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

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Finger Movement Laboratory

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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 with reaching to the object's location. Nevertheless, reaching and grasping commonly are considered to be independent processes, with the motion of proximal joints depending solely 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 on the object grasped 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 cued to reach to one of four objects: mallet, pull handle, push button, or sphere. These objects were located in one of eight radial locations. Kinematics were derived from 36 optical markers on the animal's right arm and digits tracked with a motion capture system sampling at 200 Hz (Vicon Motion Systems).

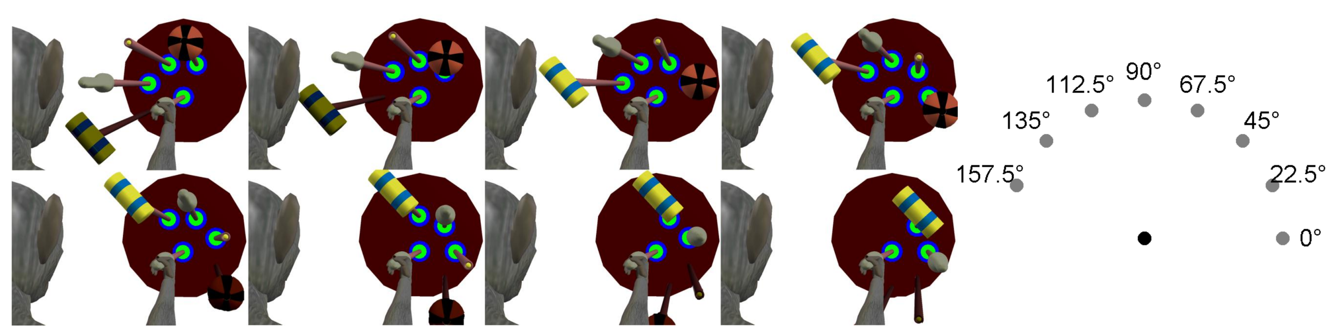


Figure 1. Reach-to-grasp task. For each block of trials, the objects were rotated as a group to one of eight zones. The eight possible locations for a given object were 157.5° (most left location), 135°, 112.5°, 90°, 67.5°, 45°, 22.5°, and 0° (right horizontal location). Objects not located at one of these locations for a given zone were not included in the task. (Illustration created with MSMS software courtesy of R. Davoodi and G. Loeb)

