SIMULTANEOUS PERFORMANCE OF TWO TASKS BY THE FINGERS OF THE HUMAN HAND

Wei Zhang [1] John P. Scholz [2] Vladimir M. Zatsiorsky [1], and Mark L. Latash [1]

[1] Pennsylvania State University, University Park, PA, USA
[2] University of Delaware, Newark, DE, USA
E-mail: wuz107@psu.edu
Web: www.kinesiology.psu.edu/research/laboratories/mcl/index.html

INTRODUCTION

Several studies used the framework of the uncontrolled manifold (UCM) hypothesis (Scholz and Schöner 1999) to quantify the multi-finger synergies stabilizing the total force (F_{TOT}) and total moment of force (M_{TOT}) in multi-finger tasks. The method of the UCM hypothesis allows to separate variance of the commands to fingers into two components, within a sub-space (UCM_F or UCM_M) that corresponds to multiple solutions of finger coordination that all achieve the same desired value of a performance variable such as F_{TOT} and M_{TOT} and within another sub-space that corresponds to finger force combinations that change the value of that variable. Most studies compared the amounts of variance in those two sub-spaces to find out whether a synergy existed stabilizing the performance variable (reviewed in Latash et al. 2002).

In this study, we explored the patterns of variance within the UCM computed for F_{TOT} (corresponding to the explicit task, UCM_F) when implicit requirements for M_{TOT} changed. We expected the subjects to be able to stabilize both F_{TOT} and M_{TOT} (Latash et al. 2001; Scholz et al. 2002). However, since four fingers form a redundant set with respect to tasks with two constraints, we expected the subjects to use flexible combinations of commands to fingers to satisfy the task requirements.

METHODS

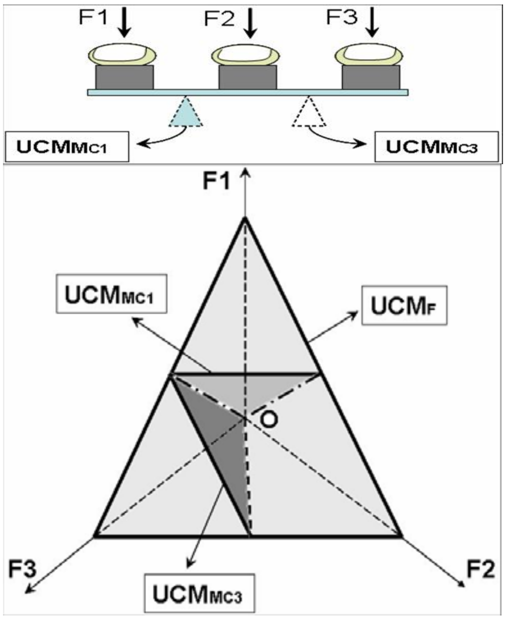

Figure 1: A simplified illustration of the task conditions (C1, C3) and UCM for F_{TOT} (UCM_F) and M_{TOT} stabilization (UCM_M). Note that a 3-finger case is illustrated!

Ten (5M, 5F) healthy, young, right-handed subjects participated in this study. Subjects sat comfortably facing a test table and placed the fingertips of the right hand on the four force sensors. The forearm/hand position was fixed. Subjects were instructed to produce a series of accurate steady-state values of the total force at 5%, 7.5% and 10% of the four-finger maximal force, following a template displayed on the computer screen. The force sensors could rest on the table (***Stable***) or on a narrow support (***Unstable***) placed between the index and middle fingers (**Pivot_IM**), middle and ring fingers (***Pivot_MR***), or ring and little fingers (***Pivot_RL***).

The UCM hypothesis was used to compute an index (ΔV) reflecting the multi-finger F_{TOT} and M_{TOT} stabilizing synergies at each time sample over sets of trials for each condition and each subject separately. The upper panel of Figure 1 illustrates task conditions but for only three finger instead of four, such that we can illustrate the UCM (UCM_F and UCM_M) in the 3-dimensional space of finger forces (the lower panel). Principal component analysis (PCA) was performed within the UCM computed for F_{TOT}. All analyses were run within the space of hypothetical commands to fingers (modes).

RESULTS AND DISCUSSION

Indices ΔV indicated synergies stabilizing F_{TOT} in all the conditions and M_{TOT} only in the ***Unstable*** conditions. PCA of the projections of the finger modes onto the UCM for F_{TOT} stabilization showed two PCs ("default PCs") accounting for over 90% of variance in all conditions. In the ***Pivot_MR*** conditions, significant loadings in these PCs corresponded to negative co-variation of modes between fingers within the IM and RL pairs. In the other two ***Unstable*** conditions, these two PCs were seen less frequently, and only in about 50% of their occurrence they contributed to stabilization of the M_{TOT}. In the ***Stable*** condition, these PCs were all but absent. In addition, eight 2-finger, eight 3-finger, and four 1-finger PCs were observed. Most of the 2-finger PCs (87%) benefited M_{TOT} stabilization in the ***Unstable*** conditions. All the 3-finger PCs could be viewed as derived from the default PCs by adding a third finger that helped M_{TOT} stabilization.

SUMMARY/CONCLUSIONS

The results show that the redundancy of the four fingers allows subjects to achieve F_{TOT} stabilization together with stabilization of M_{TOT} with flexible means. Adding a secondary constraint did not interfere with the force stabilizing synergy. The flexible solutions used by the subjects in ***Unstable*** conditions emphasize the main advantage of using multi-finger synergies and comply with the principle of superposition (Arimoto et al.; Zatsiorsky et al.).

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