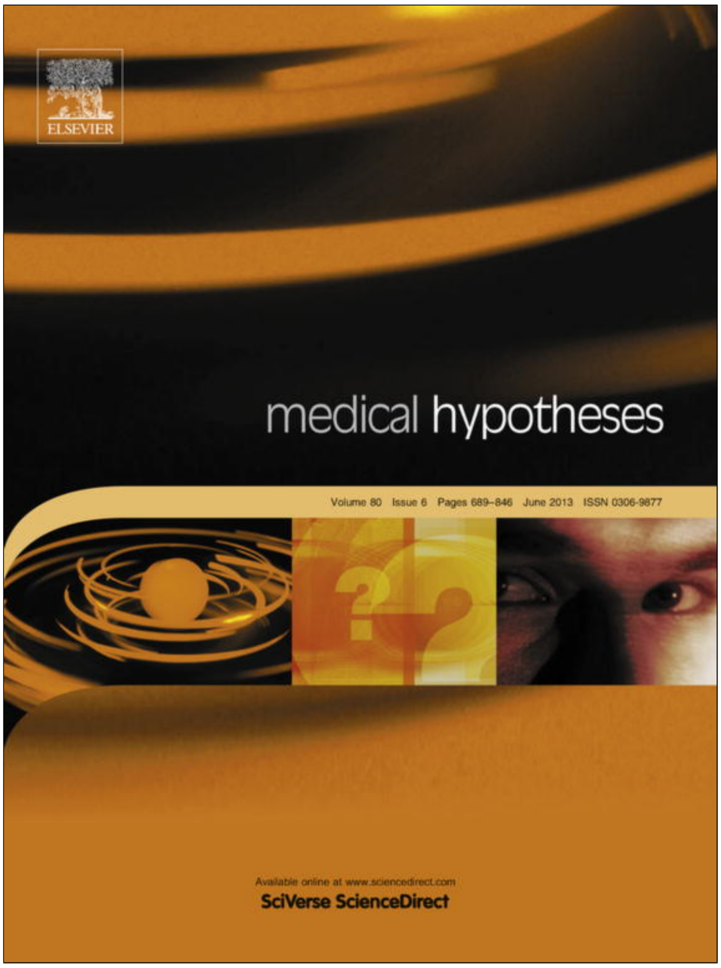
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Expanding Panjabi's stability model to express movement: A theoretical model

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ABSTRACT

Novel theoretical models of movement have historically inspired the creation of new methods for the application of human movement. The landmark theoretical model of spinal stability by Panjabi in 1992 led to the creation of an exercise approach to spinal stability. This approach however was later challenged, most significantly due to a lack of favourable clinical effect. The concepts explored in this paper address and consider the deficiencies of Panjabi's model then propose an evolution and expansion from a special model of stability to a general one of movement. It is proposed that two body-wide symbiotic elements are present within all movement systems, stability and mobility. The justification for this is derived from the observable clinical environment. It is clinically recognised that these two elements are present and identifiable throughout the body in different joints and muscles, and the neural conduction system. In order to generalise the Panjabi model of stability to include and illustrate movement, a matching parallel mobility system with the same subsystems was conceptually created. In this expanded theoretical model, the new mobility system is placed beside the existing stability system and subsystems. The ability of both stability and mobility systems to work in harmony will subsequently determine the quality of movement. Conversely, malfunction of either system, or their subsystems, will deleteriously affect all other subsystems and consequently overall movement quality. For this reason, in the rehabilitation exercise environment, focus should be placed on the simultaneous involvement of both the stability and mobility systems. It is suggested that the individual's relevant functional harmonious movements should be challenged at the highest possible level without pain or discomfort. It is anticipated that this conceptual expansion of the theoretical model of stability to one with the symbiotic inclusion of mobility, will provide new understandings on human movement. The use of this model may provide a universal system for body movement analysis and understanding musculoskeletal disorders. In turn, this may lead to a simple categorisation system alluding to the functional face-value of a wide range of commonly used passive, active or combined musculoskeletal interventions. Further research is required to investigate the mechanisms that enable or interfere with harmonious body movements. Such work may then potentially lead to new and evolved evidence based interventions.

