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Evidence for muscle synergies from virtual surgeries

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A fundamental challenge in neuroscience is understanding how the central nervous system (CNS) succeeds in controlling motor skills that require the coordination of many degrees-of-freedom. A long-standing hypothesis is that the CNS relies on muscle synergies, coordinated activations of groups of muscles, to simplify motor control. Evidence that the combinations of a small number of muscle synergies underlies the generation of muscle activation patterns has come from several studies performed in the last two decades with different species and experimental tasks. Muscle synergies, extracted from multi-muscle EMG recordings using multidimensional decomposition algorithms such as non-negative matrix factorization, capture regularities in the spatial, temporal, and spatiotemporal organization of the muscle patterns. However, whether muscle synergies are only a parsimonious description of the regularities of the motor commands rather than a key feature of their neural organization is still debated. Stronger evidence for a neural organization of muscle synergies would come from testing a prediction of how muscle synergies affect the difficulty in learning or adapting motor skills. An experiment with human subjects using myoelectric control to move a mass in a virtual environment has tested the prediction that it must be harder to adapt to perturbations that require new or modified synergies than to adapt to perturbations that can be compensated by recombining existing synergies. Novel perturbations were generated by altering the mapping between recorded EMG and simulated force applied on the mass, as in a complex surgical rearrangement of the tendons. After identifying muscle synergies, two types of virtual surgeries were performed. After compatible virtual surgeries, a full range of movements could still be achieved recombining the synergies, whereas after incompatible virtual surgeries new or modified synergies were required. In contrast, both types of surgeries could be compensated with similar changes in the recruitment of individual muscles. As predicted, adaptation after compatible surgeries was faster than after incompatible ones. These results suggest that muscle synergies are key elements organized by the CNS for controlling our complex musculoskeletal system by directly mapping task goals into a small number of synergy combination parameters.

Keywords

Motor coordination, motor adaptation, myoelectric control, dimensionality reduction, virtual reality