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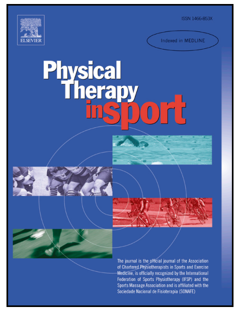
DINGENEN, Bart; Blandford, Lincoln; Comerford, Mark; Staes, Filip & Mottram, Sarah (2018) The assessment of movement health in clinical practice: a multidimensional perspective. In: PHYSICAL THERAPY IN SPORT, 32, p. 282-292.

DOI: 10.1016/j.ptsp.2018.04.008
Handle: http://hdl.handle.net/1942/27608

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PII: S1466-853X(17)30477-7

DOI: 10.1016/j.ptsp.2018.04.008

Reference: YPTSP 877

To appear in: *Physical Therapy in Sport*

Received Date: 6 September 2017

Revised Date: 7 November 2017

Accepted Date: 10 April 2018

# The assessment of movement health in clinical practice: a multidimensional perspective

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# The assessment of movement health in clinical practice: a multidimensional perspective

## ABSTRACT

This masterclass takes a multidimensional approach to movement assessment in clinical practice. It seeks to provide innovative views on both emerging and more established methods of assessing movement within the world of movement health, injury prevention and rehabilitation. A historical perspective of the value and complexity of human movement, the role of a physical therapist in function of movement health evaluation across the entire lifespan and a critical appraisal of the current evidence-based approach to identify individual relevant movement patterns is presented. To assist a physical therapist in their role as a movement system specialist, a clinical-oriented overview of current movement-based approaches is proposed within this multidimensional perspective to facilitate the translation of science into practice and vice versa. A Movement Evaluation Model is presented and focuses on the measurable movement outcome of resultants on numerous interactions of individual, environmental and task constraints. The model blends the analysis of preferred movement strategies with a battery of cognitive movement control tests to assist clinical judgement as to how to optimize movement health across an individual lifespan.

KEYWORDS

Movement system, kinesiopathology, physical therapy, biomechanics, assessment

## INTRODUCTION: THE VALUE OF MOVEMENT

Movement is everywhere in human life and is rated as critical to a person's ability to participate in society.[3] "Movement is life", as stated by the "father" of Western medicine, Hippocrates, neatly captures what movement allows, a statement succinctly revealing movement's necessity. Movement offers a means of interaction with the world, facilitating each action, from the artist's brushstroke to the sprinter's world record. The importance of movement in the maintenance of both health and quality of life has been highlighted,[6,47,109] hereby further elevating movement's value. An absence or decrease of human movement, manifesting as physical inactivity, is currently identified as the fourth leading risk factor for mortality, globally.[144]

Any exploration of the value of movement will typically encounter both its richness and complexity. The dynamic systems theory is respectful of such complexity as it considers how any observed movement pattern is an overt result of innumerable and often latent contributing and interactive components.[19,54,86,139] For each individual, the multifactorial influences on movement can be summarized by the complex interaction of factors related to the individual itself (organismic constraints), the task being performed (task constraints), and the environment or context in which it is performed (environmental constraints) (Figure 1).[19,54,86,139] Some examples of the multiple interactive factors influencing the individual,[5,13,20,40,44,48,52,56,64,101,117,124-125,131] task[119,135,141] and environment[1,10,12,21,27,55,65,70,121,126] are listed in Table 1. In ideal circumstances, the human movement system has the ability to spontaneously reorganize movement coordinative strategies in a variety of ways to adapt to the constantly changing task and environmental constraints (functional variability).[19,139]

The reorganization of movement coordinative strategies can be viewed in the short and long term. Short-term changes in movement coordinative strategies may occur, for example, due to the presence of fatigue.[116] For example, a 60 minutes running protocol, simulating an Australian football game, induced significantly increased knee flexion angles at initial contact and increased internal knee extension moments during sidestepping compared to pre-fatigue states.[117] In the long term, previous injury has been associated with differences in biomechanical measures. For example, in a systematic review, Gokeler et al[40] found that gait was altered in the sagittal, frontal and transversal planes years after anterior cruciate ligament reconstruction. In addition, an increased risk to develop tibiofemoral and patellofemoral joint osteoarthritis has been reported,[18] which can affect knee symptoms, function and quality of life 10-20 years after anterior cruciate ligament reconstruction.[93,111] Changes in movement coordinative strategies may persist, subsequently interfering with the ability to participate in sports activities later in life.[43,81-82,108] A drastic decrease in physical activity as a result from an acute injury or chronic pain may predispose a person to fall into a negative continuum of physical and psychological disability.[82,130] Therefore, the value of movement for an individual is not limited to a specific point in time, but should be considered across the continuum of an entire lifespan. For example, it is now recognized that childhood offers a unique opportunity to facilitate the development of fundamental movement skills and neuromusculoskeletal movement health, which are essential to prepare youth for a lifetime of health-enhancing physical activity.[81] Unfortunately, the technology-driven environments and sedentary lifestyles which children are currently confronted with in Western society, may lead to decreased motor skill potential later in life,[81] alongside many other negative consequences of physical inactivity. The value of movement and the factors seen to influence movement coordination strategies are also being recognized by the older population in a desire to support both participation and maintain health.[6,109] This consideration across the entirety of a person's life introduces the concept of a movement lifespan. Exploration of the multiple factors influencing movement across this broad epoch demonstrates the importance of considering the influence of the three levels of constraints on short- and long-term changes in movement coordination strategies across each individual's lifespan.