Introduction

Novel theoretical models have traditionally inspired new schools of thought. In the musculoskeletal rehabilitation field, academic discussion of theoretical models of movement have provided the platform to develop, discuss and test novel methodological concepts of evidence-based functional exercise. In the area of therapeutic exercise, individual regimes invariably reflect the theories from which their methods originated. The biopsychosocial model of health recognises the physical interrelation between the neural, articular and muscular systems, and that these must be integrated if normal movement and function are to occur. However, the role of each system and the importance of subsystems that contribute to the effective performance of movement, are areas of ongoing debate and challenge. Consequently, new paradigms and ideas are and can be proposed to describe and explain the underlying biological mechanisms that enable movement. Within this paper the most recognised and accepted theoretical model, that of Panjabi [1–4], is expanded to provide an evolved theoretical model of movement and subsequent function.

The landmark work of Panjabi conceptualised the theoretical model that described the neural, active and passive subsystems of spinal stability. This led to the rapid progression of ideas, concepts and models that have entered the literature over the subsequent two decades, particularly in relation to the management of low back pain (LBP). This infusion of ideas rationalised and acknowledged LBP as a significant contributor to dysfunction and pain, for both the individual and society [5,6] and its subsequent burden in terms of the associated costs within the framework of the biopsychosocial model of medicine [7,8]. Panjabi's model of spinal stability required the three stability subsystems to work in synergy to prevent LBP [1,2]. This consequently alludes to a

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relationship between deficient lumbar spinal stability and chronic LBP. Furthermore, the congruity of the passive system and articular ligaments were particularly emphasised by Panjabi to enable efficient muscle control and spinal stability to prevent LBP [2,3]. This conceptual approach coincided and built upon earlier proposed models of stability. Previously Belenkii had described how the central nervous system (CNS) stabilised the body prior to a predicted challenge [9]. Grillner reinforced these findings by demonstrating that the stability mechanism will increase its activity proportionally to increases in functional challenge [10]. Bouisset subsequently used EMG in a study that demonstrated stabilising activity occurring throughout the body prior to movement [11]. A further concept evolution was proposed by Bergmark who theorised that the 'local' stability muscles could be separated from the 'global' muscles and consequently the different distributions of the outer forces on the body will be managed and explained [12].

In general, exercise approaches inspired by Panjabi's model initiate training with isolation exercises for the spinal stability components [2,4]. Functional movements are then introduced at later stages [13–16]. This exercise approach was established some two decades ago and has been relatively well accepted until recently [17]. Several studies have now questioned the reliability of the scientific findings in relation to function and symptomology [18–20] which in turn challenges the concept of graded introduction of the functional components following a foundation of stability [21]. Perhaps more significantly, to date no study has found evidence that training the stability system in isolation can be attributed to long-term symptomatic relief in subjects with LBP [22–24]. These challenges raised the question as to whether the problem of LBP could be categorised as a lack of static stability, rather than a lack of harmonious movement. This perhaps encouraged the originators of stability-training to reiterate their commitment to functional movement. Hodges claimed that back pain is not an issue of a single muscle, but rather it is associated with complex changes across a whole system [25]. O'Sullivan pointed out the lack of compelling evidence to support the prescription of stability exercises to individuals with non-specific chronic LBP [13]. Panjabi had earlier referred to this by stating that "... mechanical stability contains both static and dynamic elements" [26]. This however raises another fundamental question – what is relative stability related to when discussing human movement?

