Interactive Perception in the Human Manipulation of Complex Objects

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Tactile sensing, or interactive multimodal perception, is of paramount importance in the interaction with objects of unknown shape, material, and content. Object properties become particularly challenging for humans if the object has internal dynamics; for instance, the sloshing liquid in a cup of coffee can generate complex interaction forces that need to be preempted, compensated, or corrected for. While humans can dexterously transport a cup filled with coffee, there is limited understanding about the control mechanisms and the contribution of different sensory modalities to a successful action. This study investigated the effect of visual and haptic information on humans' exploratory interactions with a simplified 'cup of coffee', an object with nonlinear internal dynamics. Subjects were instructed to rhythmically transport a virtual cup with a rolling ball inside between two targets at a specified frequency, using a robotic interface. The cup and targets were displayed on a projection screen, and force feedback from the cup-and-ball dynamics was provided via the robotic manipulandum. Subjects were encouraged to explore and prepare the dynamics by 'shaking' the cup-and-ball system to find the best initial conditions prior to the rhythmic task. Two groups of subjects received full haptic feedback about the cup-and-ball movements during the task; however, for one group the ball and its movements were visually occluded, while the other group could see the ball. Analysis of kinematic and kinetic data showed that visual information about the ball movement had three distinctive effects on the performance: seeing the ball reduced preparation time needed to understand the dynamics, the exploratory movements converged faster towards the task-required rhythm, and, importantly, preparation led to simpler, more linear input-output interactions between hand and object. These findings highlight the roles of visual and haptic information in the interactive perception and exploration of complex objects.