PTJ: Physical Therapy & Rehabilitation Journal | *Physical Therapy*, 2021;101:1–10
DOI: 10.1093/ptj/pzab024
Advance access publication date January 23, 2021
Perspective

The 4-Element Movement System Model to Guide Physical Therapist Education, Practice, and Movement-Related Research

Philip McClure, PhD, PT[1,*], Michael Tevald, PhD, PT[1], Ryan Zarzycki, PhD, PT[1], Shailesh Kantak, PhD, PT[1,2], Philip Malloy, PhD, PT[1], Kristin Day, PhD, PT[1], Kshamata Shah, PhD, PT, NCS[1], Amy Miller, PT, DPT, EdD[1], Kathleen Mangione, PhD, PT[1]

[1]Arcadia University, Department of Physical Therapy, Glenside, Pennsylvania, USA
[2]Moss Rehabilitation Research Institute, Elkins Park, Pennsylvania, USA

*Address all correspondence to Dr McClure at: mcclure@arcadia.edu

Abstract

The movement system has been adopted as the key identity for the physical therapy profession, and recognition of physical therapists' primary expertise in managing movement dysfunction is an important achievement. However, existing movement system models seem inadequate for guiding education, practice, or research. Lack of a clear, broadly applicable model may hamper progress in physical therapists actually adopting this identity. We propose a model composed of 4 primary elements essential to all movement: motion, force, energy, and control. Although these elements overlap and interact, they can each be examined and tested with some degree of specificity. The proposed 4-element model incorporates specific guidance for visual, qualitative assessment of movement during functional tasks that can be used to develop hypotheses about movement dysfunction and serve as a precursor to more quantitative tests and measures. Human movement always occurs within an environmental context and is affected by personal factors, and these concepts are represented within the model. The proposed scheme is consistent with other widely used models within the profession, such as the International Classification of Functioning, Disability and Health and the Patient Management Model. We demonstrate with multiple examples how the model can be applied to a broad spectrum of patients across the lifespan with musculoskeletal, neurologic, and cardiopulmonary disorders.

Keywords: Movement Disorders, Rehabilitation, Motor Control and Motor Learning, Energy Metabolism, Exercise: Force Production, Range of Motion, Movement

Received: June 27, 2020. **Accepted:** December 6, 2020

Introduction

The movement system has been adopted as the key "identity" for the physical therapy profession.[1]

> 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.[1]

Recognizing physical therapists' primary expertise in managing movement dysfunction is an important achievement, and much discussion has occurred around the movement system as our professional identity.[2–4] However, we believe that currently few therapists can actually articulate a meaningful description of the "movement system" either conceptually or practically. The current definition states: "The movement system is the integration of body systems that generate and maintain movement at all levels of bodily function. Human movement is a complex behavior within a specific context, and is influenced by social, environmental, and personal factors."[5]

The American Physical Therapy Association's white paper recommends that the profession develop "...a common framework and language" regarding the movement system. Such a framework would facilitate the adoption of a "movement-based approach," which is a hallmark of expert practitioners.[1] Therefore, the purposes of this perspective are to (1) discuss the need and important criteria for a unifying movement system model, (2) describe a unifying model that serves as an educational framework that we believe also translates well into a guide for practicing clinicians across various specialties within physical therapy and rehabilitation, and (3) discuss specific application of the model to patient management, education, and movement-related research.

The Need and Important Criteria of a Movement System Model

Figure 1 shows the current Movement System Diagram suggesting interaction between 6 physiological systems.[3] Although such a model does have the advantage of being very broad and encompassing, the newly created "system" becomes potentially overwhelming and not useful to both clinicians and students. As Guccione et al[6] have argued, "what structure or system of the human body does the 'movement system' exclude? What is gained by constructing an alternative and unfamiliar label to encompass all the systems of the human body?" A coherent, broadly applicable movement system model that can guide practice and education is currently lacking and represents a major barrier to physical therapists adopting an identity as movement system specialists.

Currently, some authors offer an expression or particular application of the "movement system."[3,7–10] For example, some groups have tried to create more specific movement system models that focus on particular pathological groups. A recent white paper published by Hedmen et al[3] proposes a model focused on patients with neurologic injury or disease states. A primary focus of their neurological model is motor control during discrete functional tasks that are impaired. They recommend a core set of tasks for analysis and propose

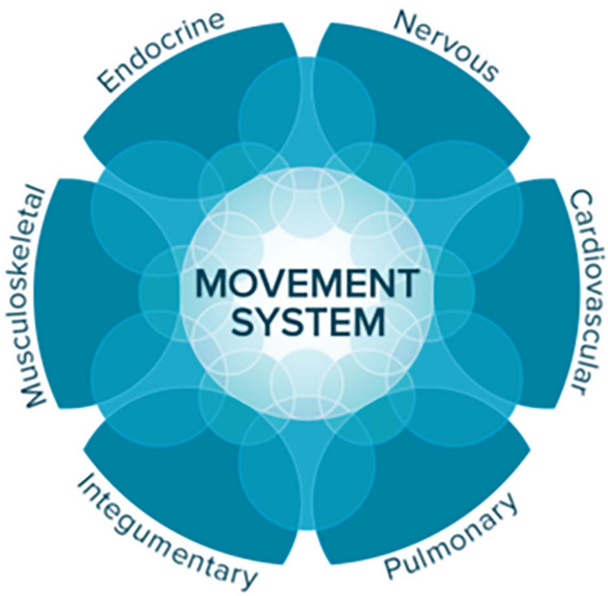

Figure 1. Current diagram depicting the movement system as representing the interaction of 6 separate physiological body systems. Used with permission of the American Physical Therapy Association

a 6-stage movement continuum to guide movement analysis. Sahrmann and colleagues[9,11] have developed systems of examination and management for musculoskeletal conditions that take quite a different approach. Their system is based on precise regional examination of movement and alignment, considering muscle performance, tissue length, and relative stiffness of different joint regions. Although the approach of building various specific models to address different groups of pathologies is likely useful, a model that identifies the essential components to all movement tasks across a broad range of pathological conditions could offer a unifying step forward. Our experience is that this is particularly relevant to entry-level physical therapy education where students often struggle to think beyond the "siloes" of traditional clinical specialty areas and associated specific examination systems.[12,13]

Proposal of a New Model

For a model to be both meaningful and widely adopted, several criteria seem necessary.