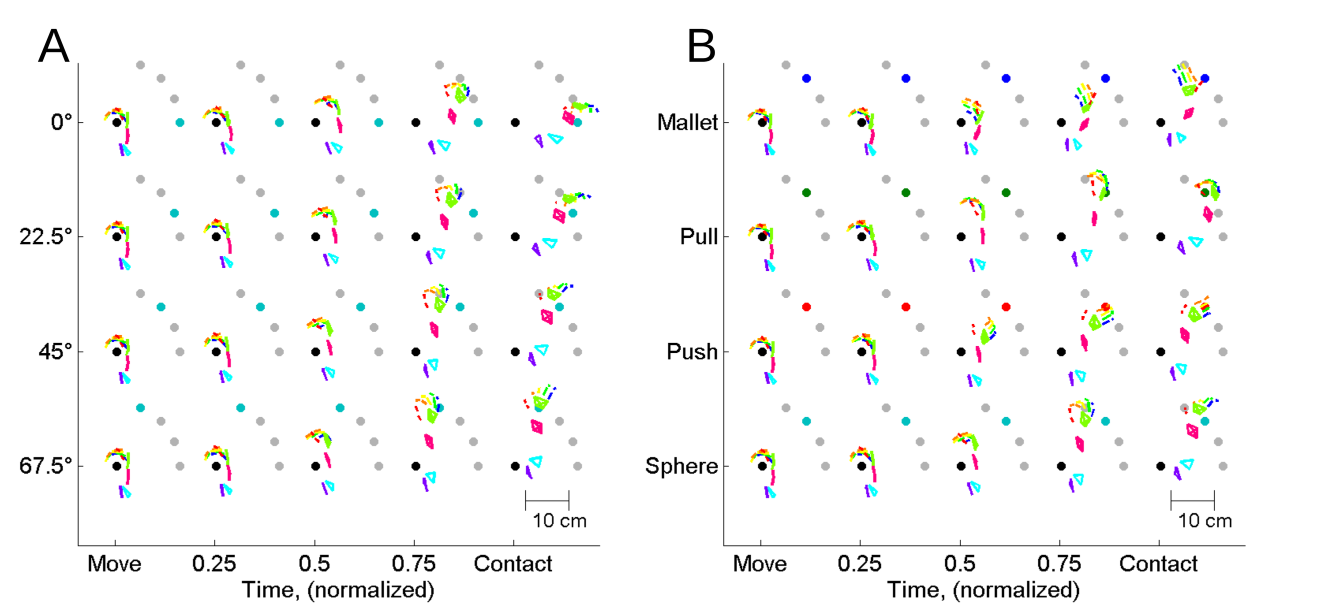
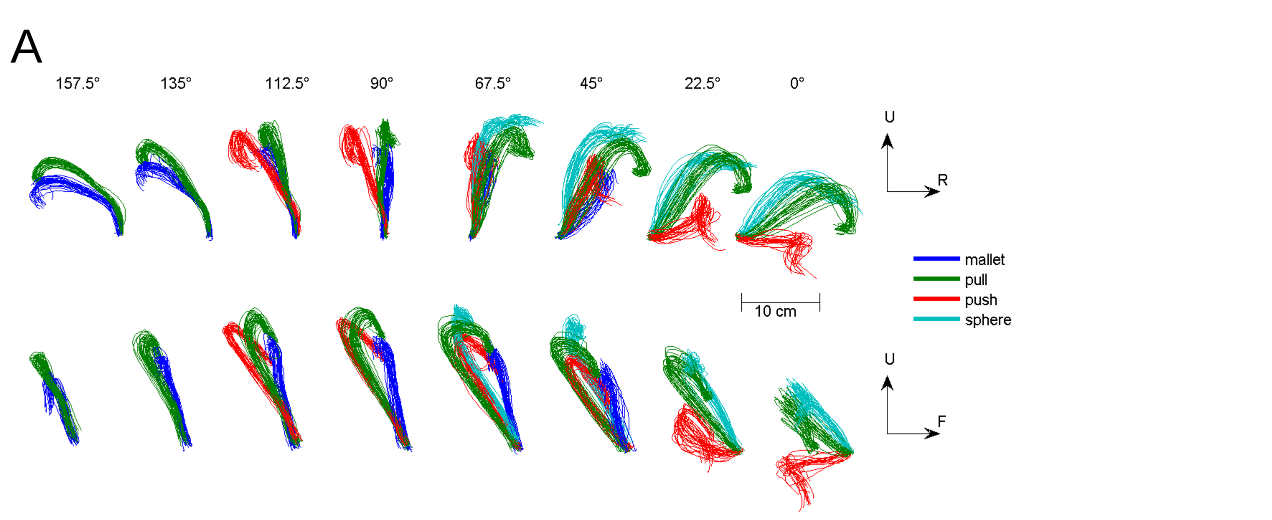


Figure 2. Arm and hand kinematics plotted from the onset of movement to the time of peripheral object contact. Marker data is averaged across all trials for a given reach type from a single session. A) Variation in kinematics for the sphere object located at four different locations. B) Variation for the four different objects each located at 45°.



