PREHENSION SYNERGIRES: EFFECTS OF FINGER MANIPULATION

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INTRODUCTION

The purpose of this study was to investigate how equilibrium of a hand-held object is maintained when the index (I) or little (L) finger was removed or added during different external torques: counter-clockwise, clockwise and zero torque (CCW, CW, ZERO). We were interested in how the finger-tip forces were organized to maintain equilibrium, whether these forces followed the principle of superposition (Zatsiorsky et al., 2004), and if they were controlled in a feed-forward manner. Subjects had to exert a pronation effort (PRO) to resist a CCW torque and a supination effort (SUP) to resist a CW torque. The study was inspired by the literature data on the effects of finger removal/addition in multi-finger tapping (Latash et al., 1998) and pressing tasks (Li et al., 2003). The data were interpreted at the virtual finger (VF) level for the thumb and fingers.

METHODS

Seven male subjects with (mean +/- STD) age = 27.6 ± 4.3, height = 177.7 ± 3.8 cm, weight = 82.6 ± 12.8 kg, hand width = 9.4 ± 0.4 cm and hand length, measured from middle fingertip to distal crease while the hand was extended, = 19.1 ± 1.2 cm participated in the study. Each subject was identified as right-handed by their reported daily activity of the use of their hands. No history of neuropathies or traumas to the upper extremities was reported by the subject. All subjects gave informed consent in accordance with the Office of Research Protections of The Pennsylvania State University.

A handle with five sensors (four for the fingers, one for the thumb) arranged such that the vertical location of the thumb was between the M and R fingers, described in more detail in Aoki et al. (2003), was used to collect data. A beam was attached to the bottom of the handle and a load of 0.55 kg was suspended from the beam at three locations to create three torques: CCW, CW and ZERO.

The data were recorded at 200Hz and low pass filtered at 10Hz. Steady state values were calculated as the average for one second at the beginning and end of the trials.

Table 1: Changes in normal and tangential force when the I or L finger is manipulated during CW, ZERO or SUP efforts. The torque agonists are in bold text, "=" indicates no significant change, "+" indicates a significant increase in force, "-" indicates a significant decrease in force. Significance was tested at $p < 0.05$.

Manipulated finger	Finger addition, 3-to-4 tasks			Finger removal, 4-to-3 tasks		
	CW/PRO	ZERO	CCW/SUP	CW/PRO	ZERO	CCW/SUP
I, normal	**=1.56**	+2.55	+2.77	**+3.60**	=0.97	-1.60
L, normal	+3.02	+2.24	**=0.16**	=0.12	=0.88	**+2.31**
I, tangential	**+2.88**	+1.70	+0.70	**–3.15**	–1.67	–0.64
L, tangential	=0.29	–0.30	**–0.87**	+0.88	+0.96	**+1.54**

A one-way repeated measures ANOVA was performed on the factor PERTURBATION (before, after); one ANOVA per moment condition and finger manipulation, for a total of 24.

RESULTS AND DISCUSSION

The normal forces significantly changed depending on the role of the finger, i.e. whether it was an agonist (helped in the exerted effort, like the I finger during PRO effort) or antagonist, see the first two rows of Table 1. The increases in normal force were not mechanically necessary because the force prior to the increase was sufficient to prevent slipping. The tangential forces significantly changed depending on the finger manipulated (I or L), see the last two rows of Table 1.

The thumb and VF normal forces highly correlated with each other, as we expected, but the normal forces did not correlate with the normal moment. The thumb and VF tangential forces correlated with each other as well as with the tangential and normal moment. The correlations were grouped into two subsets (see Figure 1), like the findings of Zatsiorsky et al. (2004), which support the principle of superposition – two

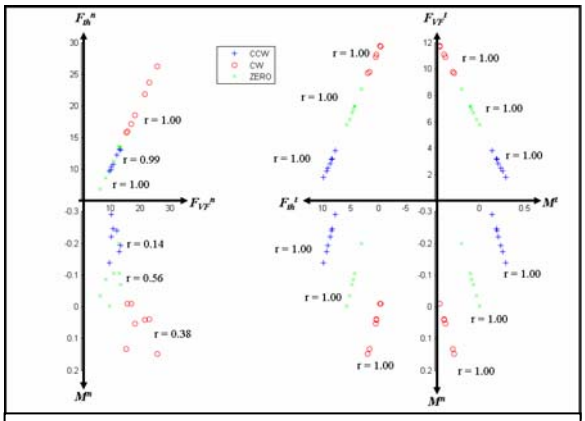

Figure 1: Correlations between the final steady state values for normal and tangential forces and moments.

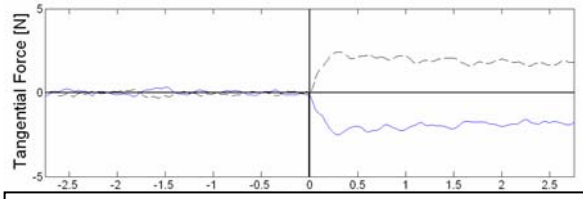

Figure 2: Thumb vs. VF (dotted and solid lines) tangential forces during an I addition, PRO effort trial.

commands were sent to the hand: "grasp the object stronger/weaker" and "prevent tilting."

The normal and tangential force of the VF and thumb changed synchronously, see Figure 2. This was supported by high Pearson correlation coefficients (~0.99) between the thumb and VF forces. Also, standard deviations of the performance variables — total tangential and total normal force and total moment — were low (the highest value for force was 0.41 N and for moment was 0.24 Ncm). These immediate compensations indicate that the CNS plans adjustments of the forces before the manipulation.

SUMMARY

Changes in normal digit force depend on the role of the manipulated finger while changes in tangential force depend on the finger manipulated. The changes were made according to the principle of superposition and in a feed-forward manner.

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