1) It must be general enough to capture the primary elements underlying the wide variety of disorders physical therapists encounter.
2) It must be specific enough to provide a framework that can meaningfully guide practice, education, and research related to movement dysfunction.
3) It should be readily incorporated into professional education, particularly where students lack clinical experience and therefore are more reliant on conceptual frameworks.
4) It should also be consistent with existing models that are widely adopted such as the patient management model[14] and the International Classification of Functioning (ICF).[15]

The proposed model was generated out of a series of discussions within our faculty aimed at developing a suitable

Table 1. Common Tests, Measures, and Intervention for the 4 Elements of Movement

Movement Element	Common Tests and Measures	Common Intervention Strategies
Motion	• Passive range of motion (ROM) • Specific tests for muscle length • Accessory motion tests • Soft-tissue mobility tests assessed by palpation • Skin mobility • Neurodynamic tests	• Active stretching • Passive stretching • Stretching combined with muscle activation followed by relaxation (hold-relax, etc) • Manual therapy including joint mobilization/manipulation and soft-tissue techniques • Low-load prolonged stress via static positioning or splinting • Neural gliding and tensioning techniques
Force	• Manual muscle testing • Hand-held dynamometry • Repetition maximum testing • Isokinetic testing • Functional performance testing	• Force generating capacity -Isometric muscle activation to restore muscle function, and reduce muscle atrophy following injury or immobilization -Isometric co-contraction to promote joint stability for function -Isolated resisted concentric and eccentric muscle strengthening -Alter range of motion amount and load magnitude to advance force generating capacity demand • Force control -Advance movement tasks from simple, single-plane movement to complex, multi-plane movement -Vary load magnitude and movement duration demands to meet individual functional requirements -Incorporate power training to improve rate of force development for an individual's functional demands
Energy	• Aerobic capacity/endurance during functional activities, mobility, gait, or standardized exercise test protocols • Circulation, including vital signs, electrocardiography, auscultation, signs and symptoms of poor perfusion, at rest and during activity • Muscle performance, including strength and endurance • Ventilation and respiration, including respiratory rate and depth, auscultation, pulse oximetry, gas analysis, signs and symptoms of dyspnea, increased work of breathing, or poor gas exchange at rest and during activity	• Therapeutic exercise, including -Continuous or interval exercise programs designed to improve aerobic capacity and/or endurance -Resistance training to improve muscle performance -Inspiratory muscle training in certain populations • Functional training, including gait and mobility training • Airway clearance techniques, if retained secretions limit endurance • Patient instruction, including -Self-monitoring of intensity, signs, and symptoms -Energy conservation techniques, including pacing, modifying tasks and/or the environment, etc.
Control	• Performance-based measures of capability (eg, 5 times sit-to-stand) • Assess task initiation, execution, and termination -Determine abnormal movement -Biomechanical analyses of multi-joint system -Determine compensations -Change task, environmental demands to determine if patient can change movements and minimize compensations • Feedforward control: measure/characterize speed, accuracy, and kinematics • Feedback control: determine response to unexpected perturbations • Sensory-perceptual and cognitive testing	• Impairment restitution- to provide resources (eg, ROM) for task execution • Task practice -Alter task, environmental demands, instructions, and manual cues to minimize compensations -Allow exploration and movement discovery -High-intensity, high-dose skill practice -Optimal challenge during practice: altering speed, perturbations, concurrent cognitive challenge • Targeted treatments to improve perception and cognition in context of task practice (eg, virtual reality)

model for entry-level DPT education. Conceptual frameworks can be useful in helping students and novice clinicians to develop the cognitive skills needed for complex reasoning. Examples of such frameworks used in physical therapy include the Patient Management Model,[14] the International Classification of Functioning and Disability,[15] and the Hypothesis Oriented Algorithm for Clinicians II.[16] Although these all serve as foundational conceptual models for the profession, it is clear that additional models are needed to fully integrate the movement system into physical therapist

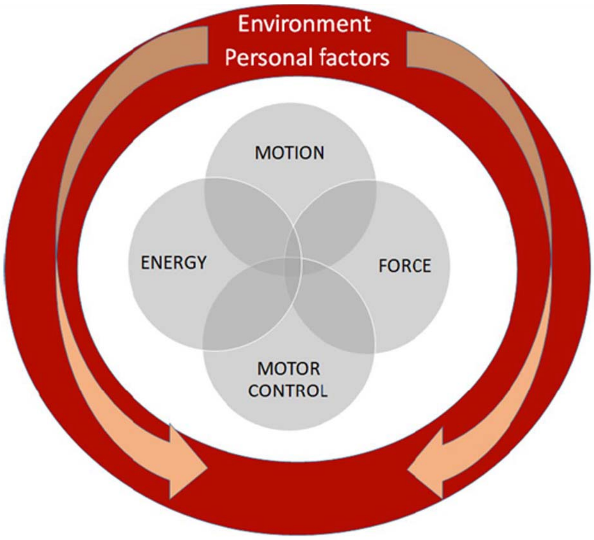

Figure 2. The 4-element model of the movement system. The 4 essential elements allowing movement are at the center and interact with one another. Because all movement occurs both within an environmental context and is affected by multiple personal factors, these features are shown surrounding the basic elements of movement.

practice and education. We believe the proposed 4-element model provides a relevant conceptual framework for the understanding and management of movement dysfunction across a wide variety of patient conditions and is consistent with existing widely accepted models.

Defining the Movement System

In medicine, a "system" classically refers to "a group of body organs or structures that together perform 1 or more vital functions."[17] However, a system can be more broadly defined as "a regularly interacting or interdependent group of items forming a unified whole."[17] The current model essentially lists 6 accepted anatomical, physiological systems and implies that movement results from the interaction among these systems. Although true, we found the model was not easily translated into teaching, analysis, or management of common movement problems treated by physical therapists.

In thinking about physical therapist practice, we chose to identify 4 primary elements that are essential components to all human movement, (motion, force, energy, and control). These elements are identified in the model shown in Figure 2. Allen[18] took a similar approach in proposing dimensions of movement that linked movement science and clinical science (flexibility, strength, accuracy, speed, adaptability, and endurance). These elements are not anatomical structures or physiological systems but rather the essential basic requirements for movement that lend themselves to clinical analysis. The primary goal of most physical therapy care is to accurately identify and subsequently manage or improve impairments related to 1 or more of the 4 major elements in an effort to ultimately improve functional movement.

By focusing on the major elements of movement rather than on broader physiological systems, the model provides greater focus on movement problems, the specific expertise of physical therapists. The 4 key elements underlying movement (motion, force, energy, and motor control) clearly overlap and interact as shown in Figure 2, but each can be examined clinically and measured with some specificity. Consistent with the ICF model, movement always happens within an environmental context and is typically affected by personal factors specific to an individual. These factors are shown encompassing the 4 basic elements of the movement system.

