MUSCLE SYNERGIES FOR HUMAN POSTURAL CONTROL ARE ROBUSTLY USED ACROSS MULTIPLE POSTURAL CONFIGURATIONS

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INTRODUCTION

Recent studies provide evidence that the nervous system does not control muscles independently during complex, natural behaviors such as standing postural control. A few neural commands activating fixed patterns of muscle activation, or muscle synergies, account for a range of postural responses in cats (Ting and Macpherson 2005; Torres-Oviedo et al. 2006).

We hypothesize that muscle synergies observed in one postural condition represent *preferred* patterns of muscle activation used by each individual's nervous system. Therefore, we predict that the same set of muscle synergies is used when the biomechanical context of the postural task changes. The implications of such a finding would be that the nervous system chooses to use a consistent set of muscle synergy patterns over a range of postures, even if they may not be optimal in a purely biomechanical sense.

METHODS

To test our hypothesis, we randomly interspersed different balance perturbation directions and biomechanical contexts. Subjects stood at 6 biomechanically distinct stance conditions – narrow, normal, wide, very wide, one-leg and crouched stance – yielding a total of 72 different perturbation direction and stance combinations. Nine healthy subjects (5 females and 4 males, aged 18-31) stood on a platform that translated in 12 directions evenly distributed in the horizontal plane. We analyzed the spatial, temporal, and inter-trial variability in 16 leg and lower back muscles of each subject's right side before and during automatic postural responses, characterized by three consecutive 75-ms time bins starting 100 ms after perturbation onset.

Nonnegative matrix factorization was used to identify muscle synergies, W_i, in a single postural task. These muscle synergies were subsequently used to reproduce postural responses in all other stance conditions by modulating the synergy activations, C_i. Task-specific muscle synergies, W^{test} were extracted from the remaining variability in the test conditions that were not well-reproduced by the muscle synergies from the control condition.

RESULTS AND DISCUSSION

In all subjects, 4 to 6 muscle synergies were required to reproduce the postural responses in the control condition (Figure 1A, normal stance).

This same set of muscle synergies accounted for the modulation of muscle activity when the distance between the feet was varied. Narrow stances evoked high levels of muscle activity, while wide stances evoke low levels of muscle activity. These variations were characterized (>92%) by changing the activation levels C_i of each muscle synergy (Figure 1B).

In one-legged stance, an additional, *task-specific* muscle synergy was required to reproduce the variability in muscle activity (Figure 1C). This task-specific muscle

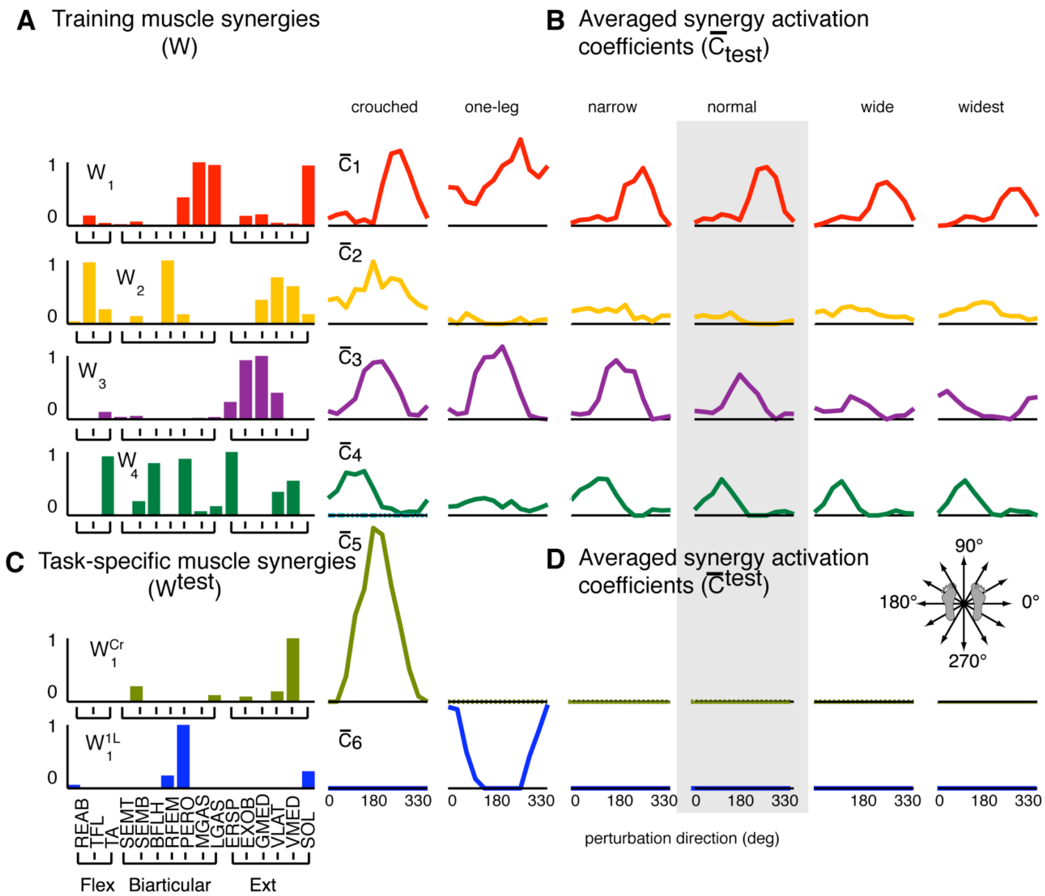

Figure 1 Muscle synergies (W) and activation coefficients (C) for all stance conditions and perturbation directions in one subject.

synergy activated ankle evertors which provide the ankle stability required for maintaining single-leg balance.

In the crouched condition, an additional task-specific muscle synergy was also necessary. However, this synergy activated only one single quadriceps muscle (Figure 1C). The same muscle is also activated by one of the *general* muscle synergies over the same range of perturbations (Figure 1A, W_2). This may reflect a nonlinear activation of muscles within a muscle synergy, which might occur via modified afferent inputs associated with large changes in joint angles.

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CONCLUSIONS

In face of different environmental contexts, the nervous system simplifies muscle coordination by modulating the contribution of a *general* set of muscle synergies. When an additional biomechanical function is necessary, such as the need to generate medially-directed forces in one-legged stance, task-specific muscle synergies may be recruited.

REFERENCES

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