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COMMENTARY

Important Movement Concepts: Clinical Versus Neuroscience Perspectives

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Human movement is complex, presenting clinical and research challenges regarding how it is described and investigated. This paper discusses the commonalities and differences on how human movement is conceptualized from neuroscientific and clinical perspectives with respect to postural control; the limitations of linear measures; movement efficiency with respect to metabolic energy cost and selectivity; and, how muscle synergy analysis may contribute to our understanding of movement variability. We highlight the role of sensory information on motor performance with respect to the base of support and alignment, illustrating a potential disconnect between the clinical and neuroscientific perspectives. The purpose of this paper is to discuss the commonalities and differences in how movement concepts are defined and operationalized by Bobath clinicians and the neuroscientific community to facilitate a common understanding and open the dialogue on the research practice gap.

***Keywords*:** human movement, measurement, neurorehabilitation

Human movement is a complex phenomenon presenting considerable challenges regarding how it is systematically and consistently described and investigated both from clinical and research perspectives (Harbourne & Stergiou, 2009; Latash, Levin, Scholz, & Schöner, 2010; Levin, Liebermann, Parmet, & Berman, 2016; Wikstrom-Grotell & Eriksson, 2012). A lesion of the central nervous system (CNS) significantly disrupts human movement, affecting every aspect of the person's life. Recovery of movement is a key aspect of neurorehabilitation, with movement performance as an essential component (Beyaert, Vasa, & Frykberg, 2015). Neuroscientific and clinical communities are interested in similar concepts of human movement, but often differ in their use and interpretation of terminology (Levin, Kleim, & Wolf, 2009). Likewise, there is a lack of uptake of neuroscientific research by neurorehabilitation clinicians, due to a perceived lack of clinical relevance of the research (McGinnis, Hack, Nixon-Cave, & Michlovitz, 2009;

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McGlynn & Cott, 2007). The purpose of this paper is to discuss the commonalities and differences in how movement concepts are defined and operationalized by Bobath clinicians and the neuroscientific community to facilitate a common understanding and open the dialogue on the research practice gap.

In a recent publication, we identified how expert Bobath neurological rehabilitation therapists conceptualize movement (Vaughan-Graham, Patterson, Zabjek, & Cott, 2017). It became clear during the analysis for that paper that there was a disconnect between the Bobath therapists' conceptualization of movement and current neuroscientific perspectives that may help to explain some of the challenges in the clinical uptake of neuroscientific evidence.

To date, how therapists conceptualize movement has received limited debate in the neurorehabilitation literature (Vaughan-Graham et al., 2017). However, how therapists understand and think about movement underpins the development of movement diagnoses, which is at the core of how therapists aim to solve movement-related problems (Vaughan-Graham & Cott, 2017). It is, therefore, important to understand how therapists think about movement in order to address the research–practice gap.

Background

Evidence-based practice is defined as "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients. The practice of evidence based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research" (Sackett, Rosenburg, Gray, Haynes, & Richardson, 1996, p. 71). Our recent work focuses on the clinical reasoning process of expert neurorehabilitation therapists that allows for this integration of research evidence with clinical expertise. The therapists we studied employ a widely used neurorehabilitation treatment approach, the Bobath concept (Vaughan-Graham & Cott, 2017). Although the Bobath concept is one of the most widely used neurorehabilitation approaches worldwide (Vaughan-Graham, Cott, & Wright, 2015a), it has been critiqued for a lack of evidence of effectiveness (Kollen et al., 2009; Winstein et al., 2016). In fact, the evidence base supporting the purported lack of evidence of effectiveness of the Bobath concept is inconclusive (Kollen et al., 2009; Winstein et al., 2016). In a recent scoping review, we identified significant flaws in the studies used to support this stance, particularly with respect to study fidelity (Vaughan-Graham, Cott, & Wright, 2015b). Continuing work examining the effectiveness of neurorehabilitation approaches is warranted. However, our research to which this paper refers is not directed at effectiveness; rather, it focuses on clinical reasoning.

Our recent studies of expert Bobath therapists identified a base of support (BOS), body configuration, postural control, movement selectivity including trajectory, coordination, timing, repeatability, as well as the role of sensation and perception as important aspects of human movement from the therapists' perspectives (Vaughan-Graham & Cott, 2016, 2017; Vaughan-Graham et al., 2017). These concepts highlight the need for a holistic understanding of movement for clinical neurorehabilitation (Harbourne & Stergiou, 2009) in which all of these aspects of movement need to be brought together for clients, such that they can move in their chosen environment (Vaughan-Graham & Cott, 2017). In contrast, for neuroscientific research to be viable, each of these aspects of human movement needs to be identifiable and measurable (Powell & Williams, 2015).