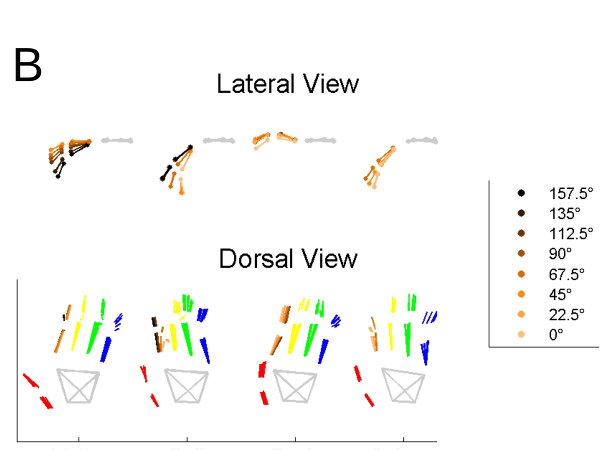
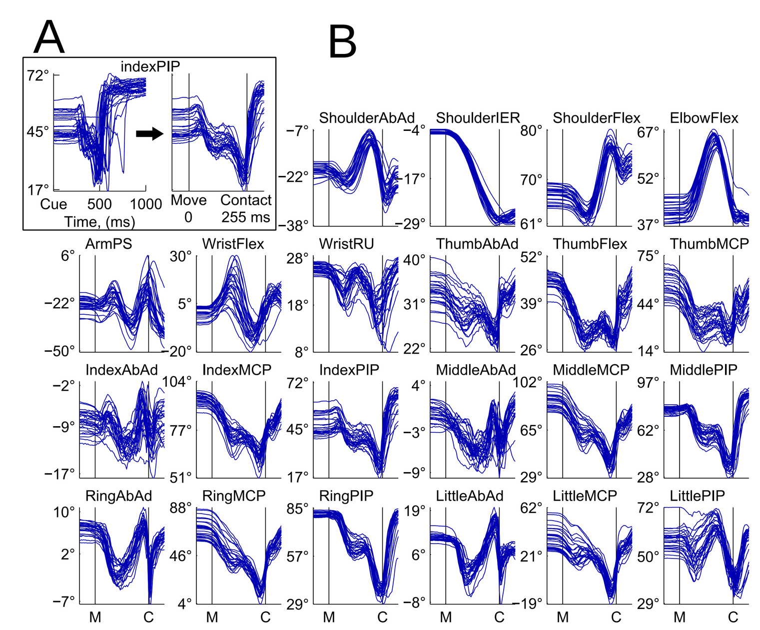


Figure 3. A) The trajectory of the arm depends not only on location but also the type of object at that location from the very onset of movement. Trajectories were determined for a point on the wrist from onset of movement until peripheral object contact and plotted for all trials from a single recording session. The same data is plotted in both the coronal plane (the monkey's view, top row) and the sagittal plane (viewed from the monkey's right side, bottom row). B) The hand configuration shows subtle differences depending on the location of the object for any particular object type. The average hand posture is plotted for each reach type at 90% of the movement between movement onset and object contact. Top: lateral view of index digit, Bottom: dorsal view of whole hand.

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 two time points: the onset of movement and peripheral object contact. Two separate analyses were performed on the joint angle data. First, two-way ANOVA was performed with the type of object (Object) 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, η^2, was normalized by using the maximum error variation at any time, rather than the error variation at each time point (Eqn. 1). Second, linear discriminant analysis (LDA) using various combinations of joints was performed to assess the ability to discriminate object and location. LDA was performed separately to predict object type for a known location and object location for a known object (Eqn. 2). The LDA predictive accuracy was assessed using 10-fold cross-validation.



