physical therapy session was not controlled for, treating therapists were provided the institutions ACL rehabilitation protocol, which included range of motion, patellar and fat pad mobility, quadriceps and hamstrings strengthening, neuromuscular control training, and hip strengthening exercises and averaged two times per week in physical therapy, immediately post-operative until the time of retesting at 12 weeks. No formal pre-operative rehabilitation was performed by these individuals. Inclusion criteria for participation in the study were 1) first time ACL-R on the involved limb, 2) between the ages of 13 and 25, 3) involved in, and planning to return to, a sport involving cutting, planting, pivoting, jumping, and landing, in which they were active a minimum of three times per week, and 4) participation in a physical therapy return-to-sport rehabilitation program. The participants were excluded from the study if there was 1) a previous ACL tear and/or reconstruction on either side, 2) other ligamentous injuries to the knee, including meniscal injuries, or 3) an associated chondral defect requiring surgical intervention. Participants volunteered and were consented into the study by an investigator in the outpatient sports physical therapy facility once they were confirmed to meet the inclusion and exclusion criteria. Child assent and parental permission were obtained for those participants who were minors at the time of the study. Once consented into the study, objective measurements were taken on the participant’s knee and patient outcome forms were completed. The Institutional Review Board of Texas Health Resources approved the research procedures.

**Y-BALANCE TEST**

The YBT-LQ was utilized as a measure of trunk and lower extremity function. The YBT-LQ assesses ROM, strength, and neuromuscular control of the lower extremity and was chosen to assess the participants’ lower limb balance. Numerous prior studies have demonstrated its utility as a clinical test to assess for lower limb balance deficits in the athletic population. Measurements were taken in three distinct directions of anterior (ANT), posteromedial (PM) and posterolateral (PL) on both the dominant and non-dominant limbs. The dominant limb was determined as the limb with which the individual would primarily kick a ball with, thus identifying the opposite limb as the non-dominant limb. The participants were instructed in the YBT-LQ protocol using a combination of verbal cues and demonstration. The Y Balance Test Kit™ was utilized throughout the study. All participants wore shoes during testing and began on their dominant limbs. The participants were asked to perform single limb stance on the extremity while reaching outside their base of support to push a reach indicator box along the measurement pipe. Elevation of the heel, toe or loss of balance resulting in a stepping strategy was recorded as a trial error indicating the trial should then be repeated. Subjects were allowed at least four practice trials in the ANT, PM and PL directions prior to recording the best of three formal trials in each plane. Three trials were completed on the dominant limb in the ANT direction followed by three trials completed on the non-dominant limb. This protocol was then replicated in the PM and PL directions. The maximal reach distance of the three trials was recorded at the place where the most distal part of the foot reached based on the measurement pipe.

The composite scores were calculated by adding the reach distances of ANT, PM, and PL, dividing by three times the participant’s leg length, and then multiplying by 100 to obtain a percentage. The leg length was determined using the distance between the most prominent portion of the greater trochanter and the floor while the individual was in a standing position. Composite YBT-LQ scores of the involved and uninjured limbs were computed for each of the athletes in this study. Inter-rater reliability was determined prior to the initiation of this study using an intraclass correlation coefficient (ICC). Reliability of the measurements for the anterior

| Table 1. Participant demographics including means and standard deviations. |
|------------------------|----------------|----------------|----------------|----------------|
| Age (yrs) | Gender | Height (cm) | Weight (kg) | Dominant Side | Injured Side |
| 15.6±1.5 | 21 | Male | Female | Right | Left | Right | Left |
| 172.1±9.6 | 72.1±16.8 | 37 | 1 | 20 | 19 |
relationships between all variables at both time points. Statistical significance was defined as \( p < 0.05 \).

All data analysis was completed using SPSS version 23.0 (Chicago, IL 60606). A priori statistical power analysis was performed using quadriceps strength as the primary outcome, and we determined that a total of 25 participants would be needed to detect statistical significance based on an 80% power calculation.

RESULTS

A main effect for time existed in ACL patients at pre-operative and 12-weeks. There was a significant increase between pre-operative and 12-week YBT-LQ composite scores on both the involved \((t = -5.109, p < 0.001)\) and uninvolved \((t = -5.333, p < 0.001)\) limbs. There was a significant decrease in involved limb quadriceps strength between pre-operative and 12-weeks \((t = 3.649, p = 0.001)\). There was not a statistically significant difference in uninvolved quadriceps strength, although there was an increase from pre-operative to 12-weeks \((t = -1.232, p = 0.226)\).

Means and standard deviations for YBT-LQ and quadriceps strength at both time points are listed in Table 2.

When examining the relationships between variables, there was a moderate positive correlation between pre-operative YBT-LQ composite scores and 12-weeks composite scores on the involved \((r = 0.660, p < 0.001)\) and uninvolved \((r = 0.601, p < 0.001)\) limbs. There was a positive correlation between pre-operative and 12-week quadriceps strength, which was moderate on the involved limb \((r = 0.772, p < 0.001)\), and highly correlated on the uninvolved limb \((r = 0.855, p < 0.001)\). There was a high positive correlation between quadriceps strength pre-operatively on the involved limb and at 12-weeks on the uninvolved limb \((r = 0.804, p < 0.001)\).

### Table 2. Means and standard deviations for measurements taken at both pre-operative and 12-weeks post-operative in both limbs.

<table>
<thead>
<tr>
<th></th>
<th>YBT-LQ</th>
<th>Quadriceps Strength (flbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Involved*</td>
<td>Uninvolved*</td>
</tr>
<tr>
<td>Pre-operative</td>
<td>89.0 ± 7.7</td>
<td>92.6 ± 6.2</td>
</tr>
<tr>
<td>12-weeks, post-op</td>
<td>94.1 ± 7.1</td>
<td>97.6 ± 6.8</td>
</tr>
</tbody>
</table>

YBT-LQ= Y-balance test, lower quarter
*Denotes statistically significant differences between time points.
was a moderate positive correlation between uninvolved limb quadriceps strength pre-operatively and 12-weeks on the involved limb ($r = 0.664, p < 0.001$). No correlations existed on either limb between YBT-LQ composite scores and quadriceps strength at pre-operative or 12-weeks. No correlation exists between involved limb quadriceps strength and normalized ANT on either limb at either time point. A weak positive correlation exists between pre-operative and 12-week normalized ANT on the involved ($r = 0.398$, $p = 0.012$) limb. All other correlational statistics can be found in Table 3.