In this paper, we examine the commonalities and differences regarding how human movement is conceptualized from neuroscientific and clinical perspectives in order to facilitate a better understanding and shared terminology with respect to postural control, the limitations of linear measures, movement efficiency with respect to metabolic energy cost and selectivity, and how muscle synergy analysis may contribute to our understanding of movement variability (see Table 1 for summary of movement concepts).

Postural Control

The current literature describes postural control as a complex sensory–motor behavior mediated by multisystem integration (de Souza et al., 2015). Postural control is discussed in terms of controlling the position of the body in space with respect to postural orientation and equilibrium/stability requiring convergent information from the somatosensory, vestibular, and visual systems such that gravity, support surface, environment, and internal references are considered (Horak, 2006; Shumway-Cook & Woollacott, 2012, p. 162).

Within the Bobath concept, postural control is viewed as the organization of stability, mobility, and orientation of the multijoint kinetic chain, which is reflective of the individual's body schema in order to maintain, achieve, or restore a state of equilibrium during any posture or activity (Vaughan-Graham & Cott, 2016). Body schema was first discussed in the early 1900s in terms of the brain maintaining a continuously updated status of body shape and posture (Morasso, Casadio, Mohan, Rea, & Zenzeri, 2015). Over the last century, the concept of body schema has evolved and is now described as a constantly updated postural model providing a spatial representation of the body and the body's limbs with respect to alignment, configuration within space, and the shape of the body surface, and it can include the spatial/dynamic properties of tools used by skilled users (Morasso et al., 2015). Body schema is, therefore, understood to be an important construct with respect to action control (Morasso et al., 2015).

It is from this viewpoint that the Bobath clinician considers the following as fundamental to the acquisition of postural control: (a) the relative alignment of the person's whole body and limbs, as well as the alignment within the trunk, limb and/or limb/s (Vaughan-Graham et al., 2017) and (b) the ability of the person to selectively adapt the motor activity and alignment of his or her body segments with respect to a supporting surface (BOS), gravity, and the context (Vaughan-Graham & Cott, 2016), thus providing the clinician with critical information about the ability of the person to receive, integrate, and selectively adapt to sensory information in order to maintain, achieve, or restore equilibrium within any posture or task (Vaughan-Graham & Cott, 2017).

In the scientific literature, postural sway, the random oscillation of the center of mass (COM) observed primarily in quiet standing as a characteristic of bipedalism, is viewed as a measure of postural control or stability (Carpenter,

Table 1 Commonalities and Differences in Movement Concepts

Movement Concept	Definition	Neuroscientific Perspective	Bobath Clinical Perspective
Postural control	A complex sensory–motor behavior mediated by multisystem integration (de Souza et al., 2015).	Controlling the body in space with respect to postural orientation and equilibrium, requiring convergent information from somatosensory, vestibular, and visual systems such that gravity, support surface, environment, and internal references are considered (Horak, 2006; Shumway-Cook & Woollacott, 2012, p. 162).	The organization of stability, mobility, and orientation of the multijoint kinetic chain, which is reflective of the individual's body schema in order to maintain, achieve, or restore a state of equilibrium during any posture or activity (Vaughan-Graham & Cott, 2016). The Bobath therapist also considers the role of cognition, perception, and emotion in the generation of appropriate postural control with respect to the task and the environment (Vaughan-Graham & Cott, 2016).
Body schema	A constantly updated postural model providing a spatial representation of the body and the body's limbs with respect to alignment, configuration within space, and the shape of the body surface, and can include the spatial/dynamic properties of tools used by skilled users (Morasso et al., 2015).	Understood to be an important construct with respect to action control (Morasso et al., 2015).	Body schema is fundamental to the acquisition of postural control: (a) the relative alignment of the person's whole body/limbs as well as the alignment within the trunk/limb/s (Vaughan-Graham et al., 2017) and (b) the ability of the person to selectively adapt motor activity and alignment of body segments with respect to a supporting surface (BOS), gravity, and context (Vaughan-Graham & Cott, 2016).