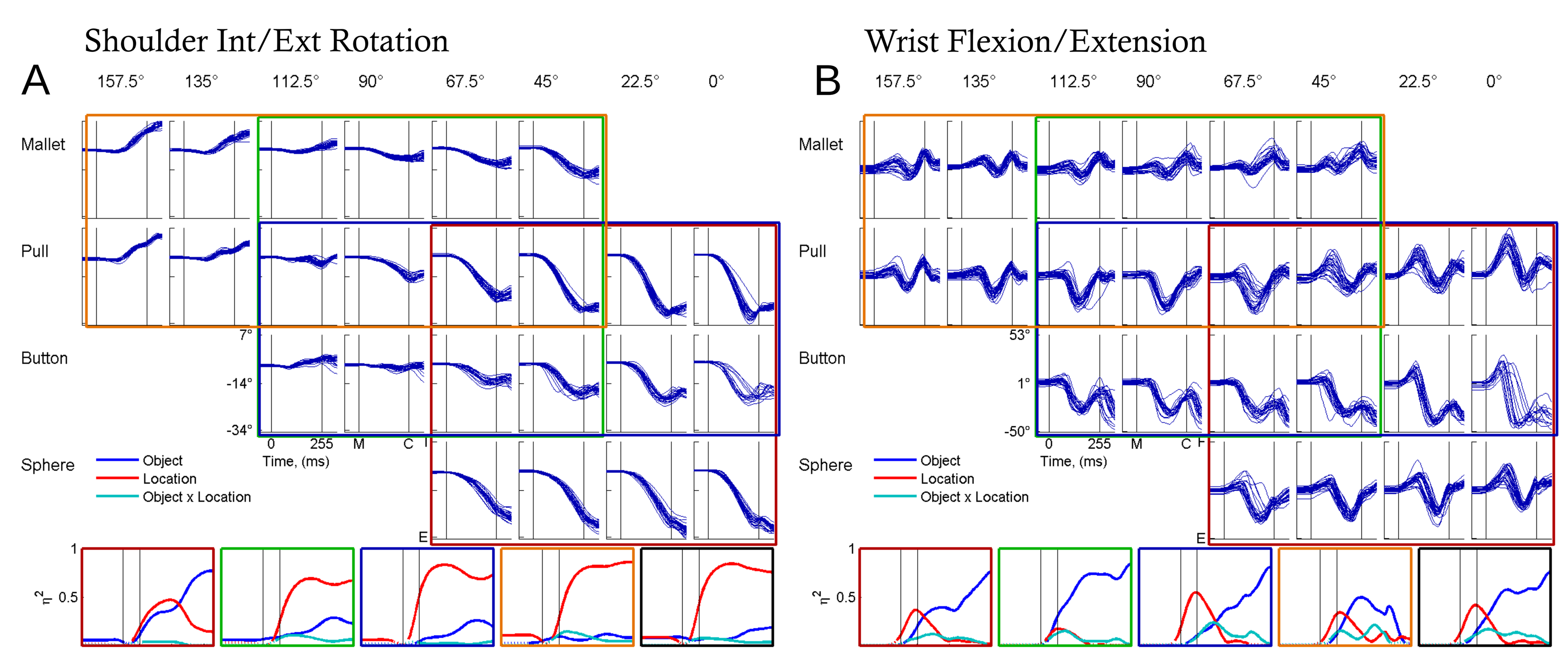
Eqn. 1 $$\eta_i^2(t) = \frac{SS_i(t)}{SS_{Obj}(t) + SS_{Loc}(t) + SS_{ObjxLoc}(t) + \max(SS_{Error})}, i = Obj, Loc, or\ Obj\ x\ Loc$$

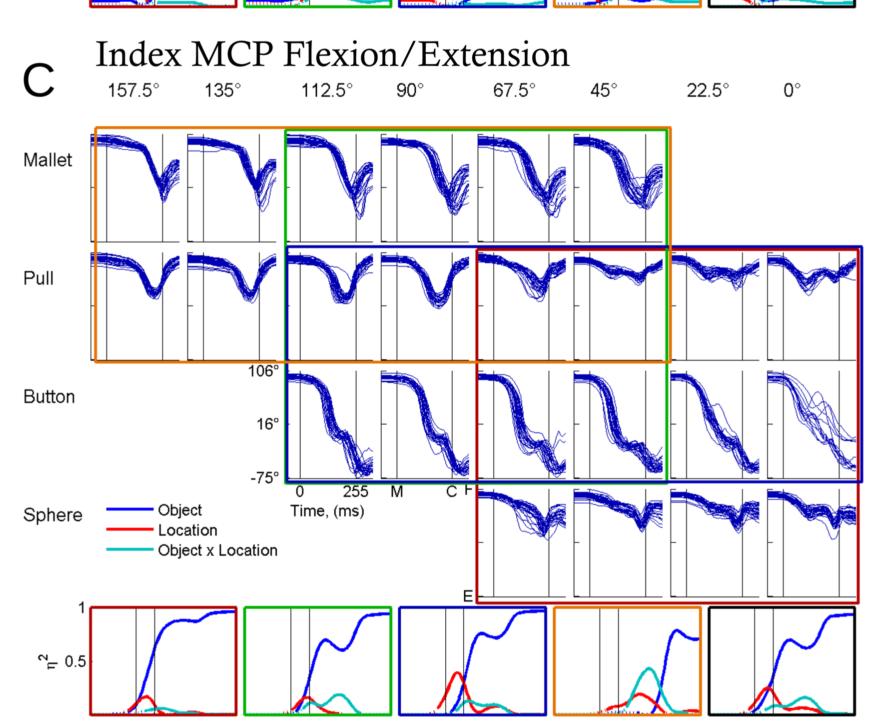
Eqn. 2 $$\widehat{Obj}|Loc = LDA(\boldsymbol{Angles_{1...N}}) \quad and \quad \widehat{Loc}|Obj = LDA(\boldsymbol{Angles_{1...N}}), \text{N subset of angles}$$

