Effects of Task Conditions on Human Hand Pose Selection Strategies in a Bimanual Fine Manipulation Task

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Many manipulations in human everyday activities rely on the collaboration of our two hands. Bimanual fine manipulation tasks are particularly demanding when precise coordination among fingers of both hands are required. Yet, despite the abundant degrees of freedom (DoFs) that need to be controlled, humans can perform such tasks nearly effortlessly. Ample evidence suggests that the central nervous system (CNS) predetermines hand poses that are compatible with task conditions prior to manipulation. However, the mechanism by which the CNS encodes task conditions and translates such information into appropriate motor commands is poorly understood.

We conducted a comparative study to infer task conditions' effect on hand pose selection strategies. Twenty right-handed subjects (aged 24.2 /-6.0, 5 women) were tasked to a precise unscrewing task consisting of two steps: placing a screwdriver on a tiny (1.6mm) screw that was tightly mounted on a watchface, and unscrewing it without sliding off. Subjects were equally assigned to two groups and performed the same task in two conditions. In the free-base condition, the watchface was left free to move on the table; whereas in the fixed-base condition, it was fixed on the table. We hypothesised that subjects use both hands to manipulate watchface and screwdriver respectively in the free-base condition, while use one hand to manipulate only the screwdriver in the fixed-base condition. Subjects were instructed to perform the task with five repetitions as fast and as accurately as possible. We monitored hand poses employed by subjects and constructed a hand pose taxonomy, based on which we analysed properties of hand pose combinations across trials.

Results showed that although subjects used similar hand poses across steps within the same experimental conditions, the hand poses differed significantly in the two conditions. In the freebase condition, subjects needed to stabilise the watch face on the table. The role distribution across hands was strongly influenced by hand dominance: the dominant hand manipulated the tool, whereas the non-dominant hand controlled the additional degrees of freedom that might impair performance. In contrast, in the fixed-base condition, the watch face was stationary. Subjects used both hands even though a single hand would have been sufficient, contrary to our hypothesis. Importantly, hand poses decoupled the control of task-demanded force and torque across hands through virtual fingers that grouped multiple fingers into functional units. This preference for bimanual over unimanual control strategy could be an effort to reduce variability caused by mechanical couplings and to alleviate intrinsic sensorimotor processing burdens. To afford analysis of this variety of observations, a novel graphical matrix-based representation of the distribution of hand pose combinations was developed that integrated atypical hand poses that have not been documented in extant hand taxonomies.