**DISCUSSION**

The primary purpose of this study was to compare quadriceps strength and YBT-LQ pre-operatively and at 12-weeks in individual’s status-post ACL-R. Following ACL-R participants demonstrated significantly reduced quadriceps strength on the involved limb at 12-weeks compared to pre-operative measures. It was hypothesized that there would be an increase in bilateral quadriceps strength between the two time points. The involved limb quadriceps strength decreased from $82.3 \pm 38.6$ ftlbs pre-operatively to $67.9 \pm 27.4$ ftlbs at 12-weeks, representing a 17% decrease. There was an increase in uninvolved quadriceps strength between pre-operative and 12-weeks ($117.3 \pm 42.0$ ftlbs and $121.7 \pm 41.5$ ftlbs), however this difference was not statistically significant. Although there was a difference from pre-operative to 12-weeks in quadriceps strength in both limbs, the uninvolved limb showed a positive increase in strength while the involved limb showed a significant deficit at a critical time point in the rehab process.

Peak extensor torque is an important objective measure used in ACL-R rehabilitation in order to gauge readiness for return to sport. Extensive research demonstrates quadriceps deficits can be present at six months and even up to and exceeding one year.\(^1\)\(^-\)\(^5\) Quadriceps strength has recently been shown to help predict reinjury rate. Grindem et al.\(^20\) found that individuals following ACL-R with a quadriceps strength deficit of greater than 10% are significantly more likely to reinjure their ipsilateral ACL. Hartigan et al.\(^7\) investigated pre-operative quadriceps strength in relation to readiness to return to sport and found that individuals who were unable to RTS at six months had a pre-operative quadriceps deficit of 14% compared to those who did return at six months having a pre-operative deficit of 1%. The current study found a pre-operative quadriceps strength deficit of nearly 30% when comparing involved to uninvolved, which is a much greater deficit than that found in the retrospective studies by de Jong et al.\(^1\) and Knezevic et al.\(^21\) who found pre-operative deficits of 17% and 15% respectively. In both the aforementioned Hartigan\(^7\) and de Jong\(^1\) studies their subjects received some duration of pre-operative rehabilitation which is in contrast to the current study. Despite the differences in study methodology, the aforementioned studies point to

### Table 3. Pearson Correlational coefficients ($r$-value) for all variables at all time points.

<table>
<thead>
<tr>
<th></th>
<th>Pre-operative</th>
<th>12-Weeks Post-operative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YBT-LQ Composite</td>
<td>Quadriceps Strength</td>
</tr>
<tr>
<td></td>
<td>Involved</td>
<td>Uninvolved</td>
</tr>
<tr>
<td>YBT-LQ Composite</td>
<td>0.732**</td>
<td></td>
</tr>
<tr>
<td>Involved</td>
<td>0.119</td>
<td>0.770**</td>
</tr>
<tr>
<td>Uninvolved</td>
<td>-0.226</td>
<td>0.691**</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>0.806**</td>
<td>0.578**</td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normalized ANT</td>
<td>0.866**</td>
<td>0.578**</td>
</tr>
<tr>
<td>Involved</td>
<td>-0.136</td>
<td>-0.089</td>
</tr>
<tr>
<td>Uninvolved</td>
<td>-0.200</td>
<td>-0.118</td>
</tr>
<tr>
<td>YBT-LQ Composite</td>
<td>0.433**</td>
<td>0.390**</td>
</tr>
<tr>
<td>Involved</td>
<td>0.314</td>
<td>0.528**</td>
</tr>
<tr>
<td>Uninvolved</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** indicates statistical significance, $p<0.05$. 

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the importance of the relationship between pre-operative measures and post-operative success.

In early post-operative stages following ACL-R protocols call for weight-bearing as tolerated, although some require periods of non-weight-bearing on the involved lower extremity ranging from two weeks to six weeks depending on surgeon preference and meniscal involvement. Regardless of surgical precautions, patients often self-select to decrease weight-bearing due to pain or fear. This decrease or lack of lower extremity use may lead to immediate atrophy of all musculature in that extremity. Chung et al.22 found that there is a bilateral decrease in quadriceps strength following ACL-R and attributed that decrease to a change in the neurological response of the muscle. Decreased use could potentially also diminish strength on the uninvolved side, as these individuals significantly reduce their activity level immediately following surgery, which includes a decrease in overall use of the uninvolved limb.

The percent quadriceps strength deficit between limbs of 44% at three months post-operatively found in this study is similar to the findings of de Jong et al.1 who investigated quadriceps strength at 6, 9 and 12 months, and found between limb deficits of 36%, 25% and 19% respectively. Previously, Shelbourne and Johnson5 measured quadriceps strength at three months following ACL-R with an average between limb strength deficit ranging from 25% to 35%, which is less than the 44% deficit found in the current study at the same three month mark. Likewise Knezevic et al.21 found quadriceps strength asymmetries at four months post-operative with deficits near 32%. Quadriceps strength at the 12-week mark following ACL-R sets the foundation for success when returning to sport.23

The significant quadriceps deficit identified in the current study at the 12-week mark is alarming for many reasons. At three months, many protocols call for the initiation of higher level activities such as hopping and jogging.23 Often objective measures such as YBT-LQ composite and single leg squat endurance/quality are used to determine readiness to perform these higher level activities. Other important factors to consider at this point in rehabilitation include equal weight bearing with double leg squatting, reactive effusion to an increase in activity and amount of kinesiophobia. Questions arise about an individual’s readiness to perform higher level activity, with this alarming difference in quadriceps strength. Although neuromuscular control may be adequate to perform YBT-LQ and extensive single leg squatting, these tasks do not point to the quadriceps muscles ability to generate adequate force for higher level activities.

Participants had improved YBT-LQ composite score on both the involved and uninvolved limbs at 12-weeks compared to pre-operative measures. These findings support the secondary hypothesis that there would be a significant increase in YBT-LQ in both extremities from pre-operative to 12-weeks. Along with being significantly improved, YBT-LQ scores were also highly correlated between limbs and both time points. Even when the YBT-LQ ANT reach was normalized to leg length, there was an insignificant relationship between this measure and quadriceps strength. Normalized ANT in both limbs was moderately correlated between pre-operative and 12-weeks. Previous research by Texas Health Sports Medicine drew attention to YBT-LQ ANT reach at 12-weeks, and its ability to help predict return to sport at six months.12 The current study found poor positive correlations between YBT-LQ normalized ANT in the involved leg at pre-operative and 12-weeks, as well as in the uninvolved leg at those same time points. There was no correlation between YBT-LQ normalized ANT and quadriceps strength measures at either time point, in either the involved or uninvolved limb. It is impossible to draw a causal relationship, however similarly to quadriceps strength the results point to those individuals with better pre-operative YBT-LQ comp scores continuing to have better scores at 12-weeks in relation to those with lower scores pre-operatively.

The increase in YBT-LQ from pre-operative to 12-weeks is in line with the current study’s hypothesis despite the significant decrease in involved limb quadriceps strength. This finding may point to the fact that the YBT-LQ is a trainable skill in which quadriceps strength plays a role in improvements following ACL-R, in addition to neuromuscular control, hip strength and range of motion of the entire lower extremity. Garrison et al.24 found that gluteal
strengthening contributes to YBT-LQ ANT. Individuals that scored higher on the YBT-LQ at 12-weeks, but had decreased quadriceps strength may have had an increase in gluteal strength between the pre-operative assessment and assessment at 12-weeks.