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 was linearly interpolated with all trials aligned on the onset of movement (M) and peripheral object contact (C).

B) B) All 22 joint angles after time alignment and interpolation. Traces are all trials from a single session for the pull handle at 45°.





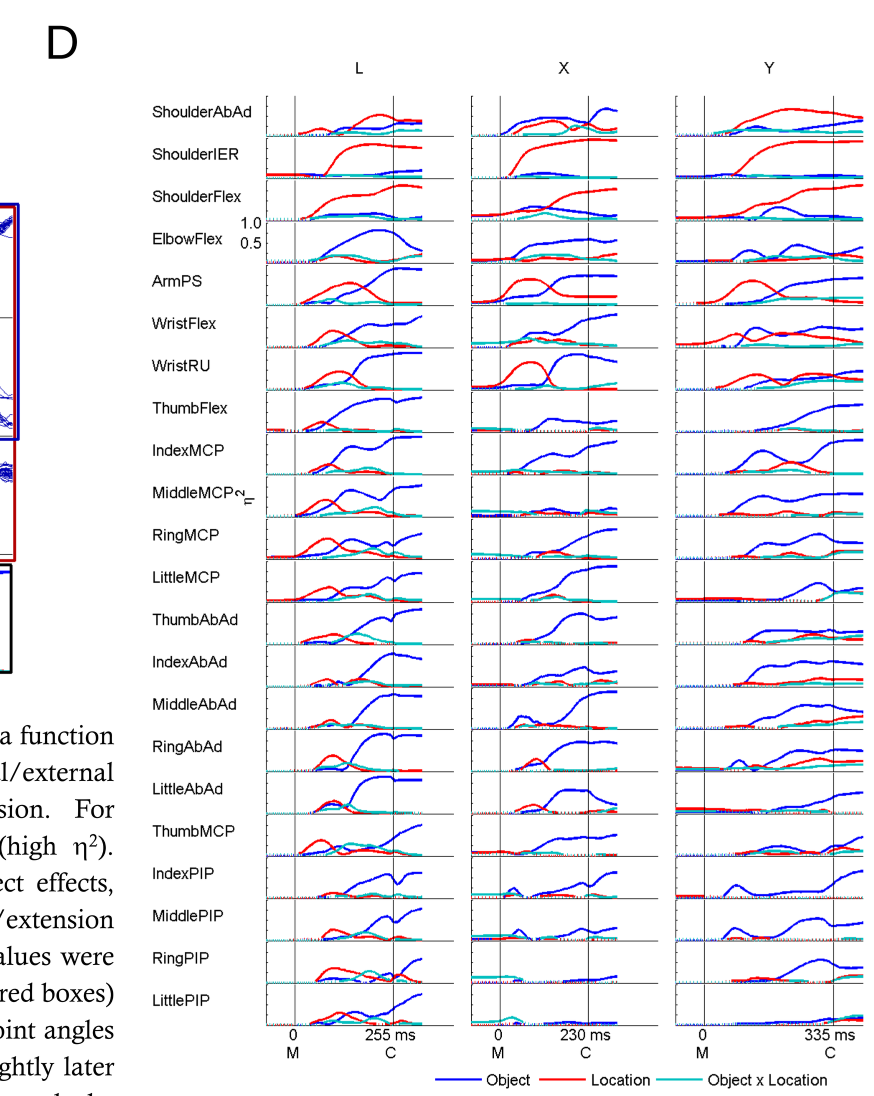


Figure 5. The effect of object and location on individual joint position as a function of time. The individual joint angles are plotted for A) Shoulder internal/external rotation, B) Wrist flexion/extension, and C) Index MCP flexion/extension. For shoulder internal/external rotation (A), location has a major effect (high η^2). 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. η^2 values were calculated for four balanced subsets of object/location combinations (colored boxes) and for all object/location combinations (black box). D) The η^2 for all joint angles for all three monkeys. There is an initial location effect along with a slightly later 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.