It is currently widely accepted that musculoskeletal disorders should be managed within the context of the biopsychosocial model of health as proposed by Engel [27]. It is well recognised that understanding of the human as a whole, and their presentation with symptoms and conditions that can include pain, requires incorporating and balancing of the three aspects of the biological, psychological and sociological [28]. Without this balance interruptions that disturb the ideal status quo will manifest as problems, symptoms and/or pain [29]. The identification of those at risk of delayed recovery is influenced by the presence of factors that affect this balance [30]. Consequently human movement and stability cannot be viewed as purely a physical phenomenon but a consequence of the interfacing interaction of dynamic activity and the individual's biopsychosocial status.

The purpose of this paper therefore is to: synthesise the current knowledge relating to conceptual models of movement and to standardise these within the context of Panjabi stability model while retaining the framework of the biopsychosocial model of health; and to express functional movement as a dynamic expansion that interfaces with this model. Finally, a critical aspect is to expose musculoskeletal rehabilitation and exercise methods based upon the proposed expanded theoretical model.

Stability and mobility as observed in movement

To analyse and discuss exercise approaches based on movement rather than stability, this paper has expanded Panjabi's model. We propose the inclusion of a matching relative mobility system in parallel with the existing relative stability system. It is postulated that these two systems of movement are separate but relative to each other as they interface to provide an integrated system. The manner in which they cooperate and work synergistically can determine the quality of movement throughout the body. There is an autonomous determination of the ratio of stability/mobility according to the set functional requirements of the task at hand. For example, a person involved in archery will emphasise relative stability at the expense of mobility, yet the same person may conversely emphasise relative mobility when dancing. Both the stability and mobility systems of movement might be observed separately, but they are functionally dependent upon each other to counterbalance and merge forces in order to create the actions of full-body movement. Examples of this concept can be seen in activities such as a supine single straight leg raise where the hip joint and the long hip flexor muscles of the moving leg might be viewed at as a mobility system [31]. To counterbalance this action, typical stability system structures are recruited such as the sacroiliac joint (SIJ) and the pelvic stability muscles assisted by the static body. This example complies with Mens et al's validation of the active straight leg (ASLR) test [32]. In this test, the stability system is challenged to stabilise the pelvis when raising a straight leg from the supine position. Abnormal ASLR test results are recorded if the pelvis (or other body segments) uses excessive superficial muscles to provide stability, suggesting a dysfunction of the deep pelvic stability muscles. Normalising this compensation by applying external pelvic stability forces consolidates a positive ASLR test result [32,33].

According to this presented concept, impaired movements may be apparent if the body functions without adequate synergy between the stability and mobility systems. This is supported by electromyography where Hodges et al. [34] demonstrated that stability is dependent on movement of multiple body segments. Conversely, pain may also deleteriously disrupt the harmony between the systems. Hodges and Moseley [35] demonstrated an alteration of the normal activation timing between the stability and mobility muscles in the presence of experimentally induced pain, similar to the alterations observed in people with LBP. Imparity between the two systems may not be sufficiently significant to contribute to immediate tissue damage or significant pain. However, this condition may have negative influences in the case of an unpredicted challenges to stability and if not corrected may deteriorate with time, eventually leading to one or more chronic musculoskeletal disorders of a complex biopsychosocial source [36].

Stability versus mobility

The acknowledgement of two body-wide systems working in synergy to create movement can facilitate the understanding of integrated whole body movement. This includes the complex similarities and differences that exist between individual movement components and how movement is initiated and conducted. This section analyses the stability and mobility specific elements in muscles, joints and nerve conduction.

Muscles

It is generally accepted that muscle fibres can be considered as two main types; slow twitch (or Type 1 or 'Red') muscle fibres and fast twitch (or Type 2 or 'White') muscle fibres. Fast twitch fibres can be further categorised into the Type 2a (hybrid between slow and fast twitch fibres) and Type 2b fibres (typical white fast twitch fibres). Early studies discovered that a variable contribution of fast and slow twitch fibres exist in most skeletal muscles [37–39]. However it was also found that the transversus abdominis and lumbar multifidus, which are deep stability muscles, appear to contain more tonic or Type 1 fibres than the more superficial abdominal muscles [39,40]. Later studies have alluded to the phenomenon in which slow twitch fibres convert to fast twitch fibres with age, but also in association with chronic musculoskeletal disorders, in both cases related to sub-optimal performance [41–43].