**LIMITATIONS**

One of the limitations of the current study is the fact that pain could have limited participant function during both the YBT-LQ and quadriceps strength testing. All of the patients in this study had a patellar tendon autograft which has been shown to cause greater anterior knee pain and graft site irritation compared to hamstring graft following ACL-R.24 Ipsilateral patellar tendon use puts a disruption in the quadriceps complex impeding the pulley system utilized at the knee joint. The tendon and surrounding structures including the infrapatellar fat pad play a crucial role in the ability to generate strength.3 Although patients were instructed to stop all testing secondary to an increase in pain, none chose to do so. All participants were able to complete testing without complaints of pain.

As previously mentioned, core and hip strength, as well as lower extremity range of motion play a role in YBT-LQ scores.25 For the purpose of this study core and hip strength were not quantified, and therefore make it difficult to ascertain the cause of increase in YBT-LQ scores.

**CONCLUSION**

Involved limb quadriceps strength is significantly weaker pre-operatively and remains significantly reduced at 12-weeks status post ACL-R. Despite a significant reduction in quadriceps strength, individuals were able to improve their YBT-LQ scores bilaterally between pre-operative and 12-weeks.

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ABSTRACT

Background/Purpose: Athletes experiencing hip, groin, and low back pain often exhibit similar clinical characteristics. Individuals with hip, groin and low back pain may have the presence of multiple concurrent pathoanatomical diagnoses. Regardless, similar regional characteristics and dysfunction may contribute to the patient's chief complaint, potentially creating a sub-group of individuals that may be defined by lumbopelvic and hip mobility limitations, motor control impairments, and other shared clinical findings. The purpose of this case series is to describe the conservative management of elite athletes, within the identified aforementioned sub-group, that emphasized regional manual therapy interventions, and therapeutic exercise designed to improve lumbopelvic and hip mobility, stability and motor control.

Case Descriptions: Five elite athletes were clinically diagnosed by a physical therapist with primary pathologies including adductor-related groin pain (ARGP), femoral acetabular impingement (FAI) with acetabular labral lesion and acute, mechanical low back pain (LBP). Similar subjective, objective findings and overall clinical profiles were identified among all subjects. Common findings aside from the chief complaint included, but were not limited to, decreased hip range of motion (ROM), impaired lumbopelvic motor control and strength, lumbar hypomobility in at least one segment, and a positive hip flexion-adduction-internal rotation (FADIR) special test. A three-phase impairment-based physical therapy program was implemented to resolve the primary complaints and return the subjects to their desired level of function. Acute phase rehabilitation consisted of manual therapy and fundamental motor control exercises. Progression to the sub-acute and terminal phases was based on improved subjective pain reports and progress with functional impairments. As the subjects progress through the rehabilitation phases, the delivery of physical therapy interventions were defined by decreased manual therapies and an increased emphasis and priority on graded exercise.

Outcomes: Significant reductions in reported pain (>2 points Numeric Pain Rating Scale), improved reported function via functional outcome measures (Hip and Groin Outcome Score), and continued participation in sport occurred in all five cases without the need for surgical intervention.

Discussion: The athletes described in this case series make up a common clinical sub-group defined by hip and lumbopelvic mobility restrictions, lumbopelvic and lower extremity motor control impairments and potentially other shared clinical findings. Despite differences in pathoanatomical findings, similar objective findings were identified and similar treatment plans were applied, potentially affecting the movement system as a whole. Subjects were conservatively managed allowing continued participation in sport within their competitive seasons.

Conclusion: Comprehensive conservative treatment of the athletes with shared impairments, as described in this case series, may be of clinical importance when managing athletes with hip, groin, and low back pain.

Level of Evidence: Therapy, Level 4, Case Series

Key Words: Groin, Hip, low back pain, movement system, return to sport
INTRODUCTION
Athletes who participate in sports that require twisting and high-intensity change of direction forces, such as football, basketball, soccer, and hockey, often experience hip, groin, and low-back pain.\(^1,2,3,4\) In athletes with groin and low back pain, accurate diagnosis and appropriate treatment can be challenging due to complex anatomy and similar clinical patient complaints.\(^5,6,7\) Musculoskeletal differential diagnosis within the lumbopelvic hip complex includes discernment regarding pathologies that may be intra-articular (i.e. acetabular labral tears, cartilaginous damage) or extra-articular (muscular in nature) to the hip. Dysfunction related to the core and adductor muscle complex and/or the pubic, inguinal, and lumbar regions must also be considered as a potential source of groin pain.\(^2,7\)

Further complicating the presentation is the possibility of multiple coexisting diagnoses\(^3\) and regional interdependence as a contributing factor to local pain and impairment,\(^8\) as well as global movement system dysfunction. It has been found that up to 94.1% of athletes diagnosed with athletic pubalgia have radiographic evidence of femoral acetabular impingement (FAI)\(^9,10,11\) while hip and groin pathology and low back pain have been proposed to be found concurrently in the same patient population.\(^12,13,14,15\) Multiple diagnostic methods and modalities\(^7,15,16,17\) including a layered pathoanatomical approach,\(^1\) have been proposed to help clarify the identification of specific diagnoses, guide treatment, and explain potential mechanisms of injury within the hip and lumbopelvic region.

Pathoanatomy of the hip has been proposed as a potential causative factor for injury.\(^1,2,3\) FAI syndrome, which often includes a cam, pincer, or mixed cam/pincer morphology of the hip joint, has been proposed to contribute to athletic-related groin pain.\(^15,18\) This anatomical presentation may result in abnormal hip ROM, which has been suggested as a risk factor for many of the previously noted injuries, such as intra-articular hip, core and adductor related injury, and LBP\(^1,2,11,19\). However, these bony and intra-articular features have also been identified in a large proportion of asymptomatic athletes and may not be solely responsible for pathology.\(^20\) Athletes with asymptomatic hips have commonly been reported to present with cam (54.6%) and pincer (49.5%) morphology respectively, while 65.4% were found to have an acetabular labrum defect.\(^21\) ROM limitations, regardless of bony architecture, have been associated with athletic groin injury.\(^22\)

Athletic movement requires appropriate hip mobility. When limited, altered motor control\(^23\) may lead to compensatory redistributions of force across the pelvis in order to perform the desired sport-specific movement.\(^24\) For example, hip ROM limitations associated with cam morphology has been linked to increased motion and stress at the pubic symphysis\(^25,26\). Aside from morphology, regional contributions may also affect hip mobility, as the posture of the pelvis can further reduce the ROM available at the hip\(^27\) while those with FAI syndrome demonstrate a decreased ability to functionally rotate the pelvis posteriorly.\(^28\) It has been suggested that the relationship of FAI and the lumbopelvic region play a role in LBP.\(^2,12,14\) The mobility of soft tissue structures surrounding the hip joint can also contribute to functional losses in ROM.\(^13,16,29,30\)