The recognition of movement's value to participation and wider health highlights the need to investigate the means of maintaining the health of movement itself. Movement health has been defined as a "state in which individuals are not only injury free, but possess choice in their movement outcomes".[72] This "choice" in movement encompasses not only what movement is performed, as individuals interact and engage with their world, but also how it is performed, as they employ differing movement strategies to achieve their desired goals in both the short and long term. Movement health is something we should enjoy throughout our life, an element extending across the human lifespan, positively contributing to each individual's quality of life. In light of this perceived value, therapists should try to preserve or restore the characteristics contributing to the health of movement. However, movement coordination strategies and resulting movement patterns are influenced by multiple dynamic and interactive factors. The clinical intervention picture may be complex and must take into account a large number of relevant constraints. Even though equally important, this paper does not focus upon individual constraints such as pain, strength, mobility or fatigue, but considers means of evaluating movement, presented here as the overt outcome of multiple and complex interactions between individual, task and environmental constraints. Finally, we will propose a novel movement evaluation model within a multidimensional clinical perspective.

## FROM PATHOKINESIOLOGY TO KINESIOPATHOLOGY

Certain characteristics of movement may alter in the presence of injury and pain.[52] This study of "abnormal" movement resulting from pathology is typically referred to as the pathokinesiological model.[113-114] Within this model, the diagnostic process is mainly based on the identification of the patho-anatomic structure generating pain or pathology (e.g. M. supraspinatus tendinopathy or a herniated disc). From a historical point of view, this is a longstanding approach, and is currently still prevalent. However, several limitations have been acknowledged when exclusively employing this model.[66] A patho-anatomic diagnostic label such as "rotator cuff disease" or "patellofemoral pain syndrome" is often very broad, ambiguous and non-specific. Different individuals with the same patho-anatomic diagnostic label may possess non-comparable, and highly discrete variations within their clinical presentations, while the same clinical presentation can be generated by a variety of other patho-anatomic structures. Diagnostic labels based on tissue-specific pathology often fail to accurately direct clinical decision-making.[15] Therefore, a patho-anatomical diagnosis may not always be helpful or perhaps even misdirect physical therapists' clinical judgement and cause them to deliver inadequate or ineffective interventions. The underlying phenomena eliciting the pain or injury are not specifically identified. The patho-anatomical diagnosis has led to the prevalence of using "protocols" to treat the same patho-anatomical diagnostic label, resulting in everyone with the same label getting the same treatment intervention regardless of the variations within their clinical presentations. Furthermore, increasing evidence fails to show strong relationships between structural abnormalities and function,[9,132-133] while often the specific anatomical structure causing the pain remains unknown.[66] These findings support the notion to evaluate a person within a multidimensional clinical reasoning approach.[92] Within a multidimensional perspective, the previously proposed dynamic system theory offers routes of explanation as to how the same interactions with a task and environment can lead to highly divergent outcomes for a specific individual, which may or may not be related to pathology, pain, symptoms and function.[19,54,86,139]

Despite the global recognition that movement in the form of physical activity and exercise can have positive consequences on general health, there is still only a limited general notion that the characteristics or "ways" a person moves impacts neuromusculoskeletal injury risk, performance and quality of life. The study of movement essential to enhance task-specific performance and prevent movement-related disorders is referred to as kinesiopathology.[115] The human movement system has a tremendous ability to adapt quickly to tissue loading to maintain tissue homeostasis and function.[31,52,58] Within the concept of kinesiopathology, the loss of tissue homeostasis of innervated neuromusculoskeletal tissues is considered to be more important than the structural abnormalities of the tissues itself.[30-31] The basic principle is that repeated and/or biomechanically less advantageous movements can lead to stresses to neuromusculoskeletal structures that exceed an individual's tissue capacity, which can contribute to pain, symptoms and pathology, regardless of whether the altered movement patterns may be the cause or result.[30-31,113] For example, an increased internal rotation of the femur has been related to increased patellofemoral joint stress during a squatting task in persons with patellofemoral pain.[63] The boundaries of an individual's tissue capacity and pain tolerance are influenced by numerous factors including the sensitization of the nervous system, pain mechanisms, psychosocial factors, loading and injury history, diet and nutrition, sleep, endocrine and hormonal status, medication, diseases and systemic factors.[41,137] The kinesiopathological approach was originally described by Sahrmann[113] and leads to a redirection of a clinical examination to the identification of the movement characteristics that contribute to the development of pathological processes, instead of only focusing on the structural variations in pathological conditions.[115] Diagnostic "labels" of movement characteristics are rather focused on the underlying phenomena that assist in guiding physical therapy intervention, instead of the diagnostic labels naming the pathological structure.[115]

