Characterizing reflexive grip responses to rotational perturbations of an object in precision grasp

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INTRODUCTION

Spinal cord reflexes are often credited with mediating corrective fingertip forces for stabilization during unexpected/expected perturbations to a grasped object (e.g., Johansson and Westling, *Exp Brain Res*, 1987). Prior work documents afferent activity, muscle activity, and kinetic data. However, there are very little data available on hand kinematics during these perturbations. Of these data, most focus on tasks that elicit flexion and extension corrective responses (e.g., lifting objects). This work investigates the human hand response to rotational perturbations that elicit abduction and adduction of the fingers as well as flexion and extension (to a lesser degree) in both the kinetic and kinematic arenas.

METHODS

In this study, we used a Vicon motion-capture system with retro-reflective markers to collect kinematic data on the thumb and index finger of the dominant hand of an unimpaired subject (24 markers) and our test object (3 markers). In addition, the time response of the first dorsal interosseous (FDI) was measured for each subject using surface EMG (Biopac EMG 100C). Our rigid test object is instrumented with two six degree-of-freedom load cells (ATI Nano-25 F/T), each with independent grip plates (one for the thumb and one for the index finger). Subjects were instructed to grasp the parallel-faced object in a precision grasp with one digit centered on each grip plate and to hold the object in midair. We then subjected the test object to an unannounced rotational perturbation (clockwise or counterclockwise) using a mass and pulley system (100 or 150 grams). The subjects' task was to "right" the object after the onset of perturbation. Using MATLAB, we extracted joint angles and fingertip forces for both digits.

RESULTS AND DISCUSSION

The kinetic analysis revealed that for clockwise perturbations the thumb acts as a pivot point and the index finger acts as the primary corrective agent. Figure 1 shows that the grip force (force in the z direction) is slightly greater in the thumb than in the index finger, whereas the lifting force (force in the y direction) is slightly greater in the index finger than in the thumb. This is reiterated by the center of pressure data which shows that after perturbation, the index finger moves upward in a corrective motion as the thumb moves initially toward the center of the object (position=0) and then

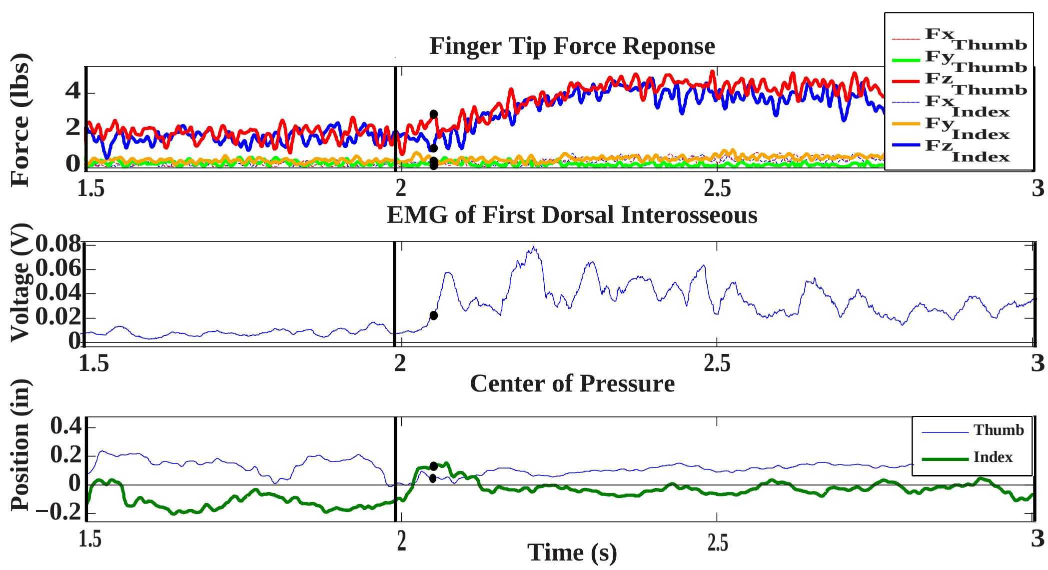

Figure 1: Fingertip force response, surface EMG of the first dorsal interosseus (rectified, filtered, smoothed), and y-position of fingertip center of pressure are shown for the 100g, CW case for a single 5sec trial of a right-hand dominant subject. The random perturbation occurred at t=1.99s (vertical line). The black markers indicate the moment of maximum test object rotation. Center of pressure data shows that the index finger performs the corrective movement in this case, whereas the thumb tends to act as a pivot.

slowly corrects upward. This relationship, of the thumb acting as a pivot, holds true across all subjects (n=3), all masses, and all trials for the clockwise perturbation direction. For perturbations in the counterclockwise direction, the opposite trend holds true. This suggests that each digit plays a different role depending on the direction of the rotational perturbation.