In addition to limited hip ROM, other risk factors include impaired regional strength and motor control. Inadequate strength profiles of the hip musculature have been identified in those who have sustained groin and lower extremity injury,\(^31,32,33,34\) while individuals with groin pain and LBP have been found to demonstrate motor control deficits of the lumbopelvic region and lower quarter.\(^14,23,24,35\) Those with FAI have been reported to demonstrate altered lower body kinetics and force attenuation, potentially resulting in excessive impulse to the joint.\(^36\) Motor control deficits have been linked to reports of impaired sport performance and pain.\(^35,37\)

Uneven distribution of forces across the pelvis, in part due to limited regional mobility\(^22\) and impaired strength\(^31,32,33\) and neuromuscular control\(^35,38\) may result in mechanical overload and subsequent acute or chronic injury,\(^1,4\) ultimately impacting the movement system. These previously noted findings about the hip and lumbopelvis have been proposed to be related irrespective of any individual pathoanatomical diagnosis.\(^1,4\) Recently, authors have recommended assessment and intervention focusing less on painful structures and more on the resolution of
comprehensive movement impairments and injury risk reduction strategies.24,37 The purpose of this case series is to describe the conservative management of elite athletes, within the identified aforementioned sub-group, that emphasized regional manual therapy interventions, and therapeutic exercise designed to improve lumbopelvic and hip mobility, stability and motor control.

CASE DESCRIPTIONS
Five male athletes, aged 19 to 27, were included in this case series. The subjects were all evaluated and treated by one of two physical therapists, and referred for diagnostic imaging and evaluation by their respective team orthopedic physician as necessary. Outcomes were assessed by utilizing the Numeric Pain Rating Scale (NPRS),38 outcome measures specific to the chief complaint (i.e Hip and Groin Outcome Score for groin pain cases)39 and return to sport participation. Long-term follow up was performed at one year following the initial course of treatment.

Subject Presentations

Subject 1
Subject 1 was a 22 year-old professional basketball player who reported chronic, (> 3 months) progressive, left-sided groin pain of insidious onset. Pain was produced with sprinting and cutting maneuvers and was occasionally experienced bilaterally when the presentation was most severe and irritable. The subject described at least two instances of ‘sharp pain’ and ‘tearing’ sensations in the adductor musculature during linear sprinting and cutting in the weeks prior to the initial evaluation. Plain radiographs revealed bilateral cam morphology while MRI revealed a mild anterosuperior labral lesion of the left hip.

Subject 2
Subject 2 was a 19-year-old professional basketball player who presented with acute low back pain and episodic bilateral groin pain. The chief complaint was pain across the inferior lumbar spine. Also reported was inconsistent ‘sharp’ pain through the proximal 1/3 of each medial hip/thigh with running and multiplanar sport tasks. MRI of his lumbar spine revealed a chronic, grade 1 L5-S1 spondylolisthesis. Plain radiographs demonstrated cam morphology of bilateral hips.

Clinical Examination
A detailed subjective history, systems review, and objective examination was performed on each subject. Clinically relevant subjective information included, but were not limited to, pain reported in the groin, popping, clicking, or locking of the hip, chronic groin tightness, local pain when bearing down, and “C” sign.3,7,18 Physical examination consisted of regional palpation,7,17 active and passive lumbar and hip range of motion, strength assessment via manual muscle testing, passive joint motion, neurodynamic testing,46 and appropriate special testing determined from the information gathered during assessment.18 In particular, the hip FADIR and FABER (flexion-abduction-external rotation) test,16 the adductor

Subject 3
Subject 3 was a 20-year-old collegiate hockey player who reported tripping on the front blade of his skate during competition, moving his left hip into excessive extension and external rotation, resulting in acute hip and groin pain. MRI revealed a moderate anterosuperior labral tear unilaterally and mixed cam and pincer hip morphology bilaterally. His team physician provided him the option of surgical or conservative care.

Subject 4
Subject 4 was a 20-year-old professional basketball player who presented with acute LBP. The athlete experienced intense LBP when he attempted to pivot left (abduct and externally rotate about the right hip) and change direction while playing defense. MRI of the lumbar spine was unremarkable. Plain radiography revealed cam morphology of the right hip. Follow-up MRI identified bilateral cam morphology and anterosuperior labral lesions.

Subject 5
Subject 5 was a 27 year-old male professional basketball player who presented with acute low back pain and episodic bilateral groin pain. The chief complaint was pain across the inferior lumbar spine. Also reported was inconsistent ‘sharp’ pain through the proximal 1/3 of each medial hip/thigh with running and multiplanar sport tasks. MRI of his lumbar spine revealed a chronic, grade 1 L5-S1 spondylolisthesis. Plain radiographs demonstrated cam morphology of bilateral hips.
squeeze test, and abdominal curl-up test were identified as clinically valuable due to their ability to assist in ruling in and out during differential diagnosis. Sacroiliac dysfunction was assessed via provocation testing. Movement testing (i.e. overhead squat, lunge, single leg squat, Y-Balance Test) was also utilized to identify aberrant or painful movement and compared to prior assessment when possible. Clinical findings that were similar across subjects were abnormal hip (decreased and/or asymmetrical, specifically in internal and external rotation, abduction, and flexion) ROM, impaired lumbopelvic strength and motor control defined by aberrant motion and/or functional movement assessment, at least one segment of the lumbar spine that was painful and/or hypomobile, and a painful, but not necessarily concordant, FADIR test. Respective patient clinical findings are found in Table 1.

**INTERVENTION**

Three phases of rehabilitation were implemented: Acute, Sub-Acute, and Participation. Transition between phases was dependent on clinical presentation, NPRS, pain reduction in identified sport-specific impairments (i.e. sprinting, defensive shuffling, pivoting, angular jumping, skating push-off) and performance on objective measures. Programs were individualized to treat identified impairments. All athletes were impacted during the competitive season (including pre-season) and required individualized activity modification, particularly in the acute phase. At a minimum, practice time was lost or decreased due to injury, while games lost due to injury was based on severity of presentation.