## FROM RESEARCH TO PRACTICE

In a welcome attempt to ensure clinical practice is more scientifically and empirically grounded, the role of evidence based medicine has grown significantly over the last decades.[42] There is increasing consideration in the literature for the contribution of specific characteristics of altered movement variables resulting in the emergence, continuation and/or recurrence of pain and pathology, hereby supporting the kinesiopathological model. The relationship between movement and pathology is based on a combination of (i) cross-sectional studies relating different movement patterns with loading of specific anatomic structures or body regions,[25,74-75,96,127,140] (ii) retrospective studies showing maladaptive movement patterns in pathological populations,[2,33,36-37,68,84-85,98,102,134] (iii) prospective studies showing alterations in movement patterns in those persons who sustain injuries[23-24,50-51,53,62,83,88-90,99,112,120,128,136] and (iv) intervention studies showing improved clinical outcomes and decreased injury risk with specific training programs focusing on improving movement patterns.[4,29,118,129,145] Nevertheless, this complex relationship between movement and pathology is far from conclusive and only beginning to be understood in the literature.[52,73]

However, from the clinician's point of view, some concerns can be formulated based on the majority of study designs currently used within this evidence-based approach. One major question arising is whether group-based average results emerging from clinical trials can be translated to the individual with a highly specific clinical presentation.[42] This consideration highlights problems of the interpretation of the "mean value" as it can often flatten out the individual case. Everyone moves differently and a degree of variability in movement patterns is both "normal" and regarded as an important marker of movement health.[45,60] The presence of variability makes evaluating movement patterns within and between individuals challenging. However, the high degree of variability within and between individuals does not implicate that a specific movement pattern may not be clinically relevant for an individual.

A general concept of an ideal or "normal" way to move probably doesn't exist. Given the multifactorial nature and intrinsic variability of human movement behavior, a "one size fits it all" approach to its subsequent management appears unwarranted. Rather, movement may be highly idiosyncratic, diverging from any normative values yet still efficient by ensuring functional tasks are able to be performed in a sustainable manner.[14] Considering pathological and non-pathological groups as two distinct homogeneous groups may therefore fail to detect individual relevant alterations in movement. Likewise, an average treatment effect, which is the primary outcome of most clinical trials, may be diluted by the inclusion of a continuum of groups of patients or individuals for whom the average treatment approach is not effective,[35] hereby again hampering the transfer from research to clinical practice.

Another limitation in the literature is that multifactorial pathological conditions or an individual's functional capacity are often considered within a reductionist perspective, hereby focusing solely on very specific parts of an individual subsystem of the body (e.g. the movement system) in an attempt to explain or understand a clinical phenomenon or function of a person as a whole.[8] The individual, environmental and task-specific context of this evaluation is often neglected, which can lead to flawed clinical decision-making. Given the multidimensional nature of the human movement system, the use of multifactorial and complex models is warranted in future studies.[8]

Furthermore, most previous studies relating movement patterns to musculoskeletal injuries have largely neglected the role of workload.[142] There is emerging evidence that athletes who experience a spike in workload for which they are not prepared for (e.g. expressed as a high acute/chronic workload ratio), are at increased risk of injury.[38] Moller et al[78] were the first to examine the relationship between internal risk factors, workload and shoulder injury risk in a group of 679 elite youth handball players. These authors found that scapular dyskinesis and a decreased external rotational strength of the shoulder exacerbated the effect of a rapid increase in training load on shoulder injury risk. As such, a state of less optimal movement health may decrease the ability to tolerate an increase in workload before an injury occurs. These findings support the models of Windt & Gabbett[142] and Nielsen et al[87] where intrinsic and extrinsic risk factors are integrated with the effects of the application of workload on injury risk, hereby further reinforcing the need to use a multidimensional approach.

## THE ROLE OF A PHYSICAL THERAPIST

According to the 2013 House of Delegates American Physical Therapy Association's vision statement, the movement system is the core of the professional identity of physical therapists.[3] The physical therapist is 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.[3] Based on this professional identity of a physical therapist, the ability to evaluate movement is now becoming the cornerstone to customize a targeted individual plan of care, improve movement health, maximize functional capacity and reach individual goals on the short and on the long term.[3] Key to managing individual movement impairments is a thorough understanding of human movement and the ability to identify changes in movement coordination strategies with a clinical assessment, followed by a comprehensive clinical reasoning process within a multidimensional perspective.

