A Motion Capture Study to Analyze Finger Joint Coordination during Daily Tasks

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Introduction: The hand is a complex structure with twenty-seven bones and twenty-nine joints. The majority of these joints contribute to finger motion, thereby facilitating grasp and object manipulation. Finger motion has been widely studied due to its importance across the fields of humanoid robotics, prosthetic design, and rehabilitation. Importantly, researchers have described how the muscular anatomy of the hand results in coupled motion across the metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints [1]. Yet, most studies focus on studying finger motion during highly constrained tasks, such as finger flexion or cylindrical grasp [2, 3], with few studies examining more complex activities, such as eating [4]. As a result, how finger joint movements are coordinated during typical, daily tasks is not fully understood. In this study, we examine finger joint coordination during six tasks and propose a quantitative method, based on ratios, to evaluate coordination.

Materials and Methods: Three healthy subjects (2 male, 1 female; 22.3 ± 2.5 years) participated in this IRB approved study. For each subject, right arm motion was recorded using a 12-camera Vicon system and 31 markers, similar to prior marker models [5, 6]. During testing, each subject performed six tasks using the YCB object set, a benchmark for grasping research [7]. The tasks were two simple tasks involving only the thumb and index finger (key pinch of cup and small box) and four complex tasks involving the entire hand (pegboard, grasp cylindrical can, grasp ball, and grasp large box). To calculate joint angles, inverse kinematic simulations were performed in OpenSim 3.3 using a kinematic model of the hand [8] scaled by hand size. Joint angles were compared across subjects. Joint coordination was analyzed by examining finger joint ratios. Specifically, for each finger, MCP:PIP, MCP:DIP, and PIP:DIP ratios were calculated.

Results and Discussion: The magnitude of finger joint flexion varied by subject and task. For example, during the cylindrical grasp task, all four fingers adopted a similar posture, while during the key pinch task, finger posture varied substantially (Fig. 1). When examining joint ratios for these two tasks, the magnitude of the MCP:PIP ratio was consistently larger than that of the MCP:DIP and PIP:DIP. Specifically, for the index finger the mean ratios were 1.22, 0.86, and 0.72 for the cylindrical grasp task and 1.89, 0.95, and 0.50 for the key pinch task (ratio order is MCP:PIP, MCP:DIP, and PIP:DIP). The consistent magnitude order of these ratios suggests the index finger adopts a similar joint coordination strategy for both tasks.

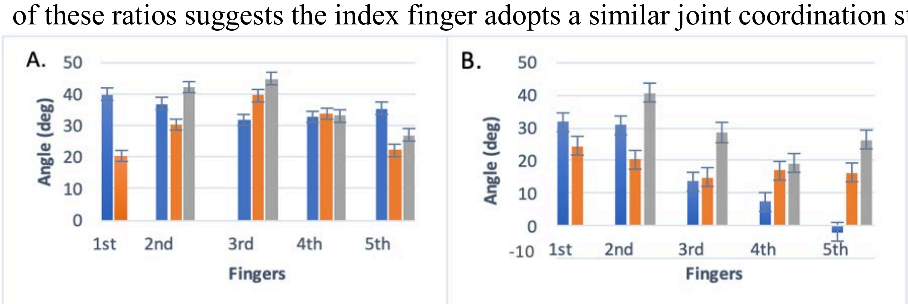

Figure 1. Maximum flexion angle average during cylindrical grasp (A) and key pinch task (B) for the MCP (blue), PIP (orange), DIP (gray) joints. Error bars represent the standard deviation for each joint angle.

Conclusion: Our work demonstrates that we can successfully measure joint angles during both complex and simple tasks encountered in daily life. We also illustrate that joint ratios can provide a quantitative method to examine joint coordination across tasks. In the near future, this work will be expanded to examine how age, sex and hand dominance affect joint coordination.

References: [1] Landsmeer J. et al. *Plast Reconstr Surg,* 1964 [2] Hussain Z. et al. *Appl Bionics and Biomech,* 2018 [3] Vergara M. et al. *J Hand Ther,* 2014 [4] Braido P. et al. and Zhang X. et al. *Hum Mov Sci,* 2004 [5] Carpinella I. et al. *Gait and Posture,* 2006 [6] Sancho-Bru J. *J Eng Med,* 2014 [7] Calli B. et al. *Int J Adv Robot Syst,* 2015 [8] Buffi J. *J Biomech Eng,* 2014