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Table 1 *(continued)*

Movement Concept	Definition	Neuroscientific Perspective	Bobath Clinical Perspective
Motor control theory	Dynamic Systems Theory (Bernstein, 1967; Latash et al., 2010; Muratori et al., 2013) EP (referent configuration) Theory (Feldman, 2011; Latash et al., 2010) Computational Approach (Guigon et al., 2008)	A distributed control of the nervous system recognizing the interaction of the individual, task, and environment in motor control (Cano-de-la-Cuerda et al., 2015; Clark et al., 2010; Feldman & Levin, 2009; Muratori et al., 2013; Sainburg, 2015; Schaal et al., 2007; Shumway-Cook & Woollacott, 2016). "Central to the EP hypothesis is the notion that there are specific neural structures that represent spatial frames of reference (FRs) selected by the brain in a task-specific way from a set of available FRs. The brain is also able to translate and/or rotate the selected FRs by modifying their major attributes—the origins, metrics, and orientation—and thus, substantially influence, in a feed-forward manner, action and perception" (Feldman, 2011, p. 287). The computational approach is a model based on a set of principles assuming the nervous system: "1) processes static (e.g., gravitational and dynamic (e.g., inertial) forces separately; 2) calculates appropriate dynamic controls to master the dynamic forces and progress toward the goal according to principles of optimal feedback control; 3) uses the size of the dynamic commands (effort) as an optimality criterion; and, 4) can specify movement duration from a given level of effort" (Guigon et al., 2008).	The Bobath concept is informed by contemporary theories of motor control, neuromuscular plasticity, biomechanics, and motor learning, providing the theoretical basis for the interpretation of posture, functional human movement analysis, and recovery following a lesion of the central nervous system (Vaughan-Graham & Cott, 2016). Bobath clinical practice is based on the understanding that sensation, action, perception, cognition, and emotion are interlinked and interactive (Levin & Panturin, 2011; Vaughan-Graham & Cott, 2016; VGraham et al., 2009). Clinically, within the Bobath concept, posture and movement are viewed as inseparable and interdependent (Vaughan-Graham & Cott, 2016). Quality of movement and the ability to coordinate movement while maintaining an appropriate postural background during a specific activity are a core focus of the Bobath concept (Vaughan-Graham & Cott, 2016).

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Table 1 *(continued)*

Movement Concept	Definition	Neuroscientific Perspective	Bobath Clinical Perspective
Motor behavior	Typical movement	The reappearance of typical movement patterns and sequences used before stroke for performance of a task (Levin et al., 2009, 2016).	Describes the range of similar motor behavior available to persons without a lesion of the central nervous system (D'Avella et al., 2006; Lacquaniti et al., 2012; McCrea et al., 2002; Vaughan-Graham & Cott, 2016).
	Atypical movement	Not currently operationalized.	Describes the motor behavior of the more affected body segments or limbs (Clark et al., 2010; Levin et al., 2016; Michaelsen et al., 2006; Pain et al., 2015; Vaughan-Graham & Cott, 2016).
	Compensatory movement	The use of additional or alternate kinematic patterns during task performance (Levin et al., 2009, 2016).	Describes the motor behavior of the less affected body segments or limbs (Levin et al., 2016; Michaelsen et al., 2006; Pain et al., 2015; Vaughan-Graham & Cott, 2016).
Efficiency/selectivity of movement	The metabolic energy cost, and/or the spatial and temporal components of movement (Bernstein, 1967; Borich et al., 2015; McCrea et al., 2002; Muratori et al., 2013).	The amount of energy expended in achieving the task goal (Lacour & Bourdin, 2015; Sparrow & Irizarry-Lopez, 1987).	Efficiency of movement to describe the qualitative aspects of movement, and the term selectivity to describe constraining the degrees of freedom, that is, optimizing postural control, to potentiate a typical movement strategy (Vaughan-Graham & Cott, 2016). The terms *efficiency* and *selectivity of movement* are used synonymously (Vaughan-Graham et al., 2017).

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Table 1 ***(continued)***

Movement Concept	Definition	Neuroscientific Perspective	Bobath Clinical Perspective
BOS	The mechanical aspects of the BOS.	The contact area, boundaries, and texture of the BOS (Anderson et al., 2016).	Also includes the sensory perceptual aspects of the BOS, the interactive relationship between the body segment and the BOS with respect to gravity, the task, and the environment (Vaughan-Graham & Cott, 2016).
Body configuration—alignment	Orientation of the multijoint kinetic chain with respect to gravity and BOS.	COM, which is a virtual point at the center of total body mass (which is dependent upon body segment alignment), and/or the COG, which is the vertical projection of the COM (Shumway-Cook & Woollacott, 2012).	The active alignment of one body segment with another, and the BOS, with respect to gravity, task selection, and the environment (Vaughan-Graham & Cott, 2016). The consideration of sensory information arising from alignment created by selective muscle activity and orientation of the body with respect to BOS and gravity, and thus, the role of body schema (Vaughan-Graham & Cott, 2016).

Note. EP = equilibrium point; BOS = base of support; COM = center of mass; COG = center of gravity.

Murnaghan, & Inglis, 2010; Powell & Williams, 2015; Shumway-Cook & Woollacott, 2012, p. 162). Based on this understanding of postural control and postural instability, the following aspects of motor behavior are considered integral to postural control research (Shumway-Cook & Woollacott, 2012, p. 162): (a) COM, a virtual point at the center of the total body mass, dependent upon body segment alignment (Wu & MacLeod, 2001); (b) center of gravity, the vertical projection of the COM; (c) BOS, the area of the body in contact with the support surface (Scariot et al., 2016; Voudouris, Radhakrishnan, Hatzitaki, & Brenner, 2013); and (d) center of pressure (COP), the vector sum of all of the ground-reaction forces under the foot (Alonso et al., 2015; Carpenter et al., 2010).