Consequently, according to this concept, slow twitch muscles are considered stability-biassed. Fast twitch muscles are long levered and associated with bursts of explosive firing and are therefore considered mobility-biassed muscles. Previous authors investigating movement have also related this aspect to two separate muscular systems. Rood classified muscles as mobilisers and stabilisers [44]; Bergmark used the term global and local muscles [12]; Panjabi referred to the muscles and tendons surrounding the spinal column as the subsystem of spinal stability which provided active stability [1–4]. According to the presented concept, sorting movement muscles into two distinct groups is not simplistic. During normal movement, muscles share stability and mobility roles dependent upon the situation. For example, during gait, the gluteus medius on the weight bearing side addresses more of a stability challenge compared to its function on the non weight-bearing side. This mechanism is further challenged as it continuously alternates according to the speed of gait. Evidence of the functional stability/mobility differences between the gluteus medius on both sides of the body can be found by observing unilateral differences in pelvic stability when one of the muscles is weakened [45]. Additionally, 'hybrid' muscles might serve both systems equally. Evidence of a local stability role for the posterior fascicles of the psoas major muscle was described by Gibbons [46]. It was also noted that the posterior fascicles of psoas major are ideally suited to perform a local stabiliser role. It was concluded that local and global muscular dysfunctionality may allow the development of a movement dysfunction [47].

Joints

Different joints might be classified as specialised for either stability or mobility, even though they share elements such as hyaline cartilage surfaces, synovial fluid and surrounding ligaments and muscles. For example, when comparing the approximate hip and SIJ, morphologic and functional differences in relation to their stability or mobility specialisation become evident. The SIJ is a synovial joint. Its cartilaginous articular surfaces however are marked by a number of irregular elevations and depressions [48,49]. Vleeming et al. [50,51] described a combined mechanism in which the SIJ plays a major role in lumbopelvic stability due to the morphology and orientation of its joint surfaces (form closure). This is achieved when the surrounding stability muscles compress the stability-designated SIJs (force closure).

The hip joint is considered a mobility-designated joint, because it is a large ball-and-socket synovial joint. It is formed by the reception of the head of the femur into the cup-shaped fossa of the acetabulum and long mobility muscles originating from the pelvis surround it [48]. This allows for the relatively large and smooth ranges of motion of the femur upon the pelvis. Even though the hip joint is considered a mobility joint according to these criterions, the massive structure of the joint and mass of muscles surrounding it provide relative hip stability that is necessary for function. Equally stated, the stability specialised synovial SIJ has mobility qualities that are also required for normal function. This relationship is not unique to the lumbo-pelvic complex, as similar relationships between active and passive subsystems exist in other body areas. For example in the cranio-cervical region a linear relationship has been shown between the amplitude of deep cervical flexor muscle activity and incremental stages of the movement of craniocervical flexion [52]. Yet this movement alters in both quality and quantity with progressive age [53].

Neural conduction

The neural activation time gap that occurs between the stability and mobility systems has been of special interest to authors in the fields of human movement and chronic LBP. As mentioned previously, different authors have demonstrated that the CNS prepares for predicted challenges to stability by pre-movement muscular activations [9]. Conversely, the stability mechanism increases its activity proportionally to the functional challenge [10]. Consequently, specific anticipatory muscular activity occurs throughout the body prior to movement [11]. Hodges and Richardson provided evidence that the CNS initiates a stability mechanism led by activation of the transversus abdominis muscle prior to the occurrence of lower limb mobility [54]. They further supported this for mobility of the upper limb by demonstrating a similar feed-forward mechanism with respect to stability of the lumbar spine [55]. Significantly, they demonstrated that the presence of temporary LBP switched the sequence of firing between the systems with the mobility muscles being activated prior to those for stability. This phenomenon subsequently reverted to normal when the pain resolved. It was concluded that this altered activation strategy deleteriously disrupted the timing required for normal movement. This consequently led to the attention of new protocols for musculoskeletal rehabilitation [56]. In an electromyographic study, Moseley et al. demonstrated variations of activation of the deep and superficial components of the medial lumbar muscles according to the biomechanical action of the muscle component [57]. This might be attributed to a dynamic and continuous effort of the stability and mobility neural subsystems to adapt and provide the body with the most efficient movement and posture according to the set condition. This mechanism of separate stability and mobility neural activations is not unique to the lumbopelvic region. For example, a trend towards a delayed onset of the vastus medialis oblique relative to vastus lateralis was found in those with anterior knee pain in comparison to those without [58].