The 4 elements are common requirements to movement, regardless of the nature of a particular pathological condition or pathoanatomical diagnosis. Within our curriculum, we have successfully applied the model in case analyses involving neurologic, cardiopulmonary, and musculoskeletal problems across the lifespan. The model provides a conceptual foundation for the vast array of clinical examination and intervention techniques presented to students and provides a way to organize thinking and information across traditional clinical specialty siloes.

Four Elements of Movement

Motion

In the context of this model, motion refers specifically to the ability of a joint or tissue to be moved passively. Passive motion is largely a function of the length and mechanical characteristics of tissues surrounding synovial joints and may be judged as hypomobile, normal, or hypermobile. The relative stiffness of a joint or tissue (resistance to displacement) may also be considered. Broadly, the tissues most commonly limiting passive movement would include periarticular structures (ligaments, capsule/synovium, fat pads, menisci), musculotendinous structures, and neural tissues as well as the skin. These tissues may physically restrict motion directly via adaptive shortening or adhesion formation, or they may become injured or sensitized, leading to pain with motion and protective muscle guarding.

The length and mechanical characteristics of these individual structures affecting motion can be assessed with some specificity. In addition to traditional passive range of motion testing, periarticular structures can be assessed by accessory motion testing and other special tests with varying accuracy.[19–22] In addition to the amount of motion present, the end-feel or nature of resistance perceived at or near end-range and whether symptoms are produced can be assessed. The length of specific musculotendinous structures can only be isolated well when a muscle crosses 2 joints. This allows differentiation from periarticular structures by lengthening the muscle over both joints simultaneously such as with tests for hamstring length as an example.[23–25] Muscle may also limit motion due to the presence of spasticity, generally noted by heightened resistance to quick stretch or by myofascial trigger points within the muscle identified by palpation.[26] Sensitized neural tissue can also be a source of limited passive motion as shown with a straight-leg raise test or with various upper extremity neurodynamic tests.[27,28] Skin may also be a source of limited motion, particularly with burn injury but also by other mechanisms such as post-operative scarring and adhesion formation.

Interventions for limited passive motion depend on the nature of the problem. If motion is limited by a physical restriction attributable to adaptive shortening or adhesion formation, the treatment generally involves applying tensile stress to induce growth and increased length to the restricting tissue.[29,30] This may be achieved with exercise, manual therapy, static positioning, or some method of splinting. If a motion is limited by a painful sensitized tissue and muscle guarding, the treatment approach typically involves protecting that tissue from physical stress, allowing pain and inflammation to resolve. There has been increased interest in methods aimed at abolishing trigger points or restrictions believed to be from myofascial tissue, but evidence is still limited for various approaches.[31]

Force

In the context of this model, force refers to the ability of the contractile (ie, muscles) and noncontractile structures (ie, tendons) to produce movement and provide dynamic stability around joints during static and dynamic tasks. Impairments in force production are common in patients with musculoskeletal, neurological, and cardiovascular conditions/injuries. Impaired force can be related to peripheral factors and/or central factors. Peripheral factors related to muscle composition include muscle atrophy, changes in fiber type composition, and/or changes in pennation angle.[32,33] Peripheral factors may also include peripheral nerve injury or loss of tendon integrity.[34] Central factors related to impaired neural drive include voluntary activation failure, reflex-inhibition, and altered cortical excitability.[35–37]

There are various methods to quantify force in a clinical setting. The most common way to quantify force is to measure peak isometric force production, which can be done with manual muscle testing or dynamometry. Force/torque can also be measured through a range of motion and at a constant velocity via an isokinetic dynamometer or through repetition maximum (RM) testing. Finally, the rate of force/-torque development and power measure a person's ability to produce force over a given time. Impairments in isometric strength, isokinetic strength, the rate of force/torque development, and power are present in a wide variety of conditions, including athletes recovering from anterior cruciate ligament reconstruction (ACLR), stroke survivors, and children with cerebral palsy.[38–42] Additionally, deficits in force production are associated with altered movements in various populations; for example, after ACLR, athletes with quadriceps weakness demonstrate decreased knee flexion excursion during the stance phase of gait and greater asymmetry during landing from a single-leg drop landing task in knee flexion excursion, peak trunk flexion angle, and peak knee extension moment.[43,44] Also, weakness is present in stroke survivors[45,46] and may contribute to greater impairments in upper extremity function measured by the Fügl-Meyer assessment.

Movement alterations after ACLR and stroke are not purely a result of weakness. Rather, movement alterations in these populations likely involve impairments in force, motor control, range of motion, and perhaps energy (eg, peak oxygen consumption). Evaluations of all 4 elements are needed to determine the primary impairments contributing to a specific movement alteration.

Interventions directed at force impairments should be specific to the impairment identified. For example, weakness identified through isometric testing or 1RM testing should be addressed by isolated strengthening of the involved muscle and dosed appropriately. For example, isotonic strengthening recommendations include 60% to 70% 1RM, 8 to 12 repetitions, 2 to 3 d/wk; isometric strengthening recommendations are 8 to 10 maximum effort contractions for 5 seconds at multiple angles.[47] Impairments with isokinetic testing and/or rate of force/torque development should be addressed with higher speed movements, and higher repetitions. In addition, neuromuscular electrical stimulation, when properly dosed, is effective in improving strength in patients with various pathologies, including individuals recovering from total knee arthroplasty, athletes after ACLR, and children with cerebral palsy.[48–50]

Energy

Energy refers to the ability to perform sustained or repeated movements and is dependent on the integrated functioning of the cardiovascular, pulmonary, and neuromuscular systems. In addition, energy is strongly influenced by other systems (eg, endocrine) and psychological factors. Energy impairment is common across a wide range of pathologies affecting multiple systems. It is a hallmark symptom of many diseases affecting the heart and lungs (eg, heart failure, COPD), but is also common in neuromuscular (eg, multiple sclerosis) and musculoskeletal conditions (eg, rheumatoid arthritis) as well as a major consequence of deconditioning and a sedentary lifestyle.

Physical therapists typically examine energy by assessing an individual's response to the performance of sustained or repeated movement. This can take many forms, from questions asked during a history (eg, "How many stairs can you climb before you feel tired?") to maximal or submaximal[51] exercise testing. Peak oxygen consumption obtained during a maximal exercise test is the gold standard for assessing aerobic capacity, a key aspect of "energy," and is strongly related to a variety of health outcomes[52,53] However, the greater feasibility and safety of submaximal exercise tests make them much more common in everyday practice. The 6 Minute Walk Test, for example, is commonly used in physical therapist practice in a variety of populations, including children and adults with cardiovascular and pulmonary,[54,55] neuromuscular,[56,57] and musculoskeletal[58,59] conditions. Interpreting the results of these tests requires the physical therapist to consider not only the performance on the test (eg, the distance walked in 6 minutes) but also objective (eg, heart rate, blood pressure) and subjective (eg, rating of perceived exertion, dyspnea) measures of the individual's response to performance of the task. In addition, the rapid growth in the availability and sophistication of electronic exercise-monitoring devices (eg, Fitbit, Apple Watch) provides physical therapists with additional means to assess the impact of energy impairments on patient movement in their own environment as well as to prescribe and monitor the response to interventions designed to improve energy.