As expected, the rotational perturbation elicited adduction/abduction responses in both the thumb and index finger in addition to flexion/extension (Figure 2). Interestingly, the kinematic analysis shows that peak index finger joint angles were synchronized with peak object rotation angles (~65-80ms after perturbation) while thumb joint angles lagged behind. This was true regardless of perturbation direction and was consistent across all subjects (n=3) and masses. The lag between maximum object rotation and joint angle response (peak or valley) ranged from 2ms for the MCPFE and MCPAA of the index finger to 23-24ms for the CMCFE and CMCAA of the thumb. The standard deviation ranged from 2.7ms for the MCPFE and MCPAA of the index finger to as much as 39.1ms for the DIPFE of the index finger.

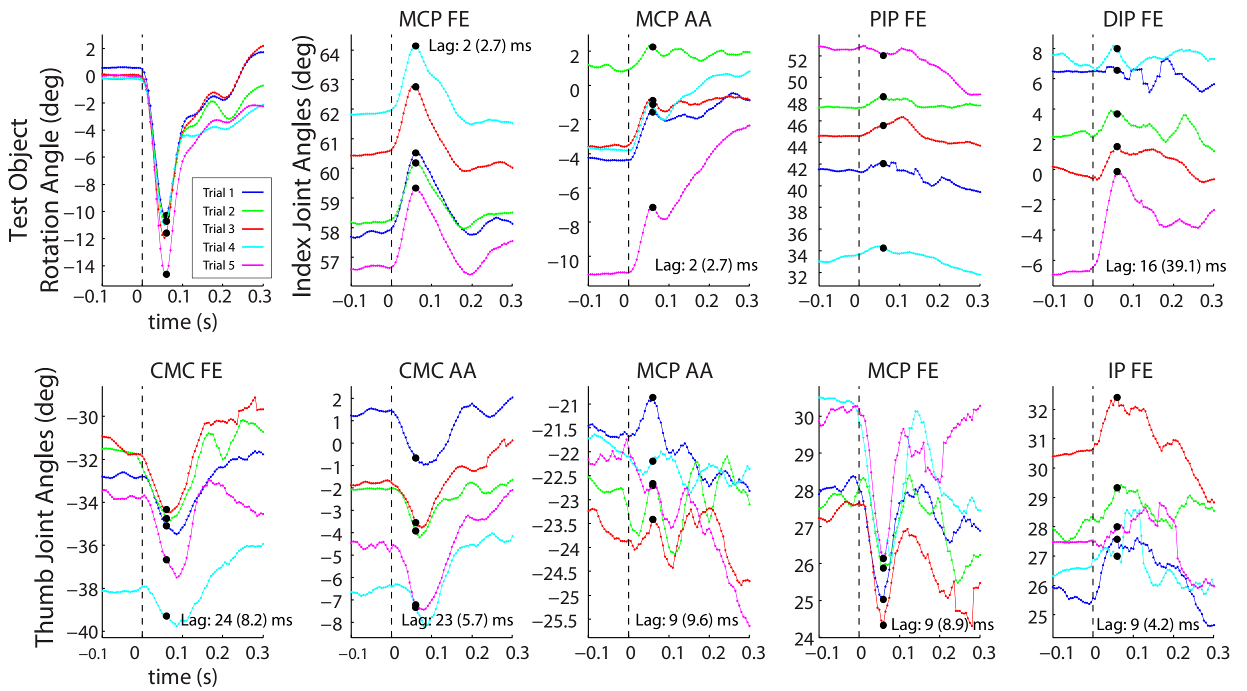

Figure 2: Test object rotation angle, index finger joint angles (top) and thumb joint angles (bottom) are shown for the 100g, CW case for a single right-hand dominant subject. The object rotation angle was used to set t=0 (vertical line). The black markers indicate the moment of maximum object rotation due to the perturbation. Positive joint angles indicate flexion or adduction while negative joint angles indicate extension or abduction. The lag between maximum object rotation and joint angle response (peak or valley) across the five trials is shown as mean(std) wherever possible. Joints: CMC = carpometacarpal, MCP = metacarpophalangeal, IP = interphalangeal, PIP = proximal interphalangeal, DIP = distal interphalangeal; Motions: FE = flexion/extension, AA = adduction/abduction.

CONCLUSIONS

This study suggests that each digit plays a different role depending on the direction of the rotational perturbation. Furthermore, it was shown that these perturbations elicit kinematic responses involving adduction/abduction in addition to flexion/extension. However, additional analysis is still required to further understand the delayed thumb kinematic responses. Future studies may look at the effects that cutaneous anesthesia has on the response of the fingertips to rotational perturbations and the randomization of our experimental trials through the use of stepper motors. Characterizing reflexive grip responses for adduction/abduction in conjunction with flexion/extension will be critical to designing autonomous reflexes for artificial hands, especially as prosthetic and robotic finger kinematics become more anthropomorphic.