VARIATION IN FORCE AND MOMENT STABILIZING SYNERGIES WITH DIFFERENT FINGER COMBINATIONS: AN UNCONTROLLED MANIFOLD ANALYSIS

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INTRODUCTION

One of the challenges of motor control is to demystify the mechanism by which the Central Nervous System (CNS) controls the apparently redundant systems for the effective movement of human body. The human hand is an excellent example of both kinetic as well as kinematic redundancy. However, it has been suggested that the CNS might actually use this apparent redundancy to incorporate better control strategies. This hypothesis has been called the principle of abundance. We presented an isometric force production task to the subjects and used the framework of Uncontrolled Manifold Hypothesis (UCM) for our analysis [2]. The current study addresses the question that which performance variable, total force or total moment is stabilized by different combinations of multi-finger synergies and how the stability and the constant errors in force production change with the number of fingers involved in the task.

METHODS

Nine right handed subjects (4 males and 5 females) participated in the experiment (age: 27 ± 4.3 years; weight: 64.2 ± 7 kg; height 1.69 ± 0.09m). The experimental setup can briefly be described as follows: the wrists and the forearms of the subject were rested in a wrist-forearm brace and held by Velcro straps. The subject sat in a chair and watched the computer screen to perform a task. The two-directional force sensors (tension and compression) were attached to an aluminum frame and the C – shaped thimbles were attached to the bottom of the sensors. The subject inserted the distal phalange of each finger in the thimbles. Signals from the sensors were conditioned, amplified, digitized at 1,000 Hz and low pass filtered at 20Hz. A custom software program made in LabVIEW and a desktop computer were used for data acquisition and data was processed using MATLAB.

Maximum Voluntary Force (MVF) was measured for all the fifteen finger combinations. This single digit task MVF data was used to estimate the enslaving matrix **E** as described previously [3]. A target force line representing 0% of MVF (in multi finger tasks) for the first three seconds and 20% of MVF for the next seconds for a particular subject was displayed on the computer screen. The summed force output of the task fingers was also shown with a different color. Subjects were asked to focus on the task fingers only, and no visual feedback about the non task finger forces was provided to them. Trials in which the non task finger was lifted from the force sensors were rejected and performed again. Subjects were asked to follow the target force lines.

Finger forces were converted into force modes (central commands) and the UCM was computed for both force and moments separately (see [3] for details). The total amount of variance (V_{TOT}) in the mode

space, computed for each time sample (0.01s) across trials of each series performed by each subject (between 7s and 12s) was divided into two components, V_{ORT} (variability orthogonal to UCM) and V_{UCM} (variability within UCM). A normalized index ΔV of multi-digit synergies was computed [3].

Constant Errors were measured using the formula: CE= (Σ(xi – T)/n)/MVC, where 'x_i' is average force produced in a ramp trial between 5-8s, 'T' is target force and 'n' is number of trials. The errors were normalized by the MVC for each subject.

RESULTS AND DICSUSSION

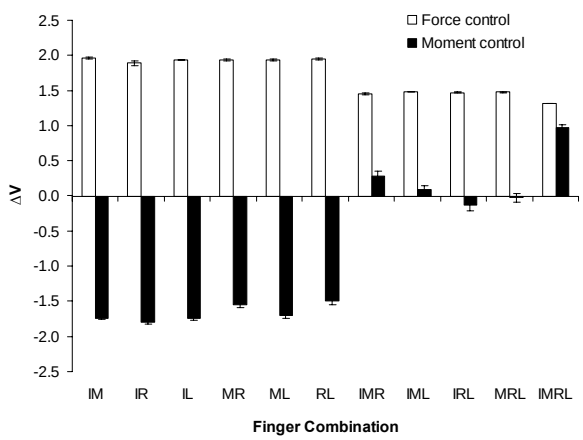

Fig. 1 The index of covariation of finger modes (ΔV) was computed with respect to the (A) force control hypothesis (white bars) and (B) moment control hypothesis (black bars) and averaged for the time interval 7s to 12 s for the constant force production task. Mean values and standard error bars are shown for both the hypothesis.

For the force control hypothesis, the index ΔV was 1.9 ± 0.045 (mean ± SD) for two finger combinations and

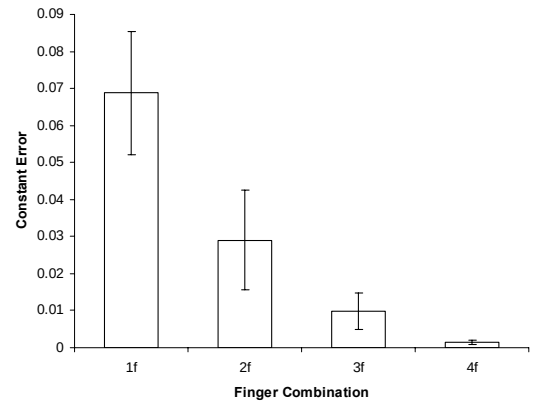

Fig. 2 Constant errors normalized by the MVC values of the four, three, two and one finger combination respectively. Mean values and standard error bars are shown.

decreased to 1.4 ± 0.025 for the four finger task (ANOVA: $p<.05$.ΔV was negative for all the two finger tasks for the moment control hypothesis, thus suggesting that the moments are not stabilized by these combinations of fingers (ANOVA: $p<.05$). The constant errors decreased from *0.07 ± 0.0019 to 0.002 ± 0.0006* from single finger combinations to four finger combinations (ANOVA: $p<.05$).These results suggest that the choice of stabilized task variable is task dependent. Also, the constant errors decreased by adding the number of fingers, suggesting that the principle of abundance might be used by the CNS in an isometric pressing task.

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