

SOLUTIONS OF A REDUNDANT MOTOR TASK WITH SUB-TASK CONFLICT

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INTRODUCTION

Although robotic researchers often try to create biologically inspired grippers, the control strategies used by the human central nervous system (CNS) to solve mechanically challenging problems have not been thoroughly studied. In this study we employed a two-finger manipulation task with a mechanical redundancy and investigated how the human CNS solves the problem of the mechanical redundancy during multi-digit manipulation (Shim et al. 2005). In addition, the manipulation task had two sub-tasks (i.e., controlling resultant force and resultant moment) which had a control conflict between them. For example, when a task is to achieve a static position of a hand-held object, the CNS is required to control both translational and rotation position of the object, but performing stable translation and rotation require negative and positive covariations of finger forces, respectively, which cause a conflict sub-task control between them (Latash et al. 2001). The aim of this study was to investigate CNS control strategies when a task has conflicting sub tasks.

METHODS

Eight right-handed males participated as the subject, and the subjects were asked to press two six-component sensors equally distanced on a horizontal panel using index and middle fingers. A fulcrum was positioned between two sensors at the midway of a flat panel (Fig 1). For each trial, the subjects pressed the sensors while maintaining a constant level of force (i.e., force control) and keeping balance (i.e., moment control). Subjects performed the task under four conditions: two different

pressing force magnitudes (i.e. 10N & 20N) and two moment arms (i.e., 1.4cm & 2.8cm).

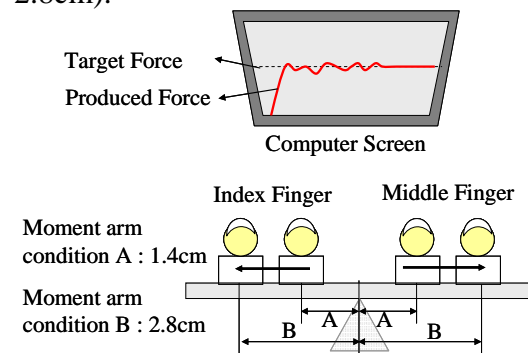


Figure1: Experimental set-up.

The following analysis was performed.

Principal Component Analysis (PCA)

For each condition, a set of variables (Index and middle finger forces, moment of normal forces) were grouped, and coefficient of correlation between variables were computed. This matrix was used to perform a principal component analysis (PCA).

Uncontrolled Manifold (UCM) analysis:

Two variances were calculated in 2-dimensional force or moment space and divided by the numbers of degrees of freedom for each variance: one variance along the task space (V_{UCM}) and the other variance orthogonal to the task space (V_{ORT}).

RESULTS & DISCUSSION

Principle component analysis

The PCA on a set of variables (index and middle finger normal forces, tangential force, and moments of normal forces) indicated three PCs accounted for $92.46 \pm 2.07\%$ of the total variances.

Table 1: Loadings of principal components (PC1 to PC3). Loadings in table are the averaged values across all 4 conditions.

	PC1	PC2	PC3
F_n^{Index}	-0.93	0.08	-0.09
F_n^{Middle}	0.79	-0.06	0.27
F_t^{Index}	0.12	-0.56	0.26
F_t^{Middle}	0.25	0.84	0.20
M_n^{Index}	0.64	0.05	-0.15
M_n^{Middle}	0.09	0.19	0.95

The normal forces of index, middle fingers had large loading showing different signs in the same PCs while small loading in other PCs (Table.1). The increase in F_n^{index} is accompanied by a decrease in F_n^{middle} so that there is a negative covariance between them. This is typical CNS strategy for the force stabilization. The tangential forces of both fingers were in the second PC showing large loadings. The negative covariance was shown between two fingers tangential forces. This means that the resultant moment of tangential force would be close to zero moment because the moment arms of tangential forces are constant in this task. Therefore, the tangential forces acted for the moment stabilization even though the moment of tangential force is the part of total moments in this task. The loading of M_n^{Index} was large in PC1 where the large loading of F_n^{index} and F_n^{middle} were shown. Especially, an increase in F_n^{index} is accompanied by a decrease in M_n^{Index} . This implies that an increase in F_n^{index} is coupled with a lot of decrease in moment arm (d_n) of F_n^{index} . M_n^{Index} and d_n are independent each other due to the movement of finger tips. M_n^{middle} had a large loading solely in the third PC. This finding means that CNS control M_n^{middle} independently. On the other hands, moment arm of F_n^{middle} (d_n^{middle}) was independent to F_n^{index} and F_n^{middle} .

Uncontrolled Manifold (UCM) analysis

For the force control hypothesis, V_{UCM} was always greater than V_{ORT} increasing the

target force levels and decreasing given moment arm conditions. However, V_{ORT} was almost equal (F1) or greater (F2) than V_{UCM} . Therefore, an increased in target force caused CNS explore broadly along task space accompanying large error variances in force control. However, the variance in force control hypothesis decreased with the length of moment arm, implying that CNS explores small task space with longer moment arm condition. In the moment control hypothesis, an increase in the target force needs an increase in a variance along task space as well as the error variance. In addition, the moment control strategy is changed with an increase in the moment arm under the increased target force (F2).

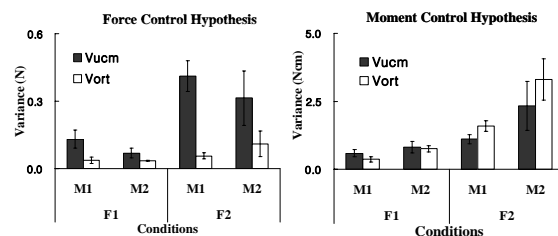


Figure3: V_{UCM} and V_{ORT} of force and moment control hypothesis. Averaged variances across subjects were represented for each condition. F1 and F2 represent 10N and 20N as target force levels, respectively. M1 and M2 are given moment arm conditions. (i.e, M1:1.4cm, M2:2.8cm)

CONCLUSIONS

When the task requires the control of force and moment simultaneously, the moments of finger force were more stabilized than the finger forces. Especially, if the moment arm is increased, the variance along task space is decreased in force control hypothesis while increased in moment control hypothesis. PCA results show that normal forces behave to stabilize the resultant force while the tangential forces act to stabilize the resultant moment.

REFERENCES

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