The assumption of most theories is that the CNS aims to maintain the stability of the COM around a specific point that is being constantly challenged by perturbations caused by, for example, muscle activity, breathing, or even heart rate (Carpenter et al., 2010). Therefore, the variation in COP is considered to be part of our feedback control system responding to multisensory information and seeking to maintain the estimated position of the COM, and thus, postural sway is a result of delays or errors within our feedback system (Carpenter et al., 2010).

Based on this theoretical assumption, the variability in postural sway or postural instability, is traditionally measured using stabilometry commonly comprising of linear measures, such as COP excursions, resultant distance, or COP path length; sway accelerations; or time-to-contact of the COP to the boundary of the BOS (Haddad, Gagnon, Hasson, Van Emmerik, & Hamill, 2006; Mancini et al., 2012; Powell & Williams, 2015). However, linear measures only provide information about the amount of variability, for example, the magnitude or distance, and generally refer to measures of central tendency, such as the *SD* or variance, thereby providing information on the average or mean amount of variability (Harbourne & Stergiou, 2009). It has been identified in the literature that linear measures of variability only provide a limited view on the "amount" of variability of human movement (Harbourne & Stergiou, 2009; Mansfield, Danells, Inness, Mochizuki, & McIlroy, 2011).

From the perspective of the Bobath therapist, postural control is more complicated than minimizing postural sway. The reliance on linear measures to define and describe postural sway obscures the complexity inherent in human movement (Harbourne & Stergiou, 2009) and does not define or measure the constructs of movement important to rehabilitation therapists, such as the nature of the variability, the ease, rhythm, coordination, specificity, and repeatability (Vaughan-Graham & Cott, 2016). Alternatively, nonlinear measures of variability, such as Approximate Entropy, which provides a measure of the temporal variability from which the stability of the motor performance can be ascertained, have been shown to be more sensitive to changes in the characteristics of postural sway and are better suited to deal with the complexity of human movement (Harbourne & Stergiou, 2009; Powell & Williams, 2015).

Interestingly, an exploratory role of postural sway has been recently proposed in which postural sway is considered as part of a "perceptual-action strategy" (Carpenter et al., 2010). From this perspective, the CNS may be utilizing movement variability to ensure a continuous flow of multisensory information, enabling the person to gain critical sensory information with respect to their interaction with the environment. The exploratory hypothesis provides a unique perspective when considering sensory loss or degradation following CNS injury or disease, as potentially, an increase in postural sway may be due to the CNS seeking additional sensory information from alternative sources (Carpenter et al., 2010; Murnaghan, Carpenter, Chua, & Inglis, 2017; Murnaghan, Horslen, Inglis, & Carpenter, 2011; Murnaghan, Squair, Chua, Inglis, & Carpenter, 2014).

Therefore, if policy decisions are being made on the effectiveness of interventions for the recovery of postural control, its theoretical underpinning, as well as the applicability and sensitivity of the measures being utilized, requires critical attention.

Selectivity and Variability of Movement—The Degrees of Freedom Problem

Bernstein, a nineteenth-century Russian neurophysiologist, laid the groundwork for the concept of multiple systems working together to produce an optimal movement strategy, providing a framework for the variability and adaptability of context-based motor behavior (Bernstein, 1967; Latash et al., 2010; Muratori, Lamberg, Quinn, & Duff, 2013). There is currently no consensus on a single motor control theory, with dynamic systems theory (Bernstein, 1967; Latash et al., 2010; Muratori et al., 2013), equilibrium-point theory (Feldman, Goussev, Sangole, & Levin, 2007), and the computational approach (Guigon, Baraduc, & Desmurget, 2008) providing differing and, in some instances, overlapping perspectives on motor control in which distributed control of the nervous system and recognition of the interaction of the individual, task, and environment are considered (Cano-de-la-Cuerda et al., 2015; Clark, Ting, Zajac, Neptune, & Kautz, 2010; Feldman & Levin, 2009; Muratori et al., 2013; Sainburg, 2015; Schaal, Mohajerian, & Ijspeert, 2007; Shumway-Cook & Woollacott, 2016). Interestingly, despite controversy among differing motor control theories, it is generally accepted that sensory information has a significant role in motor control (Levin & Panturin, 2011). Bobath clinical practice is based on the understanding that sensation, action, perception, cognition, and emotion are interlinked and interactive (Vaughan-Graham & Cott, 2016) and is, therefore, congruent with a dynamic-systems-based approach to motor control (Levin & Panturin, 2011; VGraham, Eustace, Brock, Swain, & Irwin-Carruthers, 2009).