Theoretical model

The model presented here addresses the biological aspects of musculoskeletal rehabilitation. Therefore it should be positioned alongside other appropriate fields of practise within the spectrum of the biopsychosocial model of health where all three aspects warrant clinical consideration [28].

Panjabi's 1992 landmark model focused on the special situation of spinal stability and as such it is limited to the inspiration of stability training. To generalise Panjabi's stability model, to include an expression of the dimension of movement, this proposed model conceptually creates a matching mobility system that is placed in parallel to the existing stability system. For normal movement to occur, both systems must work in harmony.

Panjabi conceptualised that the system of spinal stability consists of three subsystems; the active subsystem (muscles), the passive subsystem (joints and soft tissue), and the neural subsystem (neural conduction). It was emphasised that for the lumbar spine to enjoy sustainable stability and prevent LBP, all three subsystems must function harmoniously [1–3] (Fig. 1).

As underlined in the text, this presented theoretical model views human movement as a continuous interaction between the body's stability and mobility systems. Accordingly, in the presented model diagram, Panjabi's original model of the stability

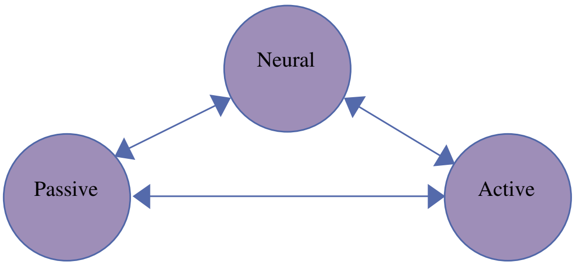

Fig. 1. Panjabi's subsystems of spinal stability [1].

system is placed opposite an equally significant mobility system, each system containing three matching subsystems (Fig. 2).

In Fig. 2, each of the six subsystems is directly connected to all other five subsystems. The symmetric symbol represents a unique situation in which all subsystems are healthy and contributing equally to the provision of harmonious movement. If any of the subsystems malfunction, all other subsystems will be compelled to compensate accordingly in order to enable the survival measure of impaired movements. In such a case, the diagrammatic symbol connecting all the subsystems will lose its symmetry.

Panjabi postulated that uncorrected ligament sub-failure injuries can lead to muscle control dysfunction, which subsequently results in chronic LBP [4]. According to this presented model, failure of any movement component will cause all other subsystems to compensate, whether stability or mobility, passive, active or neural. This will result in impaired movement regardless of the original cause. Accordingly, attempts to harmonise impaired movement should involve addressing all six subsystems simultaneously.

To provide an example of this conceptual model a hypothetical movement problem is considered. If a hip joint grossly lacks mobility towards extension, then within this proposed concept it would be considered a malfunction of the mobility-passive subsystem. Consequently, compensations in the other five subsystems may be affected as follows.

