DOES HUMAN HAND PERFORM LIKE A ROBOTIC GRIPPER? —AN EXAMINATION OF INTERNAL FORCES DURING OBJECT MANIPULATION

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INTRODUCTION

In multi-digit grasping, a vector of contact forces and moments *f* can be broken into two orthogonal vectors: the resultant force vector *fr* (manipulation force) and the vector of the internal force *fi* (*f*= *fr* + *fi*) [1]. Internal force is a set of contact forces which can be applied to an object without disturbing its equilibrium [2,3]. The elements of the internal force vector *fi* cancel each other and, hence, do not contribute to the manipulation force. The mathematical independence of the internal and manipulation forces allows for their independent (decoupled) control. Such a decoupled control is realized in robotic manipulators [4]. The purposes of this study are to examine whether in human internal force is coupled with the manipulation force and what grasping strategy the performers utilize.

METHODS

The subjects (n=6) were instructed to make cyclic arm movements with a customized handle. Six combinations of handle orientation and movement direction were tested. These involved *parallel manipulations*: (1) VV task - vertical orientation & vertical movement and (2) HH task - horizontal orientation & horizontal movement, *orthogonal manipulations*: (3) VH task - vertical orientation & horizontal movement and (4) HV task - horizontal orientation & vertical movement, and *diagonal manipulations*: (5) DV task - diagonal orientation & vertical movement and (6) DH task - diagonal orientation & horizontal movement. Handle weight (from 3.8 to 13.8 N), and movement frequency (from 1 Hz to 3 Hz) were systematically changed. The analysis was performed at the thumb-virtual finger level (VF, an imaginary finger that produces a wrench equal to the sum of wrenches produced by all the fingers). At this level, the forces of interest could be reduced to the *internal force* (the grip force) and *internal moment*.

RESULTS AND DISCUSSION

During the parallel manipulations, the internal force was coupled with the manipulation force and the thumb-VF forces increased or decreased in phase. During the orthogonal manipulations, the thumb-VF forces changed out of phase; the plots of the internal force vs. object acceleration resembled an inverted V letter (Figure 1). The HV task was the only task where the relative phase (coupling) between the normal forces of the thumb and VF depended on oscillation frequency. During the diagonal manipulations, the coupling was different in the DV and DH tasks. A novel observation of substantial internal moments is described: the moments produced by the normal finger forces were counterbalanced by the moments produced by the tangential forces such that the resultant moments were close to zero.

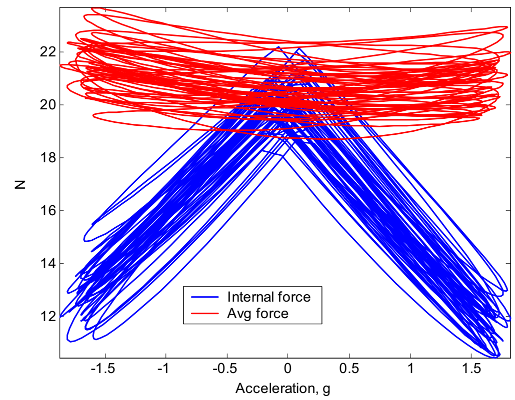

Figure 1: Internal force and average normal force versus the handle acceleration (load, 11.3 N; frequency, 3 Hz).

Internal forces do not affect equations of motion [3] and hence control of manipulation can be broken up into two sub-tasks—'holding' and 'tracking'—which can be controlled independently. Such a control strategy (which is commonly used in robotic grippers – [4]) simplifies the control. This strategy requires, however, exerting unnecessarily large forces and is in this sense uneconomical. This study, however, suggests that the CNS prefers to face larger computational costs rather than produce excessive forces. The CNS uses different patterns of the thumb-VF coordination when the manipulation force is in a tangential direction as compared with the manipulation in the normal direction. When the manipulation force is in a tangential direction, the symmetric pattern of the thumb-VF coordination is used: The thumb and VF work in synchrony to grasp the object stronger or weaker. In contrast, when the manipulation force is in the normal direction the anti-symmetric force changes are recorded: When the normal force of either thumb or VF increases, the force exerted by the opposing digits decreases. It is not clear to which degree such coordination is a consequence of task mechanics as compared with the neural control.

REFERENCES

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