MUSCLE SYNERGIES DURING THE INDUCED FORWARD SHIFTS OF THE CENTER OF PRESSURE FROM A NARROW SUPPORT

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INTRODUCTION

Upright human posture is inherently unstable due to the difficulty in maintaining the high center of gravity on the relatively small base of support provided by the feet. Voluntary movements such as forward body sway and interactions with external objects challenge the whole-body's equilibrium and threaten vertical postural balance. Obviously, when voluntary movement are made while standing, the center of pressure (COP) cannot be shifted beyond the available dimensions of the support area. In particular, when standing on boards with a decreased dimension of the support area in the anterior-posterior (AP) direction or in the medio-lateral (ML) direction ("unstable boards"), the activity of postural muscles has to be adjusted to constrain COP shifts and maintain the whole-body balance.

We used the framework of the uncontrolled manifold (UCM) hypothesis to analyze multi-muscle synergies involved in the induced forward shifts of the center of pressure on a narrow support. We hypothesized that leg and trunk muscles are organized into stable groups (muscle modes, M-modes) related to shifts of COP with a decreased dimension of the support area in the AP direction. Another hypothesis was that multi-muscle synergies stabilize a COP location in the AP direction in the steady-state phase of the tasks and that during the shift the synergies would weaken.

METHODS

Eight healthy subjects participated in the experiment. A force platform recorded the reactive forces and moments. Disposable self-adhesive electrodes were used to record the surface EMG of the following postural muscles from the right side of the body: lateral head of gastrocnemius, medial head of gastrocnemius, soleus, semi-tendinosus, biceps femoris, gluteus medius, erector spinae, tibialis anterior, vastus lateralis, rectus femoris, tensor fasciae latae, and rectus abdominis.

Six types of tasks were used. The first task required the subject to release the load (load release task, LR) suspended behind his/her body using the pulley system while standing on the force plate ("normal support" condition, LR_N). The second task required the subject to release the load suspended behind his/her body using the pulley system from the board fitted with the narrow beam in the AP direction ("AP narrow support" condition, LR_{NAR_AP}). And the third task required the subject to release the load suspended behind his/her body using the pulley system from the board fitted with the narrow beam in the ML direction ("ML narrow support" condition, LR_{NAR_ML}). These three tasks were used to explore EMG combinations responsible for COP shifts in AP direction under the different support conditions. The other three tasks required the subjects to push a load forward. The load was suspended via a pulley system in front

of the subject's extended arms about 5 cm away. The subject was asked to begin each trial by standing naturally and quietly, with the arms extending in front of the body. One of them required the subject to push load from quiet stance in "normal support" condition (LP_N). Another task required the subjects to push load forward in "AP narrow support" condition ($LP_{NAR\_AP.}$). Within the final task, the subjects were to push load in "ML narrow support" condition (LP_{NAR_ML}).

Variance in the M-mode space was partitioned into two components, one that did not affect the average value of COP shift (V_{UCM}) and the other that did (V_{ORT}). An index (ΔV) corresponding to the normalized difference between V_{UCM} and V_{ORT} was computed.

RESULTS AND DISCUSSION

M-modes were defined using principal component analysis applied to indices of changes in the EMG activity prior to releasing variable loads that were held by the subject using a pulley system with different decreased dimension of the support area. To further analyze the M-modes defined in the three LP tasks, we performed analysis of cosines of the angles between vectors in the muscle space corresponding to modes in individual subjects and "central vectors" (M_{CVi}). We used two types of comparisons, across subjects (within-a-task) and across tasks (within-a-subject). We found larger cosine values for the angles between each individual M_i-modes with M_{CVi} of the same number. Both types of analysis suggest that the similarity among M-modes across subjects was similar to their similarity across tasks.

We hypothesized that multi-muscle synergies stabilize a COP location in the AP direction prior to the induced forward COP shifts and that during the shift these synergies would weaken. Our experiments provided support for the hypotheses. In particular, we documented multi-muscle (more exactly, multi-M-mode) synergies stabilizing COP location in the AP direction in the steady-state phase of the tasks. LP_{NAR_ML} was shown to be associated with a early drop in the magnitude of the synergy index (ΔV) close to zero or even negative values, which may be interpreted as disappearance of the pre-existent synergy.

CONCLUSIONS

The findings corroborate both main hypotheses. The study supports a view that control of whole-body actions involves grouping the muscles, using fewer elemental variables to scale the muscle activity, and forming synergies in the space of the elemental variables that stabilize time profiles of important performance variables.

REFERENCES

Wang Y, Zatsiorsky VM, Latash ML (2005) Muscle synergies involved in shifting the center of pressure while making a first step. *Exp Brain Res,* 167: 196-210.

Wang Y**,** Zatsiorsky VM, Latash ML (2006) Muscle synergies involved in preparation to a step made under the self-paced and reaction-time instructions. *Clin Neurophysiol,* 117: 41-56.

Wang Y, Asaka T, Zatsiorsky VM, Latash ML Muscle synergies during voluntary body sway: combining across-trials and within-a-trial analyses. *Exp Brain Res,* (Under review)

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