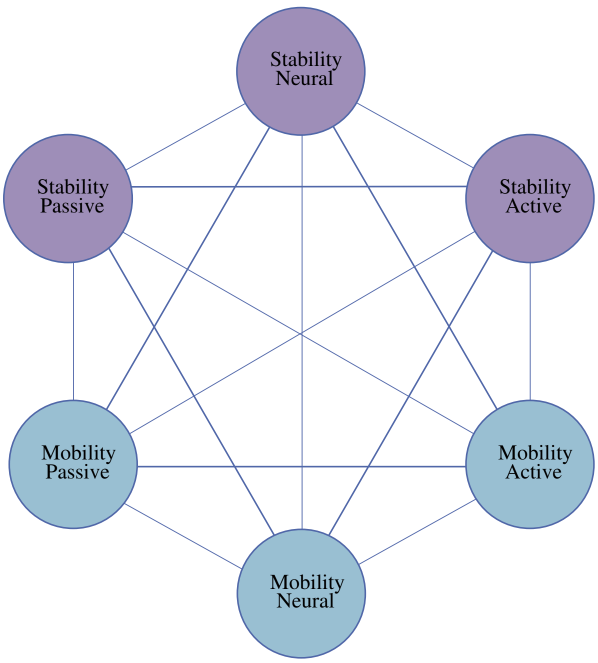

Fig. 2. The six subsystems of movement.

Stability-active subsystem – the lumbopelvic stability muscles

The lack of hip extensibility may cause pelvic imbalance after the mid-stand phase of gait. If the lumbopelvic stability muscles cannot control a normal gait cycle regularly, they will weaken where they are naturally needed, simply due to disuse.

Stability-passive subsystem – the SIJ joint surface alignment

If the pelvis is forced from its normal posture during the gait cycle, and the stability muscles are not positioned to stabilise the pelvis. Consequently the excessive movement forces impacting upon the SIJ surfaces may alter their orientation and hinder their passive locking mechanism (form closure). With time, SIJ movement disorders may contribute to the chronicity of the condition.

Stability neural subsystem – activation sequencing

If the pelvis cannot physically maintain its normal posture due to a lack of hip extensibility, the stability neural conduction alters its activation strategy to contain the compensations and provide optimal functional movement. This may contribute to an interference with the normal activation timing sequence between the systems.

Mobility active subsystem – the hip long mobility muscles

The described lack of pelvic stability is deleterious for long mobility muscles due to their origin from the pelvis and dependence upon it as a dynamically stable platform. Impairment of these muscles may be noted in accuracy, controlling power, range of motion and safety. In the ranges in which the hip movement is limited, the mobility muscle function could deteriorate.

Mobility neural subsystem – adaptive dysfunction

The mobility nerve conduction is challenged to adapt to the compensations due to the lack of hip extension. This subsystem seeks to comply and provide continuity with the rest of the body and how it manages the movement.

Functional level of musculoskeletal interventions

This presented model approaches movement from a holistic view, believing that the stability and mobility systems are not separated and that movement functions as a continuum. Active musculoskeletal interventions, inspired by Panjabi's model of separating the stability systems, have become popular in recent decades. However, evidence to support both the clinical and performance outcomes has been questionable [59]. There appears to be a link between core stability and athletic performance, with marginal benefits being demonstrated [60], though unfortunately the nature of this relationship remains unclear and further research is required [61]. There is a need for a clearer understanding of the roles that specific muscles have during core stability and core strength exercises. This would in-turn enable a greater number and variety of functional training programs to be implemented [62]. A meta-analysis of 'core stability exercise versus general exercise for chronic LBP' revealed that core stability exercise was more effective in decreasing pain in the short term. However, no significant long-term differences in pain severity were observed [63]. A single study measuring the effect of a four week integrated stability/mobility Pilates based regime indicated that both lumbo-pelvic stability and peripheral flexibility were enhanced [64]. This finding would coincide with the model presented here where the stability and mobility systems are merged in order to create functional movement.

In the musculoskeletal rehabilitation setting, it might not always be possible to create functional movement involving all the six subsystems described in this expanded model. Therefore, active or passive interventions might be used to lead to and facilitate functional movement. It is suggested that – the number of subsystems a musculoskeletal intervention targets and the level of interactions between the subsystems it trains, determines the functional level of the intervention. This may offer a practical key to differentiate between commonly used therapeutic and rehabilitation approaches. It may also assist clinicians in creating progress plans to a level in which all six subsystems can be trained in synergy.