Bernstein coined the term *degrees of freedom*, recognizing that movement variability was dependent upon the human body's numerous options for movement patterns, also known as the *principle of abundance* (Gelfand & Latash, 1998; Latash et al., 2010), and that efficient voluntary movement depended on the ability of the "systems" to appropriately minimize the degrees of freedom (Muratori et al., 2013). Bernstein discussed this concept in terms of controlling motor redundancy (Bernstein, 1967; Latash et al., 2010; Muratori et al., 2013), which we will discuss from the perspective of variability and selectivity of movement.

Variability of Movement

Human movement is complex and variable, with many more options available for a given task than is actually needed, due to the redundancy inherent within the CNS (Harbourne & Stergiou, 2009; Latash et al., 2010). Functional muscle coordination patterns, also referred to as muscle synergies (this is in contrast to the typical clinical use of the term *synergies* to describe the pathological coactivation of muscles poststroke such that the action is fixed and invariable), are suggested to be a principle of neural control, reducing the need for independent muscle control, but are flexibly combined, enabling complex human movement (Levin et al., 2016; Safavynia, Torres-Oviedo, & Ting, 2011). Muscle synergies can consist of any number of muscles, individual muscles can belong to any number of synergies, and multiple synergies can be simultaneously recruited (Safavynia et al., 2011). Muscle synergies have been proposed for postural responses (Torres-Oviedo & Ting, 2007), locomotion (Cappellini, Ivanenko, Poppele, & Lacquaniti, 2006; Ivanenko, Poppele, & Lacquaniti, 2004), and upper limb function (Levin et al., 2016), as well as functional coordination between posture and movement dependent upon the task and environment (Haddad, Ryu, Seaman, & Ponto, 2010; Ting & McKay, 2007). Likewise, the complexity and flexibility inherent within muscle synergies are reflective of the highly complex behavioral repertoire developed for skilled motor performance currently obscured by linear measures (Amado, Palmer, Hamill, & van Emmerik, 2016; Harbourne & Stergiou, 2009). The evidence suggests that in persons poststroke, the number of available muscle synergies and complexity of coordination patterns are reduced, resulting in a decreased variability of movement (Clark et al., 2010; Levin et al., 2016).

In the current neuroscience literature, motor recovery at the kinematic level is defined as "the reappearance of typical movement patterns and sequences used before stroke for performance of a task," while compensation is defined as "the use of additional or alternate kinematic patterns during task performance" (Levin et al., 2009, 2016; p.635). In an e-Delphi study, Bobath therapists differentiated between "atypical" movement describing motor behavior of the more affected body segments/limbs and "compensatory" movement describing motor behavior of the less affected body segments or limbs (Vaughan-Graham & Cott, 2016). From the clinical perspective, this differentiation is important to enable accurate descriptions of movement problems and, thus, the development of movement diagnoses in order for interventions to demonstrate their effectiveness (Guccione, 1991). Likewise, an assessment of isolated muscle strength and tone bears little resemblance to how these muscles are recruited for function (Safavynia et al., 2011). For example, consider the person with a neurological condition, who is only able to stand from sitting when the surface is a specific height; this significantly limits this person's participation, due to his or her inability to vary movement strategies with respect to a changing environment. From the perspective of the Bobath therapist, the use of a grab bar and the less affected upper limb to stand is considered compensation, while the movement strategies of the more affected body segments or limbs would be considered from the range of atypical to typical movement.

Note that, in both scenarios above, the movement of sit-to-stand would be described as *completed* or *independent* and scored accordingly on an outcome measure. However, in neurorehabilitation, the therapist is interested in how the person completes the activity, not just the task completion or "amount" of variability. Muscle synergy analysis has the potential to provide more comprehensive information on the evolving nature of muscle patterns in response to individually tailored interventions (Kogami et al., 2018; Safavynia et al., 2011).

Selectivity/Efficiency of Movement

The concept of "efficient" motor behavior implies an appreciation of the qualitative aspects of movement, that is, the spatial and temporal components of movement (Bernstein, 1967; Borich, Brodie, Gray, Ionta, & Boyd, 2015; McCrea, Eng, & Hodgson, 2002; Muratori et al., 2013). In contrast, movement can also be discussed in terms of metabolic energy cost, or the amount of energy expended in achieving the task goal (Lacour & Bourdin, 2015; Sparrow & Irizarry-Lopez, 1987). Not surprisingly, these two aspects of "efficiency" are interrelated, as the metabolic rate increases with any change to the human musculoskeletal system, or its movement coordination (Collins, Wiggin, & Sawicki, 2015). Although the literature suggests that humans adjust step length and arm movement in order to keep energy expenditure low while walking (Collins et al., 2015; Peiffer, Abbiss, Sultana, Bernard, & Brisswalter, 2016), minimizing the energy cost for reaching movements while sitting was not a dominant factor of the motor behavior (Kistemaker, Wong, & Gribble, 2010). In terms of neurorehabilitation, it is conceivable that there may be an initial higher metabolic cost as a person regains motor performance following a neurological lesion, which gradually decreases as the person's movement becomes more typical. For example, on symmetrical sit to stand use of both the more and less affected lower limbs may have a higher metabolic energy cost than using only the less affected lower limb. Similarly, when relearning to use the more affected upper limb the metabolic energy cost is likely greater than when using the less affected upper limb. Therefore, it is important to consider both the spatial and temporal aspects, as well as the metabolic energy cost of the movement, when discussing efficiency of movement, and what, if any, potential interaction there may be. However, measuring the spatial and temporal components of movement, as well as its metabolic energy cost, is not easily accessible in the clinical setting.