Many clinicians and researchers have proposed a variety of movement classification approaches in literature to assist the evaluation of movement health in clinical practice.[14,49,91,113-114] Despite the different opinions, terminology and clinical guidelines employed, in general they support each other's philosophies and provide different pieces of the bigger movement health puzzle.[14]

## MOVEMENT EVALUATION MODEL

As outlined earlier, the assessment methods presented in the current masterclass will not focus upon the multiple factors influencing movement (Table 1) but will evaluate characteristics of the movement outcomes. Any systemized approach to the assessment of movement must be cognizant of the inherent variability evident within the human movement system.[45] Indeed, acknowledging "we all move differently" presents the clinician with a challenge in evaluating an individual current state of movement health. In light of this perspective, there is then the need for clarification of the differing levels of movement variability and their interpretation. Preatoni et al[105] distinguish outcome variability (the consistency in what is achieved, e.g. step length during running) from coordinative variability (the range of coordinative strategies exhibited while performing this outcome). Both types of variability can be further classified as high or low. Traditionally, high outcome variability has been viewed as undesirable, as expertise is aligned to consistency in the achievement of a movement outcome.[32] However, in terms of coordinative variability, an opposite interpretation has been formulated in the literature.[45] High coordinative variability can be advantageous for the performance of functional tasks such as activities of daily living, occupational and sports related skills.[45] Low coordinative variability has been associated to overuse injuries, as the same tissues are stressed in the same way or the interval between tissues being exposed to stress is diminished.[45] However, too much coordinative variability may be indicative for decreased movement health as well.[45] This leads to the assumption that there is a "window" of variability in which healthy individuals function.[45] The decreased ability to reorganize and adapt to the changing task and environmental constraints is a growing area of interest for both researchers and clinicians.[22,52,60,105,139]

The Movement Evaluation Model proposed within the current masterclass is considerate of individual movement variability supporting a case by case approach. We propose a distinction between the evaluation of a spontaneous observed movement pattern (preferred or natural movement behavior) and cognitive movement control evaluation, based on a combination of a thorough consideration of current scientific literature on human movement control, clinical experience and comprehensive clinical reasoning processes.

Preferred or "natural" movement evaluation

During the preferred or "natural" movement evaluation, tasks such as running, jumping, squatting, sit-to-stand, one-leg stance, throwing or other activity- or sport-specific movements can be performed without any prior specific instruction how exactly to perform the task in terms of quality of movement. For example, during a drop vertical jump, an athlete is instructed to drop off a box and jump up as high as possible in a vertical direction after the first landing (Figure 2). No further instructions are provided. The preferred or natural way to perform the jump-landing task is measured or observed. These tasks are generally thought to possess a high correlation to the activities and joint loading encountered during daily living or sport activities and are therefore often argued to be functional tests.[95] The basic premise of this form of evaluation is to have an indication on the movement and joint loading patterns of a person which will interact with the workload and the structure-specific load capacity to produce a structure-specific cumulative load.[87]

Biomechanical studies have evaluated the effects of forces acting on or being produced by the body during these "functional" movements through measurement techniques such as kinematic and kinetic analyses which may vary according to the specific research question.[110,143] Kinematic analyses are used to describe the details of human movement, but are not concerned with the forces that cause the movement.[143] The kinematic outcomes can include linear and angular displacements, velocities or accelerations.[143] Different devices exist to measure human body kinematics, including video analysis and opto-electronic systems.[123] Kinetic analyses study the forces that cause the movement, including both internal and external forces.[123] Internal forces come from structures within the body, such as muscle activity or ligaments. External forces come from the ground or external loads such as gravity.[123] Ground reaction forces and kinematics are often measured synchronously to calculate the joint moments from equations that consider the segments of the limb, the joint position, and the location, magnitude and direction of the ground reaction forces.[124]

From a historical point of view, these movement assessments have mainly focused on isolated single-planar evaluation of one joint (e.g. knee flexion), or one body region (e.g. flexion-extension of the low back). This local approach was mostly directed towards evaluating the painful or pathological joint or body region in persons with pain or pathology. However, it is increasingly recognized that the human body functions as an integrated series of highly interacting multiple segments across multiple planes within a "kinetic chain".[25-26,59,76,104] The term "kinetic chain" originates from an engineering background in the 19th century and refers to a conceptual framework where the body is considered as a linked system of interdependent segments to achieve the desired movement in an efficient manner.[57,76,106] Each segment in a linked system influences the motions of its adjacent segments in a way that is dependent on how the segment is moving and how the segment is oriented relative to its adjacent segments.[106] The application of an external force causes each segment to receive and transfer force to the adjacent segment, generating a chain reaction.[57] As such, the term kinetic chain is used to describe both kinematic and kinetic linkages.[59] Based on this kinetic chain concept, repetitive overloading of specific tissues or even a specific acute peripheral joint injury is often the end result of a combination of individual-specific interactions of movements in different planes at different points within the kinetic chain. Focusing only on one particular segment may lead to underestimations of the relevance of movement impairments for an individual. Multi-segmental and multi-planar movement assessment approaches are therefore probably more representative of real-life situations.