Impairment in energy can manifest in a variety of ways and can include both subjective and objective components. Subjective signs of energy impairment include increased perception of effort (eg, rating of perceived exertion[60]), fatigue, or symptoms of intolerance (eg, dyspnea, dizziness, angina, etc). Objective evidence of energy impairment includes excessive physiological responses to the activity (eg, excessive increase in heart rate, blood pressure, or respiration) as well as interaction with other movement system components such as force or motor control.

Physical therapists typically address impairments in energy through exercise consisting of the repeated or sustained performance of a movement-related task. The principles of specificity and overload dictate that the mode of exercise (ie, the movement performed) should match the activities in which the individual wishes to improve their performance and that the dose (eg, intensity, duration, and frequency) be higher than that to which they are accustomed.[61] Compared with strength training, the exercise used to improve "energy" (ie, "aerobic" training) typically requires a lower load but a longer duration. Studies report intensities of 60% to 90% of heart rate maximum or 50% to 80% of heart rate reserve for a minimum of 20 minutes to improve measures of aerobic capacity.[62] Physical activity guidelines recommend that adults do at least 150 min/wk of moderate intensity activity.[63] Provided the dose is adequate, the exercise-induced changes in the cardiovascular, neuromuscular, and other systems contribute to improved performance, even in individuals with severe disease in these systems. In addition to improved performance, aerobic training is associated with a variety of other health benefits, including reduced pain,[64] improved mood and emotional well-being,[65] and greater longevity.[66]

Motor Control

Motor control refers to the ability to plan, execute, and adapt goal-directed movements such that they are accurate, coordinated, and efficient. Motor control is dependent on receiving and processing task-relevant sensory inputs from the visual, somatosensory, and vestibular systems and then selecting, planning, and executing the action to accomplish task goals. The transformation from sensation to action relies on the integrity of sensory-motor pathways as well as intact perceptual and cognitive networks in the brain, including the cerebellum and basal ganglia. Broadly speaking, motor control involves feedforward mechanisms crucial for planning and execution, and feedback mechanisms necessary for adaptation of goal-directed actions.[67] When feedforward motor control is intact, performance is efficient and smooth and occurs with appropriate coordination and timing. Intact feedback control also allows efficient adaptation if there is an unexpected disturbance during performance.

In a clinical setting, motor control is examined through a careful observation of initiation, execution, and termination of task performance with specific analyses of movement quality, coordination, and precision.[68] Standardized assessments of gait, balance, and upper extremity function provide quantitative assessment of motor control.[69,70] In addition, a qualitative examination of effort, symmetry, timing, and sequencing of different body segments provides crucial information to determine the potential source(s) of motor control deficits.[3,71] For instance, although gait speed is an important quantitative outcome measure, determining the potential contributors to abnormal gait patterns (eg, poor propulsion or knee hyperextension) through qualitative biomechanical analyses provides appropriate targets to direct additional examination and intervention. Knee hyperextension observed in midstance may further prompt the clinician to test the strength of knee extensors and plantar flexors[72] or tightness of plantar flexors[73] or to correct a flexed trunk posture. Assessment of motor control also involves examination of adaptive responses to unexpected perturbations. These adaptive responses are particularly critical in determining the integrity of feedback control mechanisms. Finally, motor control assessment includes examining how sensory and cognitive deficits, changing task demands, and instructions modulate motor performance. Abnormal motor control is evident in central nervous system disorders such as stroke, cerebellar disorders, and Parkinson disease. For example, early after stroke, individuals learn abnormal movement strategies to compensate for weakness; however, many retain those abnormal strategies even after weakness is resolved.[74] Similar learned compensations are evident in asymmetric landing and weight-bearing after musculoskeletal injuries such as ACLR.[75] Thus, abnormal motor control, in many cases, can be thought of as a "solution" that the nervous system develops and retains in response to specific impairments of other systems such as force and range of motion.

Treatment of motor control deficits requires a dual approach that combines impairment restitution in other systems (eg, range of motion) with intensive task-oriented practice. For example, excessive trunk flexion during reach-to-grasp actions after stroke is a learned compensation for insufficient shoulder flexion-elbow extension needed to reach successfully.[74] Strength training of shoulder and elbow muscles combined with intense task-specific practice yields the most optimal functional upper extremity outcomes.[76] It is paramount that task practice is intense and provides an optimal challenge[77] through exploration and feedback to enhance long-term retention. The challenge during practice is optimized by altering the demands of the task and environment, changing the amount of feedback and assistance, and modifying cognitive effort (eg, addition of a dual task). Intensity of practice can be gauged using physiologic parameters (eg, percent heart-rate reserve for gait training) or rate of perceived difficulty/exertion of practice. In summary, targeting motor control through movement analyses, examination, and motor skill practice forms a cornerstone of physical therapist practice.

Environment and Personal Factors

Environment and personal factors can influence all aspects of the movement system in various ways, and a full discussion is beyond the scope of this paper. Personal factors include items such as age, gender, comorbidities, self-efficacy, confidence, fear of movement, and motivation. Personal factors that impact movement can be assessed via directed interviewing as well as standardized tools. For example, there is an association between knee and hip kinematics and psychological readiness to return to sport (measured via the ACL—Return to Sport after Injury Scale) in patients following ACLR during gait and a single-leg landing task.[78,79] Environmental factors include items external to the patient that may influence movement, such as the support surface or terrain, weather conditions, and external distractions. Similarly, environmental factors can be assessed during the patient interview, during a home or workplace assessment, and/or by evaluating the individual's performance of the task in different environments (eg, indoors vs outdoors on the sidewalk, level ground vs rocky terrain, etc.). Including the environment and personal factors in the model is consistent with the ICF[15] and also the description of movement offered by Guccione et al[6] as a dynamic system involving a complex interaction between the task, organism (person), and environment.

