Reach-to-grasp: A single movement of the entire upper extremity

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Introduction

During reach-to-grasp, rather than reaching first and grasping second, shaping of the hand to grasp an object evolves in parallel to reaching to the object's location. Nevertheless, reaching and grasping commonly are considered to be independent processes, with the motion of proximal joints depending only on reach location and the motion of distal joints depending solely on object shape. Here we examined the extent to which the motion of proximal joints also depends in the object's grasp and the motion of distal joints depends on reach location.

Methods

Experimental Setup

Three rhesus monkeys (Macaca mulatta), L/X/Y, were trained to perform a reach-to-grasp task. Subjects were seated in a seat and required to reach to one of two objects: either a middle pull handle, thumb latch, or object. These objects were located in one of eight radial locations. Kinematics were derived from 16 optical markers on the animal’s right arm and digits tracked with a motion capture system operating at 200 Hz (Vicon Motion Systems).

Results

Joint Angle Analysis

Twenty-two joint angles were calculated from the optical marker data. For each monkey, all trials were linearly interpolated to time align the data at movement onset of movement and object-location contact. Two separate analyses were performed on the joint angle data. First, two-way ANOVA was performed to test for the effect of object (object/subject) and object location (location used as factors, as well as an interaction term object x location). To more accurately compare the effect size across time points, effect size (r) was normalized by using the maximum error variance at any time, rather than the error variance at each time point (Eqn 1). Second, linear discriminant analysis (LDA) using various combinations of joints was performed to assess the utility of discriminate object and location. LDA was performed separately to predict object type for a known location and object location for a known object (Eqns 2). The LDA predictive accuracy was assessed using 10 000 cross-validations.

Figure 4. Joint angles as a function of normalized time for the pull handle at 45°. A) Index PIP angles are used to illustrate how data were analyzed and interpreted with positional codes aligned to the onset of movement (A) and peripheral object contact (C). B) All 22 joint angles after time alignment and interpolation. These are all trials from a single session for the pull handle at 45°.

Figure 5. The effect of object and location on individual joint position as a function of time. The individual joint angles are plotted for A) shoulder internal/external rotation, B) Wrist flexion/extension, and C) Index MCP flexion/extension. For shoulder internal/external rotation (A), location has a major effect (r = 0.96); Flexion/extension of the wrist (B) initially had both location and object effects, which transitioned to a dominant object effect. The Index MCP flexion/extension (C) showed primarily an object effect from the onset of movement. r values were calculated for first balanced subsets of object/location combinations (open/closed parentheses) and for all object/location combinations (black boxes). D) The r for all joint angles for all three monkeys. There is an initial location effect along with a slight late object effect for nearly all angles. Later as the peripheral object is contacted, the shoulder angles show a location effect while all of the more distal joints are primarily object related.

Figure 6. The relative ratio of object, location, and interaction effects at two points in time. The ratios of r index values at 30% and 90% of movement were compared. A) The ratio of location and object index r values (Eqn 3) was calculated. Early in the movement, both object and location effects are found in many joints. Later in the movement, all of the joint angles related to the object are primarily object related, while the shoulder angles are location related. B) The ratio of interaction to object and location index r values (Eqn 4) was calculated. Most joints show relatively small interaction effects and thus depend on the main effects of object and location independently.

Discussion

• Reach kinematics are determined not only by location, but also by object.
• Grasp is determined primarily by object, but with subtle location effects.
• Joint angles are primarily a linear combination of object and location, with limited interaction effects.
• Proximal joints are adjusted to achieve an attitude of the hand that permits grasping an object with a relatively invariant hand shape formed by distal joints.
• Reaching and grasping constitute a single movement of the entire upper extremity.

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