A limitation of the currently used biomechanical evaluation approach is that most scientific information is based on measurements performed in laboratory settings. Despite the fact that the information coming from complex laboratory settings is highly valuable to increase our knowledge on the value of movement, these methodologies have two main limitations. First, the measurements used are often hard to apply in clinical settings where the same laboratory equipment is not available. In this perspective, the development of reliable and valid clinical-oriented methodologies such as two-dimensional video analysis[24,28] and clinical observation scales[17,34,97,138] is promising. The technological development of “wearables” offers now a tremendous opportunity to bring the lab to the field and measure movement in real-life environments. This might offer a potential solution for the second limitation, where one may question whether the findings coming from highly controlled laboratory and clinical environments are truly representative for the real-life environments,[22] hereby acknowledging the importance of the environmental and task constraints within the dynamic system theory.[19,54,86,139] For example, trunk and lower limb mechanics can be significant different during unplanned athletic activities compared to planned activities.[10] This might be particularly relevant for athletes who are confronted with quick and unplanned movements during sport-specific activities, based on increased temporal and visuospatial environmental constraints (e.g. reacting on a sudden action of another player, or movement of a ball).

Human movement variability is inherent and essential during preferred movement, and as a consequence also during the evaluation of preferred biomechanics. No repetition will exactly be the same than the previous one. As a consequence, clinicians are advised not to make clinical interpretations based on a single repetition of a certain task. However, the exact number of repetitions needed to have an appropriate outcome measure is not straightforward and dependent on the activity, the subject and the variable under investigation.[105] To be able to interpret this variability between different repetitions of a given task of the same individual, the environment should be taken into account. Too much coordinative variability between consecutive repetitions within a consistent environment (e.g. running on a flat surface) may indicate a less optimal cooperation between the different components of the dynamic system theory, resulting in less efficient movement.[46,60] For example, Pollard et al[103] showed that female athletes with an anterior cruciate ligament reconstruction who returned to full sport participation had an increased coordinative variability during a side-stepping task compared to non-injured controls. On the other hand, when the environment is less consistent or predictable (e.g. running on a surface with obstacles or catching a ball), it is imperative that the movement strategies are adapted to the environment. Several studies have shown across different populations that persons with pain, (previous) injury or older age have a decreased ability to adapt their movement coordinative strategies according to changing environmental and/or task constraints.[11,44,52,139] The alterations across both ends of the spectrum of movement coordinative variability may lead to a reduction in the number of movement strategies available for an individual to efficiently responding to specific tasks or environments.[39] A graphical summary of the relationship between the variability of coordination strategies during preferred movements during a given task and the environmental constraints is presented in Figure 3, hereby emphasizing the role of the previously mentioned more advantageous window of variability in movement coordination strategies.

Different methods have been proposed to estimate coordinative variability of kinematic or kinetic outcomes during preferred movement evaluations. The use of non-parametric estimators of spread (e.g. interquartile range or median absolute deviation) are advised when evaluating discrete outcomes (e.g. peak hip adduction).[105] Discrete outcomes are easier to evaluate in daily clinical practice, but one should be aware that this approach might provide only a limited insight in the coordinative variability across the whole movement cycle.[105] Irrespective of which methodology is used during evaluation, the clinical interpretation in function of the individual person within a multidimensional context remains essential.[22] Based on this clinical interpretation, a certain preferred movement pattern can then be considered as biomechanically more or less advantageous for a particular person at a particular point in time.

Cognitive movement control evaluation

Cognitive movement control assessment evaluates an individual's ability to cognitively coordinate movement at a specific joint or region (site) in a particular plane of movement (direction), under low and high threshold loading often during multi-joint tests within functionally orientated tasks.[14,77,79] These tests have been employed with a focus on different body regions such as the shoulder,[107] cervical spine,[100,122] lumbo-pelvic complex,[67-69] hip[61] and lower extremity[77] within a range of populations including non-injured athletes,[94,112] persons with pain,[16,61,68-69] and persons with a history of pain.[79] Described in detail elsewhere[14,67,77,80] these tests have demonstrated good to excellent inter- and intra-rater reliability.[61,67,77,100,107,122]

During function, whilst it is rare for movement to be either eliminated at one joint system while moving at another, or to move in one plane only, the ability to consciously coordinate the body's degrees of freedom in this manner can be used as test of movement control. This protocol can be seen to identify the presence of uncontrolled movement, defined as "an inability to cognitively control movement at a specific site and direction while moving elsewhere to benchmark standards" and can be representative of a loss of choice in coordinative strategies.[14] These cognitive movement control tests possess both a clearly defined starting alignment and end position, representing benchmarks which must be consistently achieved at both the initiation and completion of each test's performance. During the test, the movement coordination strategy employed to achieve these benchmarks are both observed and evaluated.[80] A person is asked to consciously attempt to prevent any observed uncontrolled movement. This questioning of the ability to vary the test's performance introduces a cognitive element to the testing, informing upon the individual's movement coordinative variability capacity.