Bobath therapists use the term *efficiency of movement* to describe the qualitative aspects of movement and the term *selectivity* to describe constraining the degrees of freedom, that is, optimizing postural control, to potentiate a typical movement strategy (Vaughan-Graham & Cott, 2016). Thus, in Bobath clinical practice, the terms *efficiency* and *selectivity of movement* are used synonymously; for example, selective wrist extension requires the postural control of the shoulder girdle. Implicit to this conceptualization of movement by Bobath therapists is that the movement comprising postural control is also selective, not rigid or fixed (Vaughan-Graham et al., 2017). Therefore, the interpretation of terminology may be a contributing factor in the Bobath research–practice gap.

One of the mechanisms that the nervous system uses to constrain the degrees of freedom to optimize movement strategies is feedforward postural adjustments. Early postural adjustments and anticipatory postural adjustments are feedforward control mechanisms that minimize the negative consequences of a predicted postural perturbation and for which there is a substantial body of literature (Krishnan, Aruin, & Latash, 2011; Massion, Alexandrov, & Frolov, 2004; Santos, Kanekar, & Aruin, 2010a, 2010b). In addition to early postural adjustments and anticipatory postural adjustments, there is a developing body of literature on anticipatory synergy adjustments. Anticipatory synergy adjustments are being explored within the Uncontrolled Manifold Framework (Latash et al., 2007;

Piscitelli, Falaki, Solnik, & Latash, 2017), which defines synergies as "a neural organization of a multi-element system that (1) organizes sharing of a task among a set of elemental variables; and, (2) ensures co-variation among elemental variables with the purpose to stabilize performance variables" (Latash et al., 2007, p. 279). Anticipatory synergy adjustments are also feedforward adjustments, but their function is to attenuate synergies that would interfere with the performance variable, thereby increasing compliance and facilitating effectiveness of the action (Klous, Mikulic, & Latash, 2011; Piscitelli et al., 2017; Ting & McKay, 2007).

Feedforward postural adjustments are experience dependent and are influenced by initial postural alignment (Tomita et al., 2011), training (Mouchnino, Aurenty, Massion, & Pedotti, 1992), velocity of the focal movement (Bouisset, Richardson, & Zattara, 2000), reaction time (Slijper, Latash, Rao, & Aruin, 2002), and prediction (Aruin, 2003). Compensatory postural adjustments, or feedback mechanisms, deal with the actual perturbations and are commonly referred to as *fixed support strategies*, such as ankle and hip strategies, and change in support strategies, such as stepping reactions and protective upper-limb strategies (Santos et al., 2010a, 2010b; Shumway-Cook & Woollacott, 2012). Approximately six muscle synergies have been identified for human postural responses (Torres-Oviedo & Ting, 2007); however, variability in postural control is a necessary function of motor behavior to accommodate for the internal and external perturbations constantly experienced by the body (Haddad et al., 2010; Önell, 2000).

Likewise, typical limb movement comprises joint motion at several joints, representing multiple degrees of freedom mediated by many muscles. However, persons with no neurological condition demonstrate similar movement patterns during reaching (D'Avella, Portone, Fernandez, & Lacquaniti, 2006; McCrea et al., 2002) and locomotion (Lacquaniti, Ivanenko, & Zago, 2012). During reach, hand paths are straight or slightly curved, requiring coordination of shoulder and elbow rotations and demonstrating kinematic and kinetic regularity while simultaneously demonstrating considerable variability and complexity in the underlying muscle patterns (D'Avella & Lacquaniti, 2013; McCrea et al., 2002). However, for persons poststroke, reaching is described as slower, segmented, and less stereotypical, and those with moderate or severe stroke demonstrate accompanying trunk compensations (Levin et al., 2016; Michaelsen, Dannenbaum, & Levin, 2006; Pain, Baker, Richardson, & Agur, 2015). Similarly, for adult human locomotion, the trajectories of the COM and feet are highly consistent, while the EMG activity of the trunk and lower-limb muscles consistently represents a combination of four or five basic patterns (Lacquaniti et al., 2012), whereas for persons poststroke, the more affected lower limb demonstrated only two or three motor modules, and those with fewer modules demonstrated a greater degree of muscle coactivation, as well as poorer walking performance (Clark et al., 2010). The evidence suggests a reduction in muscle synergies is correlated with walking speed and balance measures in standing (Chvatal & Ting, 2013). This suggests that a common set of muscle synergies may form a motor repertoire shared by locomotion and reactive balance strategies (Chvatal & Ting, 2013). Therefore, muscle synergy analysis, which may be generalizable across different tasks, has the potential to provide valuable information with respect to muscle coordination, an aspect of motor performance, illustrating the nature of variability rather than the amount of variability (Chvatal & Ting, 2013). This provides a theoretical basis to the clinical assumption within the Bobath concept that postural control and selective movement are viewed as inseparable and interdependent and that motor performance in one task influences motor performance in a different task (Vaughan-Graham & Cott, 2016).