Kinematic Analysis Summary

Eqn. 3 $$\frac{SS_{Loc}(t)}{SS_{Obj}(t) + SS_{Loc}(t)}$$

Eqn. 4 $$\frac{SS_{ObjxLoc}(t)}{SS_{Obj}(t) + SS_{Loc}(t) + SS_{ObjxLoc}(t)}$$

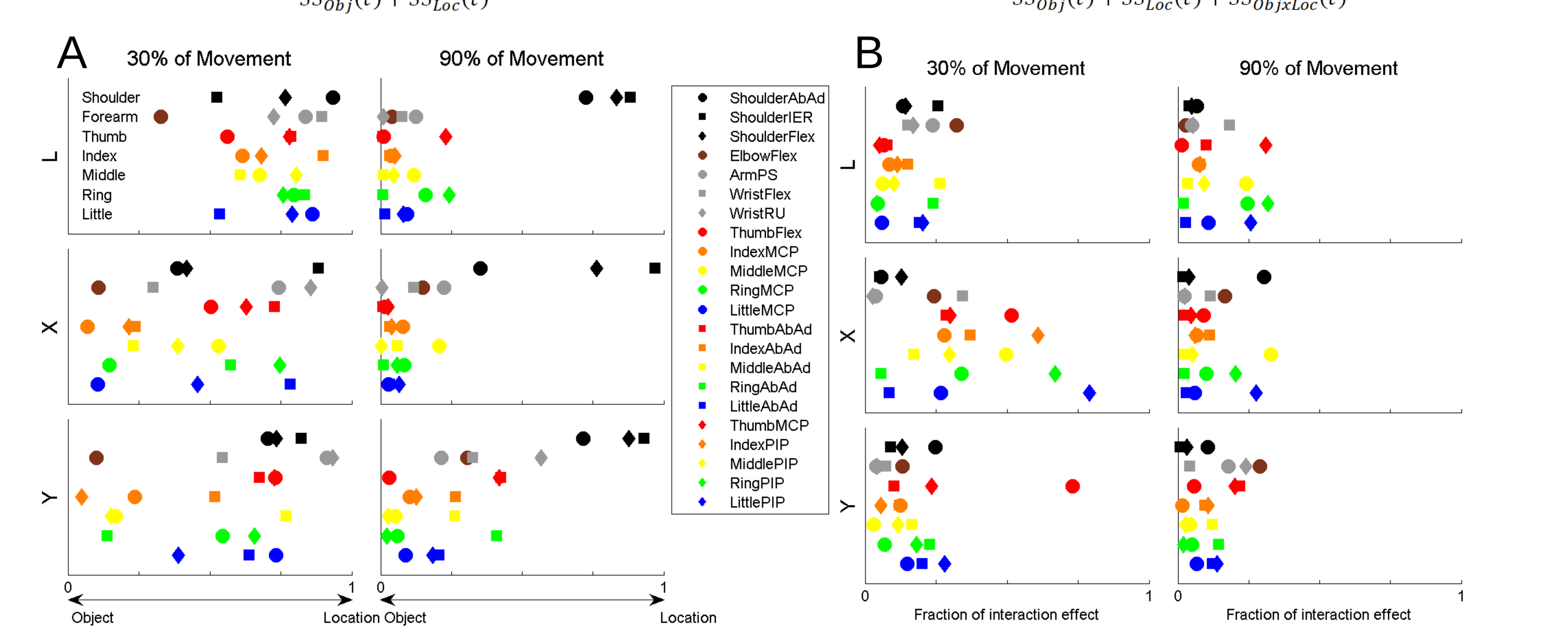


Figure 6. The relative ratio of object, location, and interaction effects at two points in time. The ratios of η^2 values at 30% and 90% of movement were compared. A) The ratio of location and object η^2 values (Eqn. 3) was calculated. Early in the movement, both object and location effects are found in many joints. Later in the movement, all of the joint angles distal to the elbow are primarily object related, while the shoulder joints are location related. B) The ratio of interaction to object and location η^2 values (Eqn.4) was calculated. Most joints show relatively small interaction effects and thus depend on the main effects of object and location independently.