For example, during the double knee swing test, the start position is a small knee bend. The person is asked to maintain a neutral lumbo-pelvic position and to swing both knees in tandem from side to side, allowing the feet to roll into supination and pronation but keep all metatarsal heads on the floor (Figure 4).[71] The benchmark dictates that the knees have to reach 20° to each side from the midline. The ability to control the pelvis to during this test demonstrates efficient cognitive movement control at this site (pelvis) and direction (rotation). If other coordination strategies are observed (e.g. rotation of the pelvis to the left or right) during this cognitive movement control test, this demonstrates inefficient cognitive movement control at this site and direction.

Arguably the more coordinative strategies an individual can display to achieve a movement outcome the greater the possession in the choice of movement, a key element in movement health. Failing a movement control test demonstrates loss of choice on how the movement outcome is achieved. We consider this as inefficient cognitive movement control and a compromised state of movement health. This loss of choice/uncontrolled movement (inefficiency) is evident as an inability to achieve the benchmarks of cognitive movement control testing and can be labeled with the site, direction and the threshold of muscle recruitment at which they manifest.[80] Testing with respect to the threshold of motor unit recruitment is suggested to reveal the movement "choices" consistently employed during postural and non-fatiguing tasks (low threshold recruitment) and those in which fatiguing load and speed are present (high threshold recruitment). As these different loading/intensity environments are influenced by different physiological mechanisms, testing is suggested to inform on loss of movement choices and the presence of low movement coordinative variability across a spectrum of tasks. The ability to pass a battery of cognitive movement control tests in all planes of movement illustrates a desirable wealth of choice in movement options (high movement coordinative variability).

Interpretation and implication of the Movement Evaluation Model

The proposed Movement Evaluation Model blends the analysis of the preferred (or natural) movement strategy (more or less biomechanically advantageous) with cognitive movement control evaluation (efficient or inefficient) in our clinical journey to understand and interpret the influence of multiple constraints and their interactions impacting movement health (Table 2). The purpose of the integration of the distinct characteristics of the two assessment methods within this model is not to provide a concept to predict injuries, but to present a multidimensional approach to assist the identification of movement control strategies to assess movement health from a clinical perspective. Based on the classification within our framework (group A, B, C or D), an appropriate combination and sequencing of movement control retraining and functional performance retraining can be developed (Table 3). We acknowledge that this classification is a basic framework to support clinical reasoning within a person-centered approach, and again, emphasize that movement should be interpreted within a broad and multidimensional perspective. Since this is the first time this framework is presented, future studies should further evaluate its clinical validity. We hypothesize that clinical outcomes can be improved when interventions are targeted to the specific individual presentation. In addition, future studies should further explore and refine the approaches to optimize motor learning.[7,146]

## CONCLUSION

In this masterclass we have provided an overview of the role of movement health and contemporary approaches to evaluate movement. The Movement Evaluation Model focuses on the measurable movement outcome of resultants on numerous interactions of individual, environmental and task constraints. The model uses tests of preferred movement biomechanics and a battery of cognitive movement control tests to assist clinical judgement as to how to best improve movement health across an individual lifespan. The proposed content of the current masterclass may help to interpret clinical findings from movement assessment, guide treatment, facilitate communication between and within clinicians and researchers and promote a modern kinesiopathological approach within a multidimensional perspective whereby clinical reasoning skills of a physical therapist are essential.

## ETHICAL APPROVAL

None declared.

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FIGURE CAPTIONS

Figure 1:

Human movement is influenced by an interaction of the task, individual and environment (dynamic system theory) (adapted from Holt et al[44]).

Figure 2:

An example of two different persons (A-B) performing the single-leg drop vertical jump.

Figure 3:

The relationship between coordinative variability during preferred movement (x-axis) and the variability in the environment (y-axis). The green circle in the middle reflects a more advantageous zone of movement coordinative variability. Both too high and too low coordinative variability might be less advantageous, especially during respectively consistent and less consistent environments.

Figure 4:

Double knee swing to the right (A) and left (B).

