Tools to Mine the Gold

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In his target article, Mark Latash takes a refreshing look at the notion of synergies, formed at the effector or elemental level according to task demands, and how these synergies reflect coordinated movement produced by the central nervous system. Equilibrium-point shifts produce stable movement by activating different combinations of agonist and antagonist muscles at several joints in patterns that lead to efficient progress of the end effector towards the desired position. This explanation of movement production allows the nervous system to take advantage of the system’s redundancy (at several levels) while permitting the expression of individual variations in movement production (i.e., different people can perform the same action in different ways), which is what we actually observe in real life.

Flexible synergies describing movement is a departure from the more rigid, biomechanically-based explanation in which movements are thought to be ‘optimized’ and variability is often seen as an undesirable consequence of an inefficient neuromusculoskeletal system. Indeed, Latash’s notion of synergies embraces the system’s natural variability and provides an explanation by which the system may exploit that variability to accomplish goal-directed movement. This, more ecological view of movement production and the structure of variability may provide a means by which to evaluate disordered motor control in people with neuromuscular problems.

As Latash correctly points out, the term “synergy” conveys a different meaning in neurological rehabilitation compared to the motor control literature. In the rehabilitation literature, “synergy” has a negative connotation, as in “abnormal synergy”, and is defined as the simultaneous recruitment of multiple muscles and joints that result in stereotypical movement patterns (Brunnstrom 1970; Bobath 1990). This is in contrast to how the same term is used in the motor control literature, in which it describes coordination between joints to produce natural movement. Aside from the similarity of the terminology, the control of movement production in each of these cases is essentially different. Abnormal synergies as well as other signs of upper motoneuron lesions, such as spasticity, are typically observed in patients with unilateral brain damage from stroke, cerebral palsy or head trauma resulting in hemiplegia. Abnormal synergies are thought to be the expression of excessive reflex activity because of the loss of descending modulatory control due to the brain damage (Burke 1988). On the other hand, it is possible for healthy subjects to imitate postures and movements of neurologically impaired patients,
implying that abnormal synergies represent one extreme of the normal range of possible synergies, as confirmed in several studies (see below).

Not only do some individuals with neurological disorders use abnormal and limited movement synergies but they also have restrictions in the specification of referent configurations, at least for upper limb movements. Individuals with post-stroke hemiparesis have deficits in the specification and regulation of stretch reflex threshold angles (or $\lambda$s) in elbow flexors and extensors that can account for different motor impairments such as spasticity, weakness and abnormal muscle activation patterns in specific joint ranges delimited by these threshold angles (Levin and Dimov 1997; Levin et al. 2000; Musampa et al. 2007). These studies showed that the flexor and extensor muscle activation thresholds determined the angular limits within which normal muscle activation patterns could be produced during voluntary attempts to flex or extend the elbow. Attempts to make movements beyond these limits resulted in abnormal patterns of muscle coactivation and problems in movement production. For the double-joint arm system, Mihaltchev et al. (2005) found similar limitations in the specification and regulation of $\lambda$s of muscles of adjacent joints which was interpreted as a deficit in the specification of the referent configuration of the arm. Deficits in the production of referent configurations can contribute to incapacities in the production of coordinated multi-joint movement and be manifested as restricted movement synergies.

The occurrence of abnormal or pathological movement synergies in neurological patients is most marked in those with severe pathology. Brunnstrom (1970) described five stages of recovery from stroke in which severe pathology is characterized by the presence of hyperactive segmental reflexes, spasticity and, when present, movement of the limbs only within the defined flexor and/or extensor synergistic patterns. Recovery from stroke is characterized by the ability of patients to make fractionated movements and movements out of the pathological synergies. Thus, recovery is characterized by a decrease in synergistic coupling between joints. In addition to pathological synergies, studies in patients in various stages of recovery from stroke have identified a wide range of impairments, defined according to the International Classification of Functioning (WHO 2002), as occurring at the Body Structure level (i.e., muscle, nerve, body segment, etc). At this level, studies have mainly focused on the characterization of individual motor impairments in movement precision, peak velocities, or joint ranges for example and then trying to find links between impairments and functional deficits at the Activity level (e.g., walking, picking up an object, etc.). Such characterization can also include measures of variability of any or all of these motor elements with the common observation that variability is too high for most variables measured (e.g., Micera et al. 2005; Petrarca et al. 2009). What we are missing, as Latash suggests, is a better understanding of whether the damaged CNS is able to use synergies adaptably and how this ability evolves during recovery.

If one considers that movements are produced by synergistic action at multiple joints, as elegantly described by Latash, it is not surprising that links between impairments and functions in neurological patients have been very difficult to find. Information about how much variability a person has in elbow extension during a reaching task for example, may not tell us much about the level of functional ability of the whole arm. Nor would it lend much to our understanding of how to remediate the movement deficit in that person. A common approach has been to
teach the patient to produce “more optimal” joint paths or use “more optimal” patterns of muscle activation.

Aside from the problem of defining such optimal movement paths or muscle activation patterns, it would be difficult for therapists to ask a patient to attend to the movements of multiple joints while trying to accomplish a motor task. Indeed, a more natural way of learning movement is to allow the system to find its own solution to the task while the therapist attempts to elicit typical movement patterns through controlled sensorimotor experiences or delivery of feedback about key movement elements (Bobath 1990; Cirstea and Levin 2007; Davies 2000; Panturin 2002). Neurological clinicians also use problem-solving approaches involving active learning processes in environments that enable the individual to learn to perform self-initiated actions within naturally occurring constraints (Thelen and Smith 1994; Panturin 2002; Vaughan-Graham et al 2009). An important concept in this problem-solving approach is that it permits the system to find the best set of motor solutions for a given task. Using the concept of synergies, finding more motor solutions may reflect the ability of the system to expand its limited number of synergies to a wider set, typical of non-disabled individuals. Latash has provided a tool by which such motor solutions can be quantified and progress can be evaluated via the UCM hypothesis. As Latash suggests, an evaluation of reaching or walking patterns in recovering patients using the UCM approach should be an excellent means of evaluating the efficacy of neurological rehabilitation.

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References