### Acute

Following examination, the first phase of rehabilitation consisted of pain modulation and modification of activities. Treatment was provided five to seven days per week for the duration of individual presentation. Athletes were prescribed non-steroidal anti-inflammatory drugs by their treating physician, and common variations of cryotherapy and compression modalities were utilized for their potential pain and inflammatory mediating mechanisms. Manual Therapy (MT) was provided three to five times a week for the associated comprehensive mechanical, neuro-physiological, and regional benefits. (Table 2) Ongoing assessment of the aforementioned impairments was conducted daily with note of the identification of, or changes in any comparable signs. MT techniques included, but were not limited to soft tissue

<table>
<thead>
<tr>
<th>Table 1. Clinical examination data.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Hip Rotation ROM</th>
<th>Hip Abduction Strength</th>
<th>Hip Adduction Strength</th>
<th>Lumbar Passive Joint Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 L=41 R=53</td>
<td>4/5</td>
<td>3/5</td>
<td>2/6 Hypomobile at T12/L1</td>
</tr>
<tr>
<td>2 L=59 R=61</td>
<td>4/5</td>
<td>3/5</td>
<td>2/6 Hypomobile at T12/L1</td>
</tr>
<tr>
<td>3 L=84 R=84</td>
<td>4/5</td>
<td>3/5</td>
<td>2/6 Hypomobile at T12/L1, L4/L5</td>
</tr>
<tr>
<td>4 L=54 R=63</td>
<td>4/5</td>
<td>4/5</td>
<td>2/6 Hypomobile at T12/L1, L4/L5</td>
</tr>
<tr>
<td>5 L=38 R=39</td>
<td>4/5</td>
<td>4/5</td>
<td>2/6 Hypomobile at L3/L4, L5/L6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient</th>
<th>FADIR</th>
<th>FABER</th>
<th>Squeeze Test</th>
<th>Curl Up</th>
<th>Valsalva</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>2</td>
<td>+</td>
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<td>+</td>
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<tr>
<td>3</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
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<tr>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient</th>
<th>Pop/Clik/Locking of Hip</th>
<th>Aberrant Motion with LROM</th>
<th>NPRS</th>
<th>Functional Movement Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+</td>
<td>7</td>
<td>6</td>
<td>Pain with single leg squat, Y-Balance Posterolateral Asymmetry +12</td>
</tr>
<tr>
<td>2</td>
<td>+</td>
<td>6</td>
<td>7</td>
<td>Pain with single leg squat, Y-Balance Posterolateral Asymmetry +5 cm</td>
</tr>
<tr>
<td>3</td>
<td>+</td>
<td>7</td>
<td>5</td>
<td>Pain with over head squat, lunge, and all Y-Balance</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>8</td>
<td></td>
<td>Y-Balance Posteriormedial Symmetry +8</td>
</tr>
<tr>
<td>5</td>
<td>+</td>
<td>7</td>
<td>5</td>
<td>Pain with single leg squat, pain with single leg pivot (hip IR/ER)</td>
</tr>
</tbody>
</table>

**Abbreviations**

<table>
<thead>
<tr>
<th>ABD=Abduction</th>
<th>ADD=Adduction</th>
<th>FADIR=Flexion-Adduction-Internal Rotation</th>
<th>FABER=Flexion-Adduction-External Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B=Bilateral</td>
<td>L=Left</td>
<td>R=Right</td>
<td>EKT=Extension</td>
</tr>
<tr>
<td>+Hip Rotation Tested in Prone</td>
<td>UROM=Lumbar Range of Motion</td>
<td>ROM=Range of Motion</td>
<td>LTD=Limited</td>
</tr>
</tbody>
</table>

**Notes**

- **Taken During Participation Phase**
- **Only 10 month follow-up available**

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was to promote pain-free motor recruitment of the lumbopelvic musculature and appropriate motor control of the trunk and lower extremity. Of note, isometric exercise was integrated, specifically to the adductor musculature, in part due to its potential pain-modulating effects.33,41,50 (Figure 9)

Sub-Acute
Progression to this phase was dependent upon a clinically significant (minimal clinically important difference) reduction in pain, pain-free ROM and improved strength.18,33 MT utilization was reduced by mobilization, joint mobilization and manipulation, and dry needling. Intervention was targeted towards the adductor longus & brevis, pectineus, rectus femoris, tensor fascia lata, gluteal musculature, lumbar paraspinals, the thoracic and lumbar spine, the hip joint, and their associated soft tissue structures. (Figures 1-8)

Non-aggravating activities initiated in this phase included low-level lumbopelvic exercises recommended in surgical and non-surgical progressions described in previous literature.43,44,48,49 The goal of Table 2. Manual interventions.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Manual Therapy Intervention Technique</th>
<th>Sets/Repetitions</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acute Phase (Day 1-5)</strong></td>
<td>Hip Long Axis Distraction Mobilization &amp; Manipulation</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Anterior to Posterior Hip Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Inferior Hip Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbopelvic Mobilization</td>
<td>1x1-2 and/or Change in Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Thoracic and Thoracolumbar Mobilization</td>
<td>1x1-2 and/or Change in Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbar Central and Unilateral Posterior to Anterior Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbopelvic Soft Tissue Mobilization</td>
<td>Until Change in Reported Pain or ROM Asterisk Sign</td>
<td>3-5x weekly</td>
</tr>
<tr>
<td></td>
<td>Dry Needling (i.e Adductor Longus, Tensor Fasciae Latae)</td>
<td>1-6 Twitch Responses</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>Hip Mobilization With Movement Variations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Self-Soft Tissue Mobilization (Foam Rolling)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Sub-Acute Phase (Day 6-19)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hip Long Axis Distraction Mobilization &amp; Manipulation</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Anterior to Posterior Hip Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Inferior Hip Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbopelvic Mobilization</td>
<td>1x1-2 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Thoracic and Thoracolumbar Mobilization</td>
<td>1x1-2 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbar Central and Unilateral Posterior to Anterior Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbopelvic Soft Tissue Mobilization</td>
<td>Until Change in Reported Pain or ROM Asterisk Sign</td>
<td>2-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Dry Needling (i.e Adductor Longus, Tensor Fasciae Latae)</td>
<td>1-6 Twitch Responses</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>Hip Mobilization With Movement Variations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Self-Soft Tissue Mobilization (Foam Rolling)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Participation Phase (Day 20-Beyond)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hip Long Axis Distraction Mobilization &amp; Manipulation</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-2x weekly</td>
</tr>
<tr>
<td></td>
<td>Anterior to Posterior Hip Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Inferior Hip Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>1-3x weekly</td>
</tr>
<tr>
<td></td>
<td>Lumbopelvic Mobilization</td>
<td>1x1-2 and/or Change in Asterisk Sign</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>Thoracic and Thoracolumbar Mobilization</td>
<td>1x1-2 and/or Change in Asterisk Sign</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>Lumbar Central and Unilateral Posterior to Anterior Mobilization</td>
<td>3x30 and/or Change in Asterisk Sign</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>Lumbopelvic Soft Tissue Mobilization</td>
<td>Until Change in Reported Pain or ROM Asterisk Sign</td>
<td>1-2x weekly</td>
</tr>
<tr>
<td></td>
<td>Dry Needling (i.e Adductor Longus, Tensor Fasciae Latae)</td>
<td>1-6 Twitch Responses</td>
<td>PRN</td>
</tr>
<tr>
<td></td>
<td>Hip Mobilization With Movement Variations</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Self-Soft Tissue Mobilization (Foam Rolling)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PRN=As Needed
Target Regions for Self-Soft Tissue Mobilization*

