ORIGINAL RESEARCH ARTICLE

Front. Comput. Neurosci., 21 March 2013 | doi: 10.3389/fncom.2013.00019

Are muscle synergies useful for neural control?

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The observation that the activity of multiple muscles can be well approximated by a few linear synergies is viewed by some as a sign that such low-dimensional modules constitute a key component of the neural control system. Here, we argue that the usefulness of muscle synergies as a control principle should be evaluated in terms of errors produced not only in muscle space, but also in task space. We used data from a force-aiming task in two dimensions at the wrist, using an electromyograms (EMG)-driven virtual biomechanics technique that overcomes typical errors in predicting force from recorded EMG, to illustrate through simulation how synergy decomposition inevitably introduces substantial task space errors. Then, we computed the optimal pattern of muscle activation that minimizes summed-squared muscle activities, and demonstrated that synergy decomposition produced similar results on real and simulated data. We further assessed the influence of synergy decomposition on aiming errors (AEs) in a more redundant system, using the optimal muscle pattern computed for the elbow-joint complex (i.e., 13 muscles acting in two dimensions). Because EMG records are typically not available from all contributing muscles, we also explored reconstructions from incomplete sets of muscles. The redundancy of a given set of muscles had opposite effects on the goodness of muscle reconstruction and on task achievement; higher redundancy is associated with better EMG approximation (lower residuals), but with higher AEs. Finally, we showed that the number of synergies required to approximate the optimal muscle pattern for an arbitrary biomechanical system increases with task-space dimensionality, which indicates that the capacity of synergy decomposition to explain behavior depends critically on the scope of the original database. These results have implications regarding the viability of muscle synergy as a putative neural control mechanism, and also as a control algorithm to restore movements.

Keywords: aiming movement, muscle coordination, motor control, biomechanics, optimal control

Citation: de Rugy A, Loeb GE and Carroll TJ (2013) Are muscle synergies useful for neural control? *Front. Comput. Neurosci.* 7:19. doi: 10.3389/fncom.2013.00019

Received: 12 December 2012; **Accepted:** 05 March 2013;
Published online: 21 March 2013.

Edited by: Andrea D'Avella, IRCCS Fondazione Santa Lucia, Italy

Reviewed by: Lena H. Ting, Emory University and Georgia Institute of Technology, USA
Kevin Englehart, University of New Brunswick, Canada

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