Muscle synergies: input or output variables for neural control?

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The exciting study by Steele et al.[1] is the first to use non-negative matrix factorization to quantify electromyography (EMG) muscle synergies during gait in children with cerebral palsy (CP). The identification of fewer synergies during gait in adults with stroke and the relationship of lower synergy number to greater functional limitations are of great interest in neurorehabilitation. So I commend these authors for their work showing similar findings in CP and for using such a rich database in this novel way. This paper will hopefully engage more of the CP clinical and research community in the fascinating debate about whether identified muscle synergies are an integral *input* variable for neural control of movement; or conversely, a measured *output* from a different higher control strategy. The major strengths here were the large sample size and use of non-negative matrix factorization which facilitates comparisons across studies. While this is an excellent first step, conclusions are limited by the use of only five muscles on one side and normalization to individual maxima which can distort relative muscle weightings due to variable weakness in CP. These factors among others substantially affect the number and structure of identified synergies, producing inconsistent results across studies.

The interesting, but hardly revolutionary findings here and in stroke demonstrate that complexity of neuromotor control is reduced after an injury to sensorimotor pathways and linearly related to the degree of impairment. However, if EMG synergy analyses yielded fundamental insights into how the central nervous system (CNS) controls movement and how an injury interferes with that control, then this line of research would truly be groundbreaking. But therein lies the controversy. Synergies were first discussed in relation to motor control by Sherrington and the concept was expanded by Bernstein to represent one level of hierarchical control, with more recent developments related to various computational methods that group EMG in different tasks. Synergy research has stimulated many intriguing discussions on and insights into motor control, such as the proposition by Lacquaniti et al.[2] that during gait synergies produce pulsatile muscle activations that set oscillating neuronal networks into motion.

General agreement exists that synergies or 'coherent activations, in space or time, of a group of muscles'[3] can be identified and show similarities across related tasks, but there is no consensus on where along the continuum of neural control these fit in. One prevailing view is that synergies represent a key CNS control strategy to effectively reduce or simplify the multiple redundant biomechanical degrees of freedom. However, even though prescribed patterns of muscle activity can drive a robot or neuroprosthesis, this does not imply that the CNS operates similarly. Many have alternate viewpoints, e.g. the uncontrolled manifold hypothesis which contends that the CNS harnesses, rather than eliminates, multiple degrees of freedom to increase flexibility and task precision.[4] Application of this concept to gait demonstrated that participants utilized variable combinations of leading and trailing leg-forces that produced a consistent vertical net-force and hence consistent treadmill walking speed.[5] Task elements may fluctuate due to natural variations or perturbations, which can either aid or impair goal achievement (termed 'good' vs 'bad' variability respectively). A recent study demonstrated that an optimization process to identify a 'good enough' solution to a motor goal yielded groupings of muscles nearly identical to the identified synergies, suggesting these are a consequence, not the source, of control.[6] Others have demonstrated extensive errors in task performance that would ensue if synergies were the primary neural control.[7]

Finally, the importance of synergies for rehabilitation lies in their ability to provide insights into abnormal motor control and inform development of novel therapies; I would contend we are not there yet. The sweeping conclusion here that control in CP is similar to that in stroke and in infants (and other animals) is too preliminary, but is still a compelling hypothesis that warrants continued exploration by these and other researchers in the field.

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