**Table 1. Examples of factors potentially influencing the individual, task and environment in relation to human movement health.**

| | |
|---|---|
| Individual | Gender[101,124] |
| | Age, maturation[101,124] |
| | Activity / sport level[13] |
| | Anthropometrics[5] |
| | Anatomical, morphological[125] |
| | Injury history[40] |
| | Movement history (e.g. previous experiences, practice, training, sport)[131] |
| | Pain[52] |
| | Mobility, flexibility[64] |
| | Sensorimotor factors (e.g. acquisition of sensory information, neural transmission, central nervous system processing, integration and plasticity, muscle activity, muscle activation timing, inter- and intramuscular coordination, muscle strength)[44] |
| | Fatigue[117] |
| | Psychological (e.g. beliefs, emotions, expectations, fear of movement, anxiety, motivation)[20] |
| | Visual-perceptual skills[44] |
| | Neurocognitive factors (e.g. reaction time, processing speed, pattern recognition, decision making)[48] |
| | Systemic or other physiological systems (e.g. cardiovascular, respiratory)[56] |
| Task | Activity performed (e.g. running, walking, jumping, swimming, throwing, sitting)[141] |
| | Task constraint (e.g. direction of movement, time restraints, sports rules)[119,135] |
| Environment | Base of support[1,27] |
| | Surface[121] |
| | Obstacles[12] |
| | Footwear[126] |
| | Protective equipment (e.g. bracing, taping)[21,70] |
| | School, work, society[55] |
| | Public facilities (e.g. transport, sport facilities)[55,65] |
| | Significant others (e.g. parents, friends, trainers, team mates, opponents, colleagues)[10] |

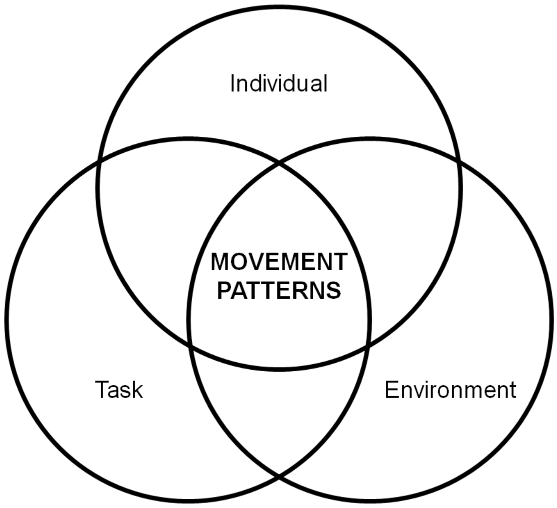
**Table 2. A framework presenting 4 different groups, based on the performance on both the preferred movement and cognitive movement control evaluation.**

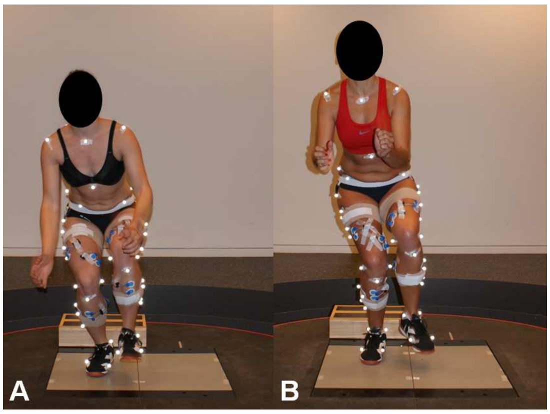
| | | Preferred movement evaluation ("natural" functional movement biomechanics) | |
|---|---|---|---|
| | | **Biomechanically advantageous strategies** | **Biomechanically less advantageous strategies** |
| Cognitive movement control coordination & efficiency | Efficient movement control | **Group A** + + | **Group B** - + |
| | Inefficient movement control | **Group C** + - | **Group D** - - |