Adductor Group
Tensor Fascia Latae/Lateral Quadriceps
Posterior Hip (Gluteal Group/Hip Rotators)
to approximately two to three times per week, with techniques continued from the first phase of treatment. Foam rolling of the lumbopelvic and lower extremity soft-tissues and pain-free self-mobility exercise, such as band assisted mobilization with movement of the hip\(^{29,30}\) was implemented to continue to improve regional mobility as appropriate while promoting self-efficacy and avoid reliance on manual therapy. (Figures 10-13)

Treatment was progressed to include increased closed chain and single leg exercises, due to their motor recruitment abilities, regional interplay and specificity to sport.\(^{18,24,51}\) (Table 3) A focus on eccentric-based exercise was implemented based on findings supporting its impact on mobility, strength, and injury risk.\(^{52,53,54}\) Core exercise was progression from specific stabilization\(^{55}\) techniques to more general stabilization and strengthening exercises that focus on global recruitment and muscle synergies. Tasks such and jogging, shuffling, jumping and skill development were implemented along with continued sport-specific cardiovascular conditioning.\(^{38}\) In this phase, four out of five subjects returned to sport participation and/or competition. (Figures 14-20)
Figure 4. Long Axis Traction Hip Manipulation.

Figure 5. Inferior and Lateral Glide Hip Mobilization.

Figure 6. Posterior Glide Hip Mobilization.

Figure 7. Prone FABER Hip Mobilization.

Figure 8. Soft Tissue Mobilization of the Adductor Musculature and Related Soft Tissues.

Figure 9. Adduction Squeeze at 45 degrees.
Participation
All subjects continued an individualized management program in the participation phase of rehabilitation that continued to focus on regional mobility, stability, strength, and power deficits. The strength and conditioning staffs primarily implemented exercise programs during this phase while the team medical staff continually monitored the athletes’ status. Each player’s plan of care consisted of booster sessions of MT that was reinforced through exercise in their respective strength and conditioning programs. Continued assessment using objective measures such as the HAGOS, Y-Balance Test, Adductor Squeeze Testing, and additional movement assessment throughout the athlete’s course of care assisted in clinical decision making, providing the clinicians with valuable information regarding severity and irritability of symptoms, response to manual interventions, progress of rehabilitation, readiness for participation, and level of function while participating in sport.
### Table 3. Exercise activities.

#### Acute Phase Exercise Intervention (Day 1-5)

<table>
<thead>
<tr>
<th>Exercise Activity</th>
<th>Sets/Repetitions</th>
<th>Frequency</th>
<th>Intensity</th>
<th>Approximate %1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine Pelvic Tilt &amp; Abdominal Draw-In</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Double and Single Leg Glute Bridging</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Sub-Maximal Adductor Squeeze in Hooklying</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Sidelying Hip Abduction</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Quadrupled Hip Extension/Birdog</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Side Plank</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Side Plank with Clamshell</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Prone Hip Internal and External Rotation</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
<tr>
<td>Prone Abdominal Draw-In with Hip Rotation Manual Perturbations</td>
<td>3x&gt;15 and/or Fatigue</td>
<td>Daily</td>
<td>RPE=4-7 Pain&lt;3</td>
<td>&lt;60%</td>
</tr>
</tbody>
</table>

**Conditioning**

- Unloaded Long, Slow Aerobic Activity (Arm Ergometer, Stationary Cycle) 1x20-60 minutes 3-5x Weekly 60-70% HRMax Pain Free

#### Sub-Acute Phase Exercise Intervention (Day 6-19)

<table>
<thead>
<tr>
<th>Exercise Activity</th>
<th>Sets/Repetitions</th>
<th>Frequency</th>
<th>Intensity</th>
<th>Approximate %1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continue Acute Phase Core Program with Progressions*</td>
<td>2-3x8-12</td>
<td>5xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td></td>
</tr>
<tr>
<td>Core-X Multi-Movement Circuit with Abdominal Hollowing*</td>
<td>2-3x8-12</td>
<td>5xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td></td>
</tr>
<tr>
<td>Front Plank*</td>
<td>2-3x45 seconds</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td></td>
</tr>
<tr>
<td>Sub-Maximal Adductor Squeeze at 0/0 with Abdominal Draw-In*</td>
<td>2-3x8-13</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td></td>
</tr>
<tr>
<td>Lateral Step-Ups</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Single Leg Step-Down Variations</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Single Leg Deadlift Regression and Progressions</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Goblet Squat</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Rearfoot Elevated Split Squat</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Hip Thrust</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Lateral Band Walking Abductor Resistance*</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Lateral Band Walking Adductor Resistance*</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Eccentric Hamstring Slides</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Reverse Slide Lunge</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Lateral Adductor Slide Non-Lunge Leg</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Half-Kneeling Anti-Rotation Cable Press (Horizontal &amp; Overhead)*</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Half-Kneeling Cable Chops*</td>
<td>3x8-12</td>
<td>3xWeekly</td>
<td>RPE=5-8 Pain&lt;2</td>
<td>60-80%</td>
</tr>
<tr>
<td>Upper Extremity Resistance Training</td>
<td>3x8-12</td>
<td>2xWeekly</td>
<td>RPE=5-8 Pain=0</td>
<td>70-85%</td>
</tr>
</tbody>
</table>

**Conditioning**

- Long, Slow Aerobic (Elliptical, Stationary Cycle, Alter-G, Pool) 30-45 Minutes 2xWeekly 60-70% HRMax Pain Free
- Graded Aerobic/Anaerobic Tempo & Interval Activity (Elliptical, Alter-G, Pool) 20-30 Minutes 1xWeekly 80-90% HRMax Pain Free
- Controlled Plyometric and Agility Drills
- Supervised Sport Skill Drills 20-30 Minutes 1-3xWeekly 60-80% HRMax Pain Free

*Included in Core Program

#### Participation Phase Exercise Intervention (Day 20-Beyond)

<table>
<thead>
<tr>
<th>Exercise Activity</th>
<th>Sets/Repetitions</th>
<th>Frequency</th>
<th>Intensity</th>
<th>Approximate %1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continue Core Program with Additions from Previous Phase</td>
<td>2-3x6-10</td>
<td>4xWeekly</td>
<td>RPE=6-9</td>
<td></td>
</tr>
<tr>
<td>Front Plank Perturbation and Rollout Variations*</td>
<td>2-3x6-15</td>
<td>3-4xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Copenhagen Adduction Isometric Hold*</td>
<td>2-3x15-30 seconds</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Lateral &amp; Crossover Step-Ups</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Forward Step-Up with Overhead Kettlebell Press</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Single Leg Step-Down Variations</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Single Leg Deadlift</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Goblet Squat</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Rearfoot Elevated Split Squat</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Eccentric Hamstring Slides</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Reverse Slide Lunge</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Lateral Adductor Slide Non-Lunge Leg</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Lateral Adductor Slide Lunge Leg</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Deadlift Variations (Hexbar and/or Inverted Dumbbell)</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Medicine Ball Slam</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Medicine Ball Overhead Toss</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Half-Kneeling Medicine Ball Lateral Toss</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Kettlebell Swings</td>
<td>2-5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
<tr>
<td>Upper Extremity Resistance Training</td>
<td>3x5x4-8</td>
<td>2xWeekly</td>
<td>RPE=6-9 Pain=0</td>
<td>80-95%</td>
</tr>
</tbody>
</table>