Sensory Information

Base of support and COM (dependent upon body configuration) are two aspects of postural control commonly discussed in research (Scariot et al., 2016; Voudouris et al., 2013; Wu & MacLeod, 2001). Fundamental to Bobath therapists' conceptualization of postural control is the individual's ability to receive, integrate, and respond appropriately to sensory information, which is reflective of the individual's body schema (Vaughan-Graham & Cott, 2016). In addition to considering somatosensory, visual, and vestibular information relative to the BOS and COM, or in other words, the organization of stability, mobility, and orientation of the multijoint kinetic chain, the Bobath therapist also considers the role of cognition, perception, and emotion in the generation of appropriate postural control with respect to the task and the environment (Vaughan-Graham & Cott, 2016).

From the clinical perspective of the Bobath therapist, the role of sensory information is intrinsically related to postural control and will be discussed with respect to BOS and COM/body configuration.

Base of Support

Base of support in the current literature focuses on the mechanical aspects of the BOS, contact area, boundaries, and texture of the BOS (Anderson, Deluigi, Belli, Tentoni, & Gaetz, 2016), whereas the Bobath therapist considers not only these aspects of the BOS but also the sensory perceptual aspects of the BOS, the interactive relationship between the body segment and the BOS with respect to gravity, the task, and the environment (Vaughan-Graham & Cott, 2016). The evidence suggests that cutaneous plantar and ankle proprioceptive information contribute to anticipatory postural adjustments and postural control (Kavounoudias, Roll, & Roll, 2001; Lin & Yang, 2011; Parsons, Mansfield, Inness, & Patterson, 2016). In addition, multisensory integration occurring through distributed cerebral networks (cortical and subcortical) underpins human movement perception (Kavounoudias et al., 2008).

With respect to foot contact with a support surface, the shape, depth, and alignment of the foot provide valuable information about how the body segment interacts with the supporting surface, just as footprints or paw prints were used by primitive man to make deductions about the activities of animals or humans (Sutherland, 2005). Thus, the reliance on COP measurement in postural control research, which provides information on the center of distribution of the total force applied to the supporting surface (Shumway-Cook & Woollacott, 2012), does not take into consideration the interaction of the whole body segment in contact with the supporting surface and the level of sensory integration afforded through the body segment. Likewise, *ground reaction force* is defined as "the force exerted by the ground in response to the forces a body exerts on it" (Kent, 2006). However, the use of ground reaction force when investigating postural control assumes that the person is exerting a typical amount of force and that the person can vary the forces he or she is exerting, depending upon the task and context. Unfortunately, this is often not the case for persons with neurological conditions who have altered muscle tone and may be generating either too much or too little force. Consider, for example, a person poststroke in standing whose left side of the body is more affected, and whose contact between the left foot and the floor is limited to the lateral border and forefoot, whose toes are flexed, whose heel is not in contact, and who is generating an involuntary but significant constant force through the forefoot. From a clinical perspective, this person's movement problem may be described as *unable to achieve an interactive relationship of the left foot with the support surface* or *unable to attain or maintain left single-leg stance*; he or she would likely have difficulty walking, in particular on sand or soft terrain. However, from a scientific perspective, the inappropriate force generated through the left foot would produce a COP measurement that may be interpreted as weight bearing and may be higher than the right foot COP measurement, suggesting that the left foot and lower limb are contributing more to the activity of stand. Herein lies a potential disconnect between the clinical and scientific perspectives. Therefore, to investigate movement problems such as postural control of persons with neurological conditions, consideration of how the whole body segment interacts with the supporting surface from a sensory–perceptual perspective is required.

Body Configuration—Alignment

Bobath therapists place significance on the influence of alignment and selective movement of body segments, as well as the stability, mobility, and orientation of the multijoint kinetic chain with respect to postural control (Vaughan-Graham & Cott, 2016). Critical to Bobath therapists' conception of the maintenance and restoration of postural control is the consideration of sensory information arising from alignment created by selective muscle activity and orientation of the body with respect to BOS and gravity and, thus, the role of body schema (Vaughan-Graham & Cott, 2016).