Analyzing Functional Movement Tasks

The 4 key elements of the movement system are typically assessed by specific tests and measures documenting specific impairments. However, prior to these tests and measures, we recommend that a qualitative assessment of the performance

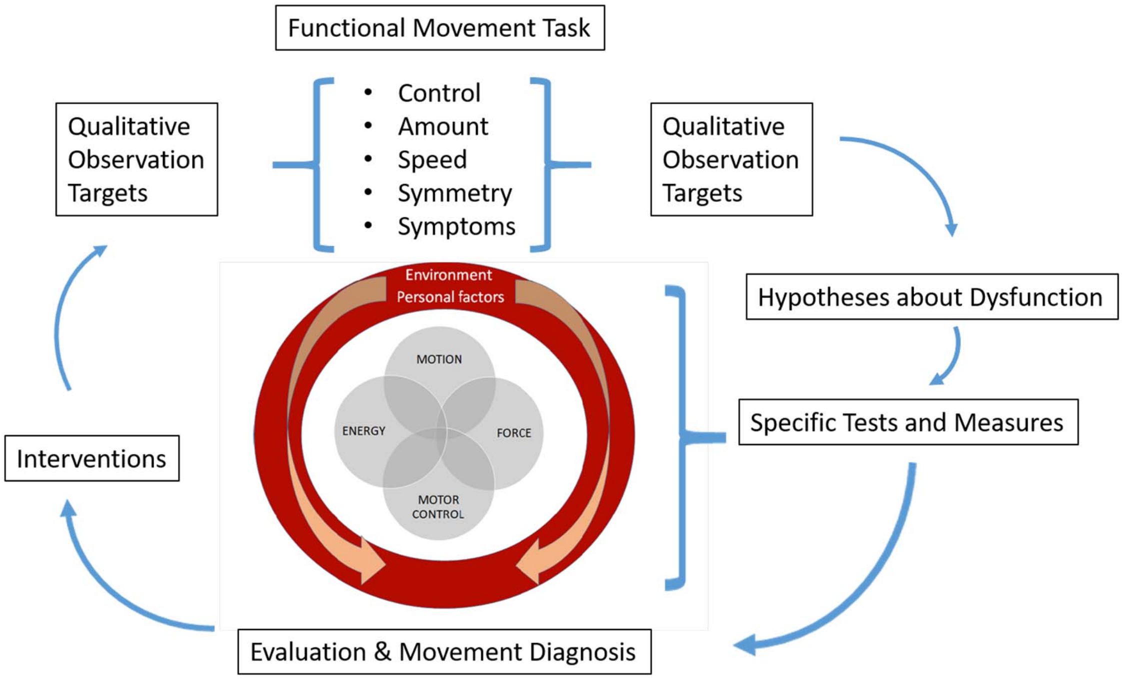

Figure 3. Application of functional movement task analysis to the movement system within the patient management model. A relevant functional movement task is systematically observed qualitatively while hypotheses are developed to explain abnormal findings. These hypotheses guide the selection of specific tests and measures performed during an examination. After functional movement task analysis and specific examination procedures, a movement diagnosis can be developed. The movement diagnosis should lead to matched intervention strategies and ultimately reassessment of relevant functional movement task(s).

of a functional movement task be conducted. Common examples of functional movement tasks would include gait, rising from a chair, bending, reaching, or gripping. Figure 3 shows the features of functional movement tasks that are typically evaluated qualitatively. To assist students learning a systematic approach to assessing movement, we focus on the following "observation targets," summarized by the acronym CASSS: control, amount, symmetry, speed, and symptoms.

Although it is possible to assess these factors quantitatively, we recommend that they first be assessed qualitatively by careful observation. We have found focusing students' observations on the targets of CASSS helps organize their examination and develop clinical reasoning skills in a process that becomes more automatic with practice. It also provides words and a framework for description when movement appears different than expected.

Control refers to the smoothness, coordination, and timing of the movement. Did each joint move at the appropriate time and in a smooth coordinated way? Amount refers to the amplitude of movement at each joint during the task. Did one joint move too much whereas another moved too little? Symmetry is obviously most relevant for bilateral tasks such as gait, rising from a chair or bending; however, symmetry between limbs could also be assessed for unilateral tasks. Speed refers to the speed of movement. Was velocity controlled appropriately with normal acceleration and deceleration during the task? Finally, was the movement associated with symptoms? Symptoms most commonly refer to pain but may also be things like clicking, dyspnea, fatigue, a sense of instability, or urinary incontinence with coughing.

Although we advocate initial qualitative analysis based on observation, mobile device applications that allow a more quantitative assessment are becoming increasingly available. These tools can be particularly useful in the analysis of rapid and/or complex tasks, such as running or jumping. These applications allow the user to record the performance of the task, manipulate the playback speed, and determine joint angles with greater precision to quantify motion and control. These tools can be used to provide direct visual biofeedback to patients regarding a movement pattern and can also be excellent teaching tools to help students focus on specific aspects of abnormal movement.

The Movement System and Patient Management

The proposed movement system becomes immediately relevant to practice when situated within the existing Patient Management Model[14] as shown in Figure 3. Along with the patient history, qualitative evaluation of the performance of movement during a task should lead to the generation of hypotheses regarding the impairments within the movement system elements that may be contributing to "abnormal" movement. These hypotheses would then be tested by discrete tests and measures, examples of which are listed in Table 1. In this way, observation of functional movement tasks can help guide and direct the physical examination. Functional movement is the final common pathway that would be affected by an impairment in 1 the 4 key elements of the movement system. Evaluation of the results of the hypothesis testing guides the selection of interventions. Although interventions may often address more than 1 of the 4 elements of the system and the interaction between them, we have found that assessing impairments in each of the 4 elements of movement helps guide selection of matched intervention strategies and tactics. In this way, we believe our model may offer promise for a coherent system by identifying which of the 4 elements of movement are primarily affected. These would lead directly to broad types of intervention strategies.

One of the strengths of the model is that it can be applied broadly across patient populations. Consider 2 patients with observed asymmetrical lower extremity loading during a chair rise task: 1 patient is an 18-year old who is 4 weeks post ACLR, and the other is a 62-year old who is 8 months post stroke. The patient with ACLR demonstrated altered symmetry depicted by a shift of his center of mass to the nonsurgical lower limb during the task. Two hypotheses for this observation include a force deficit due to inadequate quadriceps strength/activation and a motor control issue possibly due to personal factors (eg, fear) or learned behavior. The patient post stroke also demonstrated an alteration with symmetry, speed, and control depicted by slow movements decomposed into smaller steps and body weight shifted to the nonparetic side during the chair rise. The hypotheses for both of these patients could be tested clinically, and then the relevant intervention could be prescribed. Asymmetrical loading was observed in 2 patient examples; however, the underlying impairments that potentially led to asymmetry could be different. For example, force deficits may be the greatest contributor to asymmetry after ACLR, whereas motor control deficits may be the greatest contributor after stroke. Identifying the underlying elements that potentially contribute to movement abnormalities provides a rationale for making a prognosis and identifying specific targets for interventions.