**Conditioning**

- Graded Aerobic/Anaerobic Intervals (Elliptical, Alter-G, Small Sided Games) 20-30 Minutes 1-3xWeekly 80-90% HRMax Pain Free
- Supervised Sport Skill Participation 45-60 Minutes 4-6xWeekly 60-80% HRMax Pain Free
Figure 14. *Eccentric Adduction Walks.*

Figure 15. *Single Leg Deadlift.*

Figure 16. *Rearfoot Elevated Split Squat.*

Figure 17. *Eccentric Based SL Squat Variation.*
Subject Specific Intervention Strategies

Due to common regional impairments and the capabilities of a balanced strength and conditioning program, the exercise interventions were very similar across all subjects and are described in Table 3. The identification of a movement based comparable sign, or asterisk sign, was the baseline daily measure for the need for manual therapy. Although all subjects received each of the described interventions, the pragmatic application of interventions resulted in slight differences for each subject. Individual management plans were based off of intervention responses within the acute and sub-acute phases and continued throughout the participation phase.

Subject 1
In the acute phase, the application of soft tissue mobilization and dry needling to the adductor musculature resulted in reports of decreased groin 'tightness' and overall pain reductions on the NPRS. Graded hip mobilization was prioritized in the sub-acute phase, resulting in decreased pain with single leg squatting. Pain-free adductor squeeze exercises, adductor plank isometrics, and eccentric lunge variations in the participation phase coincided with improved performance on the HAGOS Sport. (Figure 21)

Subject 2
The subject showed a positive response to soft tissue mobilization of the adductor longus and pectineus in the acute phase. Graded joint mobilization of the lumbar spine resulted in improved capability of abdominal drawing-in exercises, which decreased reported pain in the groin, the pubic symphysis and proximal adductor longus attachment. Joint-based mobilization techniques were continued into the sub-acute phase, as they were preferred over manipulation by the subject. Adductor squeeze assessment

Figure 18. Core-X Pivot Squat.

Figure 19. Lateral Slide Lunge.

Figure 20. Hip Adduction Plank.
corresponded with the severity of functional complaints during subject management in the participation phase. This was utilized to grade the intensity of core exercise, with isometrics taking priority when symptom presentation was severe. (Figure 9)

**Subject 3**
The subject initially presented with an inability to perform a posterior pelvic tilt. Anterior hip pain was reproduced with posterior to anterior spinal mobility assessment (T12/L1, L4/L5). Spinal manipulation and graded lumbar mobilization resulted in visual and palpable improvement in motor control during a posterior pelvic tilt while decreasing the report of ‘pinching’ in his groin with a double leg squat and forward lunge. Hip joint mobilization and iliopsoas and adductor complex soft tissue mobilization in the sub-acute phase resulted in pain-free performance of the double leg squat. Hip mobilization using mobilization with movement techniques decreased symptoms in the forward lunge and single leg squat. Upon the resolution of pain, posterior pelvic tilt and ‘neutral’ spine motor control drills were reinforced into similar movement patterns.

**Subject 4**
Due to the acute onset of LBP, spinal manipulation was favored in the acute phase. Hip internal rotation assessed in supine (90 degrees of hip flexion) and prone (0 degrees of hip flexion) also produced the concordant pain. Graded lumbar mobilization was utilized, as mobility assessment (T12/L1, L4/L5) reproduced lumbar and groin symptoms. Graded hip mobilization was prioritized moving into the sub-acute and participation phases. This was supplemented with gluteal group dominant motor control exercises, with the intention of dynamically stabilizing aberrant lumbopelvic motion and rotary hip motions.

**Subject 5**
Within the acute phase, the subject demonstrated good intra-session improvements with soft tissue mobilization to the iliopsoas, adductor longus, and myotendinous region of the pectineus and it's tenoperiosteal junctions. Hip mobilization with movement for internal and external rotation was performed with a belt, followed by a long axis hip thrust manipulation. Lastly, the subject was provided a supine lumbopelvic manipulation technique by the treating physical therapist. These interventions immediately increasingly reduced both his inferior lumbar and medial hip symptoms. After several sessions, the treatment focused shifted trunk stability exercises in supine, then quadruped, and finally in...
weight bearing that emphasized a stable trunk during concurrent extremity movement. When the ability to demonstrate a dynamically stable pelvis coinciding with a significant decrease in pain was achieved, exercise was progressed to more global, movement-based exercise patterns in the sub-acute and participation phases.

**OUTCOMES**

All subjects were managed conservatively within their competitive seasons and training cycles. Players were able to maintain sport performance at or above their prior levels of function with significant reductions in reported pain upon returning to participation and competition. (Table 4)

**Subject 1**

Initially, the athlete was withheld from two practices. Due to scheduling, one week of active rest occurred two weeks after the initial examination, in which non-aggravating cardiovascular activity and basic lumbo-pelvic exercise were performed. No competitive games were missed. The subject's NPRS and HAGOS (Figure 1) both improved by the minimal clinically important difference by the participation phase. The athlete re-aggravated his injury two weeks following the completion of the initial bout of rehabilitation, increasing his NPRS to a 6/10. The rehabilitation protocol resumed, continuing through the end of the season, with pain decreasing to a weekly average of 2/10 and resulting in only two additional missed practices. At one-year follow-up, the athlete reported no groin pain (0/10) or groin tightness. The athlete sustained a grade three right adductor longus strain the following competitive season.

**Subject 2**

No significant changes were made for four weeks following the initial diagnosis and treatment. A scheduled break in competition allowed for the acute phase of rehabilitation to then appropriately take place with no games to be missed. Practice was missed for two weeks before graded reconditioning and sporting drills were allowed. The subject returned to full participation six weeks following initial evaluation. Significant improvement was noted on outcome measures along with full participation of the following season. After six months of relief, signs and symptoms gradually returned. The individual was referred for surgical consultation, underwent surgical repair, and returned to participation in 8 weeks. It was hypothesized that the chronic nature of his condition (> six months prior to initial evaluation) contributed to the response to conservative care.

