Motor synergies in grasping real and virtual objects

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Grasping movements on virtual objects have been found to resemble those on real objects to a high degree (Santello, Flanders & Soechting, 2000, J. Neurosci. 22: 1426-1435). Previous studies, however, used natural objects with non controllable features (e.g., Santello, Flanders & Soechting, 1998, J. Neurosci. 18: 10105-10115). We investigated the kinematics of grasping real versus virtual spherical objects of systematically varying sizes. The kinematic data was analyzed using principal components analysis (PCA) in order to extract movement synergies (Tresch, Cheung & d'Avella, 2006, J. Neurophysiol. 95: 2199-2212) and to determine invariant movement characteristics of real and virtual object grasping.

Ten right handed subjects (age: 24-39 years, 3 women) participated in two grasping experiments. During data collection, subjects stood in front of a table (with dimensions 210 x 210 x 130cm), on which a holding device was positioned in front of a computer screen, 40cm left of a target bowl. Subjects were wearing an Immersion CyberGlove II wireless data glove (Immersion Corp., San Jose, CA; data acquisition rate: 100Hz; sensor resolution: <1°) that allowed for recording whole hand kinematics (22 DoF). A 14 camera Vicon digital optical motion capture system (Vicon, Los Angeles, CA) monitored the trajectories of the hand movements via three retro-reflective markers on the back of the data glove.

Experiment 1: 8 white plastic spheres varying in diameter from 10-80mm in 10mm steps were used as real objects. Before the onset of each trial, the experimenter placed one object on the holding device. During Experiment 1, the computer screen remained blank. The objects were presented in a fixed order, in 10 pseudo-randomized blocks of 8. Subjects were instructed to place their right hand on the starting position at the edge of the table and wait for a "go" signal to put the object into the bowl, and then place their hand back on the starting position and await the next trial.

Experiment 2: The experimental procedure was exactly the same as in Experiment 1, however, instead of the real objects, images of objects were displayed on the computer screen which corresponded exactly in shape and apparent screen size to the real objects from Experiment 1. The participants were instructed to imagine the displayed object lying on the holding device and perform the same action as in Experiment 1. All subjects performed Experiment 2 directly after Experiment 1.

We recorded 22 DoF encompassing the movement of all five fingers of the human hand and the palmar arch. Grasping movements started when the hand accelerated from the starting position and ended when the hand accelerated again with the object from the holding device. Based on pooled joint angle time courses we computed PCA for each experiment separately in order to extract movement synergies. We then compared the extracted movement synergies of the two experiments.

Our results indicate that on average 80% of the variance of both the real and virtual grasping movements can be well described by only 3 principal components (PCs). A comparison of the subspaces spanned by these sets of PCs revealed a strong similarity between the two experiments. Projecting the hand postures at object contact to the extracted PC subspaces revealed that the postures clustered depending on object size and also varied systematically within the subspaces.

In conclusion, we show that whole hand grasping kinematics are low dimensional and can efficiently be described by only three PCs indicating strong linear relationships between the involved joints. Subjects use similar movement synergies during real and virtual grasping and these synergies tend to reflect the physical properties of the grasped object in a very straightforward manner. Taken together, these findings allow for a compact description of grasping movements in terms of movement synergies. Furthermore, in future grasping studies it might be possible to eliminate the need for physical objects and solely rely on virtual objects thus greatly enhancing the control of object features and the number of potential objects.