The 4-Element Movement System and Movement-related Research

A significant focus within movement-related research understands the relationships between impairments and function. The 4-element model provides concise and meaningful categories for describing the primary impairments affecting functional activity. Consistent use of these categories may enhance efforts at understanding relationships between impairments and function. Because the model also requires consideration of the environment and personal factors, consideration of these components in movement-related research will enhance the applicability of research. Finally, the model may better inform treatment studies to specify treatment targets and justify physical therapy interventions.

Limitations

Closely related to the issue of patient management is the use of diagnostic labels, which our model does not directly address. This has been a challenge for physical therapists because traditional pathoanatomic labels typically do not describe or even correlate with key impairments or functional activity limitations, which are the focus of rehabilitation interventions.[3,9–11,80] Guccione and colleagues[6,81,82] suggest diagnostic labels for movement problems, often based on impairments and initial conditions, are inadequate and recommend a greater emphasis on prognosis or "what is likely to happen." Although different systems have been described, developing effective categories and labels to guide clinical practice and research efforts will remain a long-term challenge.

The proposed model does not offer a specific means of explaining or managing pain, which is a common reason patients with musculoskeletal problems seek care. The model focuses directly on movement and includes only those elements that are basic requirements to movement itself. Although pain is clearly a common factor related to movement, we have only included it by considering symptoms during functional task analysis. The relationship between pain and movement is complex and has been studied extensively with musculoskeletal problems[83–85] but is still not understood well.

Summary

The movement system represents an ideal construct to characterize the unique expertise and identity of physical therapists within the health care system. The 4-element model defines critical elements of movement (motion, force, energy, and control) and sets them inside both the ICF model and the patient management model that are foundational to our profession. The model represents an efficient and coherent conceptual model to guide clinical management and education related to movement problems that can be applied across a broad array of patient conditions and clinical subspecialties. It may also serve as useful guide to future movement-related research.

Author Contributions

Concept/idea/research design: P.W. McClure, M.A. Tevald, R. Zarzycki, S. Kantak, P.J. Malloy, K.V. Day, K. Shah, A. Miller, K.K. Mangione
Writing: P.W. McClure, M.A. Tevald, R. Zarzycki, S. Kantak, P.J. Malloy, K.V. Day, K. Shah, K.K. Mangione
Project management: K.K. Mangione
Consultation (including review of manuscript before submitting): S. Kantak, P.J. Malloy, K. Shah, K.K. Mangione

Acknowledgments

We thank the following people who provided comments on earlier drafts of this manuscript: Rebecca Craik, Martha Eastlack, Brian Eckenrode, Ann Harrington, Janet Readinger, and Susan Tomlinson.

Disclosures

The authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

References

1. American Physical Therapy Association. White Paper: *Physical Therapist Practice and The Movement System*. *American Physical Therapy Association*. Alexandria, VA, USA: American Physical Therapy Association; 2015.
2. Field-Fote E. The human movement system in neurologic physical therapy. *J Neurol Phys Ther*. 2015;39:195–196.
3. Hedman LD, Quinn L, Gill-Body K, et al. White paper: movement system diagnoses in neurologic physical therapy. *J Neurol Phys Ther*. 2018;42:110–117.
4. Sahrmann SA. The human movement system: our professional identity. *Phys Ther*. 2014;94:1034–1042.
5. Seitz AL, McClure PW, Finucane S, Boardman ND 3rd, Michener LA. Mechanisms of rotator cuff tendinopathy: intrinsic, extrinsic, or both? *Clin Biomech (Bristol, Avon)*. 2011;26:1–12.
6. Guccione AA, Neville BT, George SZ. Optimization of movement: a dynamical systems approach to movement systems as emergent phenomena. *Phys Ther*. 2019;99:3–9.