**Subject 3**

The subject missed the final two games of the season following the injury. Initial physical therapy evaluation occurred into the off-season, approximately eight weeks following the end of the season, with no on-going sport participation. Upon beginning the sub-acute phase, rehabilitation was performed by his team athletic trainer. The subject returned to skating at 12 weeks post-injury and full participation at the beginning of the preseason. Surgical management of the condition was no longer indicated as the

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**Table 4. Clinical Outcomes.**

<table>
<thead>
<tr>
<th>Patient</th>
<th>NPRS**</th>
<th>HAGOS Sport**</th>
<th>Hip ROM Impression**</th>
<th>Hip Strength Impression**</th>
<th>Special Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>87.5</td>
<td>Painfree, Symmetrical</td>
<td>WFL</td>
<td>All (_), FADIR Uncomfortable</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>94</td>
<td>Painfree, Asymmetrical</td>
<td>WFL</td>
<td>All (_), FADIR Uncomfortable</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>84.4</td>
<td>Painfree, Symmetrical</td>
<td>WFL</td>
<td>All (_), FADIR Uncomfortable</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>N/A</td>
<td>Painfree, Asymmetrical</td>
<td>WFL</td>
<td>All (_), FADIR Uncomfortable</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>N/A</td>
<td>Painfree, Asymmetrical</td>
<td>WFL</td>
<td>All (_), FADIR Uncomfortable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient</th>
<th>Games Missed</th>
<th>Functional Impairment</th>
<th>1 Year NPRS at Worst</th>
<th>1 Year Follow-Up Subjective Complaints</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Pain-free FMS/Y-Balance/Single leg squat</td>
<td>0</td>
<td>Occasional stiffness/tightness</td>
</tr>
<tr>
<td>2***</td>
<td>0</td>
<td>Pain-free FMS/Y-Balance/Single leg squat</td>
<td>3</td>
<td>Relief lasting for 6 months with gradual return of symptoms. Completed competitive season &amp; referred for surgical consultation</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Pain-free FMS/Y-Balance/Single leg squat</td>
<td>1</td>
<td>Rare soreness</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Pain-free FMS/Y-Balance/Single leg squat</td>
<td>0</td>
<td>No complaints</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Painfree FMS/Y-Balance/Force Plate Jumping</td>
<td>7</td>
<td>One episode of low back pain resulting in 5 missed games</td>
</tr>
</tbody>
</table>

**Abbreviations**

- ABD=Abduction  ADD=Adduction
- FADIR=Flexion-Adduction-Internal Rotation
- FABER=Flexion-Abduction-External Rotation
- ROM=Lumbar Range of Motion
- R=L=Right  L=Left
- **=Taken During Participation Phase
- ***=Only 10 month follow-up available

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restrict an individual to a predisposed and compensatory regional ROM, addressing these restrictions with manual therapy may illicit comprehensive neurophysiological and mechanical effects that facilitate the retraining of impaired movement patterns and sporting tasks. The mechanical focus of MT at the hip was to improve the inferior and posterior glide of the hip while reducing the anterior stress on the joint. MT directed at the spine was implemented to induce positive changes in pelvic posture by reducing anterior pelvic tilt, increasing local mobility, and facilitating motor control. Neurophysiological effects may inhibit pain, reduce subjective reports of tightness, and enhance exercise interventions. Reinforcing ROM improvements through exercise may lead to lasting ROM development. It is hypothesized that improving ROM may alter movement patterns and favorably modify the distribution of force about the pelvis, positively impacting dynamic movement.

However, increases in mobility may be transient and overall load tolerance is likely crucial to the outcomes in these cases. The regional synergy required to athletically move about and stabilize the pelvis place an importance on addressing muscle imbalances, motor control, strength, power and work capacity abilities via an appropriately loaded training program in order to allow the athlete to develop a resistance to risk factors while preparing for sport.

The exercise programs that were prescribed in these cases potentially served to dynamically stabilize the lumbopelvic region and may have improved force distribution and load tolerance while unloading irritated structures and building a tolerance to repeated bouts of sporting activity. Additionally, a focus was placed on motor control of the lumbopelvic region and lower extremity during single leg movements. The exercise progression described, particularly in the sub-acute phase, is thought to be clinically significant, as advancing a training stimulus targeting the kinetic chain may have greater impact on the movement system as compared to structure specific exercise.

In the presence of performance limiting pathology, training load should be monitored and adjusted accordingly to address risk factors while decreasing performance.

**Subject 4**
The subject missed one practice and one game before returning to competition. It was hypothesized that the lack of regional mobility and segmental control created on uneven load through the region, creating non-specific LBP and referred groin pain. The subject quickly progressed through the sub-acute phase, returning to competition and continuing a management plan in the participation phase with no return of symptoms that limited performance or participation.

**Subject 5**
The subject missed two weeks of preseason basketball training before resuming graded basketball and weight room activities. Given the chronic nature of his L5-S1 spondylolisthesis, the authors believe his significant hip mobility impairments bilaterally, magnified during terminal stance phase (push-off) while running, contributed to increased stress to his inferior lumbar spine. The subject was able to play in a competitive game four weeks from his symptom onset.

**DISCUSSION**
This case series depicts the complex, yet similar clinical presentation and impairment-based management of five elite athletes. Common anatomical features such as posture and bony hip morphology may impact function and potentially result in pathology. However, asymptomatic findings and concurrent pathoanatomical diagnoses make treating specific structures challenging. Clinical findings and identification of movement-based functional impairments guide treatment beyond a single structure. Key clinical findings in this case series were consistent with risk factors for athletic hip, groin and low back pain previously identified in the literature.

Initial treatment focused on pain reduction while promoting exercise that addressed identified functional impairments and risk factors, and is consistent with conservative management of similarly described cases. While morphological presentation may
the stress on irritated structures. As described in the second subject, there is a high risk of re-injury risk following an initially successful bout of conservative care, thus, high priority was placed on graded sport reconditioning throughout rehabilitation, as it is important to avoid any drastic increases in training load (i.e appropriate acute:chronic workload ratio) in order to reduce the risk of re-injury while returning to prior levels of participation. Once symptoms are improved, continuing an individualized program may be beneficial in further reducing this risk.23,24,43

Additional treatment sessions including manual therapy and exercise, like those implemented in this case series, may be beneficial in the long-term management of athletes, as they continue to address any potential long-term impairments14,22,32,36,63 and may improve outcomes.37 For comparison, it is common practice for baseball pitchers to perform an individualized arm-care program in the presence of sport-specific morphological adaptations. Further research may indicate if similar programs are beneficial for the treatment and risk reduction for the sub-group identified in this case series.

Differences in pathoanatomic profiles, limited research, individualized care, and subtle variations in outcome measure utilization are limitations of this case series. Such limitations exist in all case report and case series research. Reporting of sports performance measures would have been valuable in assessing return to sport outcomes in this case series and should be used in the future. There appears to be a need for clinical trials identifying related clinical impairments and the best course of intervention to address these limitations.

CONCLUSION
Physical rehabilitation plays a large role in the treatment of athletes who experience hip, groin, and low back pain despite the lack of standardized guidelines for the conservative treatment of these conditions. Comprehensive intervention and on-going management strategies focused on addressing shared regional impairments may be of benefit for a sub-group of individuals, potentially enabling athletes to safely continue participation in sport with minimal time competition time lost.