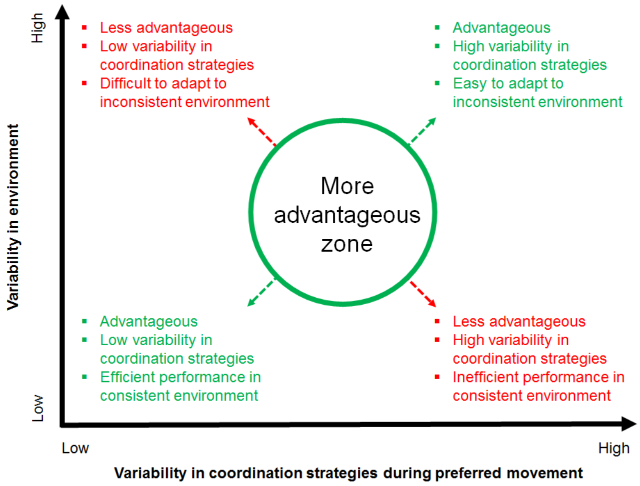
ACCEPTED MANUSCRIPT

**Table 3: Description of the Movement Evaluation Model with interpretations and recommendations.**

| **Group A: More advantageous biomechanics & efficient cognitive movement control** | **Group B: Less advantageous biomechanics & efficient cognitive movement control** |
|---|---|
| **Description:** This group demonstrates more advantageous preferred movement strategies and pass a battery of movement control tests. They display an ability to rapidly learn and reproduce technique skills. Technique correction with coaching is easily achieved and integrated into more complex movement skills.<br><br>**Interpretation:**<br>• Ability to optimize advantageous biomechanics with movement training – **effective**<br>• Potential to improve "technique" with coaching – **high potential**<br>• Performance deficiency or functional impairment – **minimal impairment**<br>• Potential to optimize performance – **high potential**<br>• Potential to enhance robustness with structured loading – **high potential**<br>• Likelihood to exceed intrinsic tissue tolerance with overload training – **low**<br><br>**Recommendation:** This group can prioritize skill and technique development with functional training strategies**.** | **Description:** This group demonstrates less advantageous preferred movement strategies but pass a battery of movement control tests. They possess movement control choices to vary performance and can quickly improve function and performance by employing movement strategies during training and skill optimization. Variability in movement control options allows effective progressions in coaching and skill development training.<br><br>**Interpretation:**<br>• Ability to improve less advantageous biomechanics with movement training – **reasonably effective**<br>• Potential to improve "technique" with coaching – **moderate potential**<br>• Performance deficiency or functional impairment – **moderate impairment**<br>• Potential to optimize performance – **moderate potential**<br>• Potential to enhance robustness with structured loading **– moderate potential**<br>• Likelihood to exceed intrinsic tissue tolerance with overload training – **moderate**<br><br>**Recommendation:** This group should prioritize biomechanical optimization and skill development with training. However, functional training should progress in structured and controlled progressions with an emphasis on technique and performance skills optimization. |
| **Group C: More advantageous biomechanics & inefficient cognitive movement control** | **Group D: Less advantageous biomechanics & inefficient cognitive movement control** |
| **Description:** This group demonstrates more advantageous preferred movement strategies but fail a battery of movement control tests. The advantageous habitual movement strategies are typically present in a limited set of functional tasks and skills and/or only in one plane of movement (e.g. sagittal plane). Inefficient control of specific movements indicates reduced variability of movement control options, which has implications for reduced robustness of tissues under load and potential to exceed tissue tolerance. They have problems controlling movement during a variety of tasks, multidirectional challenges in sport or when their attention is focused elsewhere. Inefficient control of specific movements may impact on the ability for technical or performance skill training to develop effectively and to progress quickly.<br><br>**Interpretation:**<br>• Ability to optimize advantageous biomechanics with functional movement training – **effective**<br>• Potential to improve "technique" with coaching – **moderate potential**<br>• Performance deficiency or functional impairment – **minimal impairment**<br>• Potential to optimize performance – **moderate potential**<br>• Potential to enhance robustness with structured loading **– low potential**<br>• Likelihood to exceed intrinsic tissue tolerance with overload training – **moderate**<br><br>**Recommendation**: This group would benefit from cognitive movement control training to optimize recruitment synergies to "fast track" skill development with functional training. | **Description:** This group demonstrates less advantageous preferred movement strategies and fail a battery of movement control tests. They will struggle to optimize biomechanics in functional activities or performance skills with functional training only. Inefficient movement control and reduced variability of movement options impairs the ability to improve technical skills and alter less advantageous biomechanics. This group is more likely to significantly increase tissue loading and exceed tissue tolerance with repetitive or overloaded movements in functional activities and sport.<br><br>**Interpretation:**<br>• Ability to improve less advantageous biomechanics with functional movement training alone – **ineffective**<br>• Potential to improve "technique" with coaching – **limited potential**<br>• Performance deficiency or functional impairment – **significant impairment**<br>• Potential to optimize performance – **limited potential**<br>• Potential to enhance robustness with structured loading **– low potential**<br>• Likelihood to exceed intrinsic tissue tolerance with overload training **– high**<br><br>**Recommendation**: This group would benefit from cognitive movement control training to improve ability to control the site and direction of uncontrolled movement prior to skill development. By training movement control a more optimal degree of movement variability can be established. This will enhance robustness and accelerate the ability to show improvements in functional activities and performance skill retraining. |


Individual
MOVEMENT PATTERNS
Task
Environment


A
B


Less advantageous
Low variability in coordination strategies
Difficult to adapt to inconsistent environment
Advantageous
High variability in coordination strategies
Easy to adapt to inconsistent environment
More advantageous zone
Advantageous
Low variability in coordination strategies
Efficient performance in consistent environment
Less advantageous
High variability in coordination strategies
Inefficient performance in consistent environment
High
Low
Variability in environment
Low
High
Variability in coordination strategies during preferred movement


A
B

# ETHICAL APPROVAL

None declared.

CONFLICT OF INTEREST STATEMENT

Sarah Mottram and Lincoln Blandford are employees of and Mark Comerford is a consultant to Movement Performance Solutions Ltd, which educates and trains sports, health and fitness professionals to better understand, prevent and manage musculoskeletal injury and pain that can impair movement and compromise performance in their patients, players and clients. None of the other authors have any conflict of interest to declare.