7. Ludewig PM, Lawrence RL, Braman JP. What's in a name? Using movement system diagnoses versus pathoanatomic diagnoses. *J Orthop Sports Phys Ther*. 2013;43:280–283.
8. Peel C. The cardiopulmonary system and movement dysfunction. *Phys Ther*. 1996;76:448–455.
9. Sahrmann S, Azevedo DC, Dillen LV. Diagnosis and treatment of movement system impairment syndromes. *Braz J Phys Ther*. 2017;21:391–399.
10. Van Sant AF. Movement system diagnosis. *J Neurol Phys Ther*. 2017;41:S10–S16.
11. Sahrmann S. *Diagnosis and Treatment of Movement Impairment Syndromes*. St. Louis, MO, USA: Mosby; 2002.
12. Jensen GM, Shepard KF, Gwyer J, Hack LM. Attribute dimensions that distinguish master and novice physical therapy clinicians in orthopedic settings. *Phys Ther*. 1992;72:711–722.
13. Wainwright SF, Shepard KF, Harman LB, Stephens J. Factors that influence the clinical decision making of novice and experienced physical therapists. *Phys Ther*. 2011;91:87–101.
14. American Physical Therapy Association. *Guide to Physical Therapist Practice*. 2nd ed. Alexandria, VA, USA: American Physical Therapy Association; 2001.
15. World Health Organization. *International Classification of Functioning, Disability and Health: ICF*. Geneva, Switzerland: World Health Organization; 2001.
16. Rothstein JM, Echternach JL, Riddle DL. The hypothesis-oriented algorithm for clinicians II (HOAC II): a guide for patient management. *Phys Ther*. 2003;83:455–470.
17. McClure P, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train*. 2009;44:160–164.
18. Allen DD. Proposing 6 dimensions within the construct of movement in the movement continuum theory. *Phys Ther*. 2007;87: 888–898.
19. Benjaminse A, Gokeler A, van der Schans CP. Clinical diagnosis of an anterior cruciate ligament rupture: a meta-analysis. *J Orthop Sports Phys Ther*. 2006;36:267–288.
20. Croy T, Koppenhaver S, Saliba S, Hertel J. Anterior talocrural joint laxity: diagnostic accuracy of the anterior drawer test of the ankle. *J Orthop Sports Phys Ther*. 2013;43:911–919.
21. Ellenbecker TS, Bailie DS, Mattalino AJ, et al. Intrarater and interrater reliability of a manual technique to assess anterior humeral head translation of the glenohumeral joint. *J Shoulder Elbow Surg*. 2002;11:470–475.
22. Levy AS, Lintner S, Kenter K, Speer KP. Intra- and interobserver reproducibility of the shoulder laxity examination. *Am J Sports Med*. 1999;27:460–463.
23. Davis DS, Quinn RO, Whiteman CT, Williams JD, Young CR. Concurrent validity of four clinical tests used to measure hamstring flexibility. *J Strength Cond Res*. 2008;22:583–588.
24. Dawood M, Bekker PJ, van Rooijen AJ, Korkie E. Inter- and intrarater reliability of a technique assessing the length of the latissimus dorsi muscle. *S Afr J Physiother*. 2018;74:388.
25. Lee KM, Chung CY, Kwon DG, Han HS, Choi IH, Park MS. Reliability of physical examination in the measurement of hip flexion contracture and correlation with gait parameters in cerebral palsy. *J Bone Joint Surg Am*. 2011;93:150–158.
26. Dommerholt J, Huijbregts P. *Myofascial Trigger Points: Pathophysiology and Evidence-Informed Diagnosis and Management*. Sudbury, MA, USA: Jones and Bartlett Publishers; 2011.
27. Ekedahl H, Jonsson B, Annertz M, Frobell RB. Accuracy of clinical tests in detecting disk herniation and nerve root compression in subjects with lumbar radicular symptoms. *Arch Phys Med Rehabil*. 2018;99:726–735.
28. Schmid AB, Brunner F, Luomajoki H, et al. Reliability of clinical tests to evaluate nerve function and mechanosensitivity of the upper limb peripheral nervous system. *BMC Musculoskelet Disord*. 2009;10:11.
29. Glasgow C, Tooth LR, Fleming J. Mobilizing the stiff hand: combining theory and evidence to improve clinical outcomes. *J Hand Ther*. 2010;23:392–400 quiz 401.
30. McClure PW, Blackburn LG, Dusold C. The use of splints in the treatment of joint stiffness: biologic rationale and an algorithm for making clinical decisions. *Phys Ther*. 1994;74:1101–1107.
31. Fernandez-de-Las-Penas C, Nijs J. Trigger point dry needling for the treatment of myofascial pain syndrome: current perspectives within a pain neuroscience paradigm. *J Pain Res*. 2019;12: 1899–1911.
32. Moreau NG, Simpson KN, Teefey SA, Damiano DL. Muscle architecture predicts maximum strength and is related to activity levels in cerebral palsy. *Phys Ther*. 2010;90:1619–1630.
33. Noehren B, Andersen A, Hardy P, et al. Cellular and morphological alterations in the vastus lateralis muscle as the result of ACL injury and reconstruction. *J Bone Joint Surg Am*. 2016;98:1541–1547.
34. Miller JE, Higgins LD, Dong Y, et al. Association of strength measurement with rotator cuff tear in patients with shoulder pain: the rotator cuff outcomes workgroup study. *Am J Phys Med Rehabil*. 2016;95:47–56.
35. Palmieri-Smith RM, Thomas AC, Wojtys EM. Maximizing quadriceps strength after ACL reconstruction. *Clin Sports Med*. 2008;27: 405–424 vii-ix.
36. Stackhouse SK, Binder-Macleod SA, Lee SC. Voluntary muscle activation, contractile properties, and fatigability in children with and without cerebral palsy. *Muscle Nerve*. 2005;31:594–601.
37. Zarzycki R, Morton SM, Charalambous CC, Pietrosimone B, Williams GN, Snyder-Mackler L. Athletes after anterior cruciate ligament reconstruction demonstrate asymmetric intracortical facilitation early after surgery. *J Orthop Res*. 2020;39:147–153.
38. Angelozzi M, Madama M, Corsica C, et al. Rate of force development as an adjunctive outcome measure for return-to-sport decisions after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2012;42:772–780.
39. Kline PW, Morgan KD, Johnson DL, Ireland ML, Noehren B. Impaired quadriceps rate of torque development and knee mechanics after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med*. 2015;43:2553–2558.
40. Lisee C, Lepley AS, Birchmeier T, O'Hagan K, Kuenze C. Quadriceps strength and volitional activation after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Sports Health*. 2019;11:163–179.
41. Moreau NG, Falvo MJ, Damiano DL. Rapid force generation is impaired in cerebral palsy and is related to decreased muscle size and functional mobility. *Gait Posture*. 2012;35:154–158.
42. Takeda K, Tanabe S, Koyama S, et al. Relationship between the rate of force development in knee extensor muscles and gait speed in patients with chronic stroke: a cross-sectional study. *NeuroRehabilitation*. 2018;43:425–430.
43. Ithurburn MP, Paterno MV, Ford KR, Hewett TE, Schmitt LC. Young athletes with quadriceps femoris strength asymmetry at return to sport after anterior cruciate ligament reconstruction demonstrate asymmetric single-leg drop-landing mechanics. *Am J Sports Med*. 2015;43:2727–2737.
44. Lewek M, Rudolph K, Axe M, Snyder-Mackler L. The effect of insufficient quadriceps strength on gait after anterior cruciate ligament reconstruction. *Clin Biomech (Bristol, Avon)*. 2002;17: 56–63.
45. Mentiplay BF, Tan D, Williams G, et al. Assessment of isometric muscle strength and rate of torque development with hand-held dynamometry: test-retest reliability and relationship with gait velocity after stroke. *J Biomech*. 2018;75:171–175.
46. Sanchez N, Acosta AM, Lopez-Rosado R, Stienen AHA, Dewald JPA. Lower extremity motor impairments in ambulatory chronic hemiparetic stroke: evidence for lower extremity weakness and abnormal muscle and joint torque coupling patterns. *Neurorehabil Neural Repair*. 2017;31:814–826.