The evidence suggests that sensory information (somatosensation, vestibular, vision, etc.) modifies somatosensory maps (Borich et al., 2015) and is one mechanism attributed to influencing the planning, execution, and control of motor behavior (Borich et al., 2015; Caronni & Cavallari, 2009; Kouzaki & Masani, 2008; Tomita et al., 2011). This is particularly important when considering movement performance and recovery following a lesion of the CNS, as the evidence suggests that the abnormal processing of somatosensory information contributes to atypical motor behavior (Borich et al., 2015); in other words, practicing a movement badly does not make it better. Bobath therapists consider the role of sensory information in motor control and perception a key aspect of clinical practice (Vaughan-Graham & Cott, 2016). Bobath therapists are, therefore, not only interested in the COM, which is a virtual point at the center of the total body mass (which is dependent upon body segment alignment) and/or the center of gravity, which is the vertical projection of the COM (Shumway-Cook & Woollacott, 2012), but also the active alignment of one body segment with another, and the BOS with respect to gravity, task selection, and environment

(Vaughan-Graham & Cott, 2016). The manipulation of sensory information, known as *facilitation* within the Bobath concept, is considered a skilled aspect of clinical practice and includes the use of therapeutic handling (handling developed through clinical practice), environmental setup, task selection, and the use of verbal cues to potentiate a typical movement experience (Vaughan-Graham & Cott, 2016). Thus, the Bobath clinician is particularly interested in a person's sensory experience of movement and, therefore, seeks to orchestrate the treatment scenario by simultaneously manipulating multiple aspects of sensory information to optimize the person's movement experience on a moment by moment basis.

Consider, for example, the person with a neurological condition whose single-leg stance on the more affected leg is characterized by knee hyperextension, hip flexion, adduction and internal rotation, and trunk-side flexion to the more affected side. This person may be able to maintain his or her COM within the BOS during single-leg stance on the more affected side, but the alignment suggests that the person is unable to selectively adapt motor activity and alignment of body segments with respect to the BOS and gravity (Vaughan-Graham & Cott, 2016; Wu & MacLeod, 2001). In addition, the sensory information arising from the alignment and muscle synergies will not be reflective of typical motor behavior, and therefore, atypical motor behavior will be reinforced (Borich et al., 2015; Malmström, Olsson, Baldetorp, & Fransson, 2015).

Thus, the consideration of the alignment of body segments or limbs and related muscle synergies may provide useful information with respect to identifying typical and atypical motor behavior, providing a method to investigate interventions, such as the Bobath concept, which aims to improve motor performance.

Implications for Practice and Research

Researchers and clinicians recognize the limitations of current measures of postural control, and there is a growing recognition for the need to include measures addressing the nature of the variability and not just the amount of variability. Just as important is the need to understand from the client's perspective what aspects of motor performance are important.

Explicating how therapists conceptualize movement is critical to developing an understanding of the commonalities and differences between the clinical interpretation of a movement problem and how that movement problem is researched. Developing a shared terminology to define movement characteristics is essential, as well as the development of reliable, valid, and sensitive measures such that the complexity of human movement can be more fully appreciated. Similarly, therapists' conceptualization of movement lays the groundwork for how therapists group client characteristics, other than a medical diagnosis, potentiating the development of a "clinical movement taxonomy" enabling clients to be appropriately grouped in intervention effectiveness studies.

This paper reflects the perspective of the expert Bobath therapist with respect to neurorehabilitation. Further research is required to understand the perspectives of novice Bobath therapists, as well as novice and expert non-Bobath therapists.

A constructive and respectful dialogue requires nurturing between clinicians, researchers, and clients such that physical therapy research can elucidate the critical aspects of movement performance from multiple perspectives which, in turn, will inform person-centered clinical practice while also enhancing the clinical relevance of effectiveness studies.

Conclusions

Human movement control is of significant interest to neurorehabilitation clinicians and researchers alike, as well as those persons attempting to recover movement following a CNS lesion. From a neurorehabilitation perspective, there is limited research on how therapists conceptualize movement, and from a neuroscience perspective, the debate continues with respect to gaining consensus on a single motor control theory. The clinical interpretation of movement variability and selectivity with respect to postural control and the role of sensory information intersects with the neuroscientific understanding of feedforward and feedback control and the role of body schema in posture and movement. This paper considers movement from these two different vantage points, neurorehabilitation and neuroscience, and contrasts the terminology and approaches of these two perspectives, providing an alternative perspective on the interpretation of postural control in clinical research. We explicate movement concepts such as postural control, postural sway, alignment, BOS, and the role of sensory information with the goal of facilitating interdisciplinary communication inclusive of persons with neurological conditions, their families, and caregivers such that science can inform practice and practice can inform science.

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