Effect of task conditions on human hand pose selection strategies in bimanual fine manipulation tasks

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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 as precise coordination among fingers of both hands is required. Yet, despite the abundant degrees of freedom (DoFs) need to be controlled, humans can perform such tasks nearly effortlessly. Ample evidence suggests that the human central nervous system (CNS) predetermines hand poses that are compatible with task conditions (e.g. task objective, physical properties of objects, control of force/torque required by task) 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 is 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 first condition (Exp.1), the watchface was let free to move on the table; whereas in the second condition (Exp.2), it was fixed on the table. We hypothesized that subjects use both hands to manipulate watchface and screwdriver respectively in Exp.1, while use one hand to manipulate only the screwdriver in Exp.2. 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 analyzed properties of hand pose combinations across trials.

Subjects employed similar hand poses across the two successive task steps (placing and unscrewing) within the same conditions, whereas distinct hand poses were observed between the two conditions. This suggests a generic task-oriented motion planning prior to execution. In Exp.1, subjects consistently chose similar hand poses across trials. In conformity with our hypothesis, they used each hand to manipulate one piece of equipment, as required to control for more DoFs. Contrary to our hypothesis, subjects used both hands to control the screwdriver in Exp.2, and showed diversity in hand pose combinations. Analysis indicates that subjects select hand poses to control simultaneously the task-relevant DoFs (i.e. demanded by the task) and the task-irrelevant DoFs. The latter, although not crucial to the task goal, may bring in perturbations and impair performance if not properly controlled. Moreover, subjects manifested a tendency to balance virtual fingers (fingers that move together as a functional unity) across the two hands, such that the control of task-demanded force and torque is decoupled. This strategy may be designed to achieve better task performance while reducing the control complexity.