47. American College of Sports M, Chodzko-Zajko WJ, Proctor DN, et al. American College of Sports Medicine position stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc*. 2009;41:1510–1530.
48. Kim KM, Croy T, Hertel J, Saliba S. Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. *J Orthop Sports Phys Ther*. 2010;40: 383–391.
49. Stackhouse SK, Binder-Macleod SA, Stackhouse CA, McCarthy JJ, Prosser LA, Lee SC. Neuromuscular electrical stimulation versus volitional isometric strength training in children with spastic diplegic cerebral palsy: a preliminary study. *Neurorehabil Neural Repair*. 2007;21:475–485.
50. Stevens-Lapsley JE, Balter JE, Wolfe P, Eckhoff DG, Kohrt WM. Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: a randomized controlled trial. *Phys Ther*. 2012;92:210–226.
51. Noonan V, Dean E. Submaximal exercise testing: clinical application and interpretation. *Phys Ther*. 2000;80:782–807.
52. Kodama S, Saito K, Tanaka S, et al. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA*. 2009;301:2024–2035.
53. Kokkinos P, Myers J, Kokkinos JP, et al. Exercise capacity and mortality in black and white men. *Circulation*. 2008;117:614–622.
54. Chen SY, Lu PC, Lan C, et al. Six-minute walk test among heart transplant recipients. *Transplant Proc*. 2014;46:929–933.
55. Jenkins S, Cecins N. Six-minute walk test: observed adverse events and oxygen desaturation in a large cohort of patients with chronic lung disease. *Intern Med J*. 2011;41:416–422.
56. Regan E, Middleton A, Stewart JC, Wilcox S, Pearson JL, Fritz S. The six-minute walk test as a fall risk screening tool in community programs for persons with stroke: a cross-sectional analysis. *Top Stroke Rehabil*. 2020;27:118–126.
57. Tang L, Fang Y, Yin J. The effects of exercise interventions on Parkinson's disease: a Bayesian network meta-analysis. *J Clin Neurosci*. 2019;70:47–54.
58. Dobson F, Hinman RS, Hall M, et al. Reliability and measurement error of the osteoarthritis research society international (OARSI) recommended performance-based tests of physical function in people with hip and knee osteoarthritis. *Osteoarthr Cartil*. 2017;25: 1792–1796.
59. Dobson F, Hinman RS, Roos EM, et al. OARSI recommended performance-based tests to assess physical function in people diagnosed with hip or knee osteoarthritis. *Osteoarthr Cartil*. 2013;21: 1042–1052.
60. Borg GA. Perceived exertion: a note on "history" and methods. *Med Sci Sports*. 1973;5:90–93.
61. American College of Sports Medicine, Riebe D, Ehrman JK, Liguori G, Magal M. *ACSM's Guidelines For Exercise Testing and Prescription*. 10th ed. Philadelphia, PA: Wolters Kluwer; 2018.
62. Fletcher GF, Ades PA, Kligfield P, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. *Circulation*. 2013;128:873–934.
63. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320:2020–2028.
64. Geneen LJ, Moore RA, Clarke C, Martin D, Colvin LA, Smith BH. Physical activity and exercise for chronic pain in adults: an overview of Cochrane reviews. *Cochrane Database Syst Rev*. 2017;4:CD011279.
65. Cooney GM, Dwan K, Greig CA, et al. Exercise for depression. *Cochrane Database Syst Rev*. 2013;9:CD004366.
66. Mok A, Khaw KT, Luben R, Wareham N, Brage S. Physical activity trajectories and mortality: population based cohort study. *BMJ*. 2019;365:l2323.
67. Sibley KM, Beauchamp MK, Van Ooteghem K, Straus SE, Jaglal SB. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. *Arch Phys Med Rehabil* 2015;96: 122–132 e129.
68. McDonald MW, Black SE, Copland DA, et al. Cognition in stroke rehabilitation and recovery research: consensus-based core recommendations from the second stroke recovery and rehabilitation roundtable. *Int J Stroke*. 2019;14:774–782.
69. Awad LN, Reisman DS, Wright TR, Roos MA, Binder-Macleod SA. Maximum walking speed is a key determinant of long distance walking function after stroke. *Top Stroke Rehabil*. 2014;21: 502–509.
70. Karpman C, Benzo R. Gait speed as a measure of functional status in COPD patients. *Int J Chron Obstruct Pulmon Dis*. 2014;9: 1315–1320.
71. Scheets PL, Sahrmann SA, Norton BJ. Use of movement system diagnoses in the management of patients with neuromuscular conditions: a multiple-patient case report. *Phys Ther*. 2007;87: 654–669.
72. Cooper A, Alghamdi GA, Alghamdi MA, Altowaijri A, Richardson S. The relationship of lower limb muscle strength and knee joint hyperextension during the stance phase of gait in hemiparetic stroke patients. *Physiother Res Int*. 2012;17:150–156.
73. Leung J, Smith R, Harvey LA, Moseley AM, Chapparo J. The impact of simulated ankle plantarflexion contracture on the knee joint during stance phase of gait: a within-subject study. *Clin Biomech (Bristol, Avon)*. 2014;29:423–428.
74. Mandon L, Boudarham J, Robertson J, Bensmail D, Roche N, Roby-Brami A. Faster reaching in chronic spastic stroke patients comes at the expense of arm-trunk coordination. *Neurorehabil Neural Repair*. 2016;30:209–220.
75. Chan MS, Sigward SM. Loading behaviors do not match loading abilities postanterior cruciate ligament reconstruction. *Med Sci Sports Exerc*. 2019;51:1626–1634.
76. Patten C, Condliffe EG, Dairaghi CA, Lum PS. Concurrent neuromechanical and functional gains following upper-extremity power training post-stroke. *J Neuroeng Rehabil*. 2013;10:1.
77. Guadagnoli MA, Lee TD. Challenge point: a framework for conceptualizing the effects of various practice conditions in motor learning. *J Mot Behav*. 2004;36:212–224.
78. Nagelli CV, Webster KE, Di Stasi S, Wordeman SC, Hewett TE. The association of psychological readiness to return to sport after anterior cruciate ligament reconstruction and hip and knee landing kinematics. *Clin Biomech (Bristol, Avon)*. 2019;68:104–108.
79. Zarzycki R, Failla M, Capin JJ, Snyder-Mackler L. Psychological readiness to return to sport is associated with knee kinematic asymmetry during gait following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 2018;48:968–973.
80. McClure PW, Michener LA. Staged approach for rehabilitation classification: shoulder disorders (STAR-shoulder). *Phys Ther*. 2015;95:791–800.
81. Croft P, Altman DG, Deeks JJ, et al. The science of clinical practice: disease diagnosis or patient prognosis? Evidence about "what is likely to happen" should shape clinical practice. *BMC Med*. 2015;13:20.
82. Croft P, Dinant GJ, Coventry P, Barraclough K. Looking to the future: should 'prognosis' be heard as often as 'diagnosis' in medical education? *Educ Prim Care*. 2015;26:367–371.
83. Hides JA, Donelson R, Lee D, Prather H, Sahrmann SA, Hodges PW. Convergence and divergence of exercise-based approaches that incorporate motor control for the management of low back pain. *J Orthop Sports Phys Ther*. 2019;49:437–452.
84. Scholtes SA, Salsich GB. A dynamic valgus index that combines hip and knee angles: assessment of utility in females with patellofemoral pain. *Int J Sports Phys Ther*. 2017;12:333–340.
85. Welbeck AN, Amilo NR, Le DT, et al. Examining the link between thoracic rotation and scapular dyskinesis and shoulder pain amongst college swimmers. *Phys Ther Sport*. 2019;40: 78–84.