Interventions targeting 1–2 subsystems

In situations where limited subsystems are targeted, specific consequences should result. This can be highlighted by the following examples.

Neural subsystems

Anaesthesia methods such as TCNS, acupuncture and laser therapy [65]. When used in isolation these interventions may be considered as predominantly targeting the neural subsystems.

Passive subsystems

Manual methods such as passive joint and soft tissue manipulation. These passive approaches have been suggested as targeting pain control, improvements in range of motion [66] and tissue healing [67].

Active subsystems

Exercises that isolate the mobility/active subsystem will have emphasis on training the mobility muscles without consciously integrating the stability muscles during the exercise. Conversely, exercises isolating the stability/active subsystems may include approaches that isolate the stability muscles without involving the mobility muscles [15].

As the above methods each affect a small number of subsystems and do not train normal interactions between all subsystems, the proposed symbiotic model would predict that they would not provide a sustainable return to normal movement. However, they may be indicated in situations when normal movement is not anticipated.

Interventions targeting 3–5 subsystems

The aim of normalised functional movement through training integration between the subsystems places this group of interventions at a higher level of functionality. 'Mobilisations with Movements' (MWMs) [68] is an example of this approach as it trains integration between the neural and passive subsystems. In its classic form, when performing MWMs the clinician maintains a passive holding of the joints to eliminate pain while new normalised movement is trained passively [68]. Using this model, a higher level of functionality would be achieved if the client were to perform functional active MWMs, still with the passive holding by the clinician. Adding the active/mobility subsystem to the MWMs would make the intervention inclusive of all subsystems even though the active/stability subsystem is manually assisted.

Interventions targeting all six subsystems

This level of functional training would normally include active full-body exercises that challenge the combined harmonious activation of both the mobility and the stability systems to train functional movement. Discomfort or pain, are contraindicated due to their deleterious effect on normal movement. To achieve targeted functional effects, the progression of the exercises should be towards the relevant functionality, from basic to complex, according to the ability of the client. When movement related disorders exist, the challenge of training harmonious movement subsequently rises together with the dangers of incorrect training. This adds to the importance of commencing full-body exercises in the clinical setting. Examples of this approach may be found in traditional 'body-mind' methods that include Pilates, Feldenkreiz, Alexander and Yoga [69].

A sustainable end goal of rehabilitation is important to prevent recurrences. It is suggested that prevention is ultimately achieved by continuing to train the body to harmoniously challenge a wide range of relevant functional movements after the patient is discharged from rehabilitation and considered generally healthy.

An infinite number of factors can affect human movement therefore the model is not and potentially cannot ever be complete. The other systems of the body, as well as environmental issues that are affected by movement may also need to be considered within the context of the biopsychosocial model of health. In this way the model should become sustainable as it is progressively evolves.

Conclusions

Novel theoretical models serve to bring new evidence-based insights into natural phenomenon that perplex scientific fields. As functional exercises are increasingly introduced into the clinical sphere, whether as a progression to the stability exercise approach or as an external method, such as full-body approaches, it is important for clinicians and scientists alike to understand the fundamentals of movement on a theoretical level. It is anticipated this theoretical model will provide a new direction in the understandings of human movement and disorders. It is also anticipated that this proposed concept will in turn inspire investigation and validation of combined stability/mobility based exercise approaches in the musculoskeletal rehabilitation setting. Such validation will enable full-body approaches to affirm their place in the clinical and healthcare environments. Further research is required to investigate the mechanisms that enable the body to use different specialised components to create harmonious movements. It is also important to investigate the multiple factors that influence the complexity of human movement and how the injured body manages, integrates and adapts to different intervention strategies.

Conflict of interest statement

JH is the inventor of various patented exercise devices aiming to enhance functional movement based upon the principles set forth in this paper. No funding was received to sponsor this paper.

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