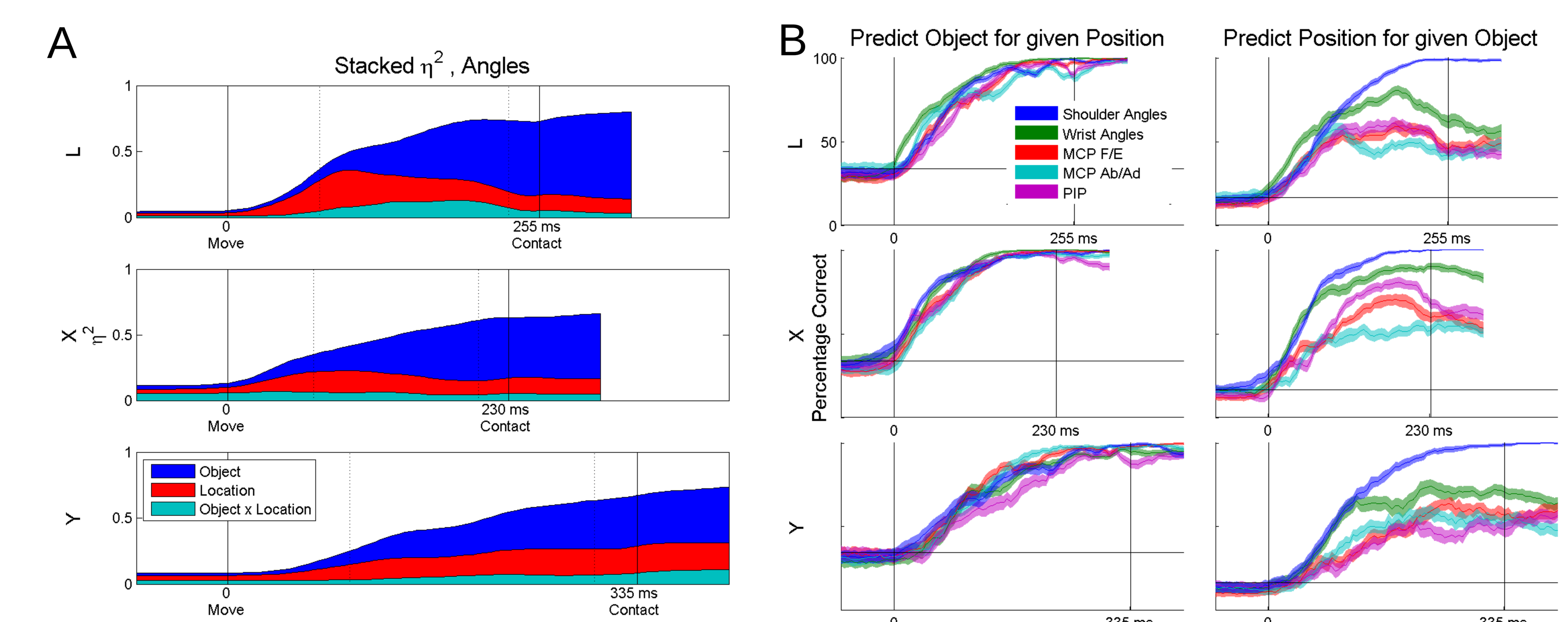


Figure 7. The effect of object and location combined across joints. A) The η^2 values were averaged across all 22 joints and stacked to represent the cumulative explained variance. After the onset of movement, there is a rise and fall in location effect and then steady rise in object effect. B) Linear discriminant analysis shows the ability to predict an object (left) and location (right) when the other factor is known using a group of joints. All joint groups follow a similar time course and allow for near perfect classification of object. For location prediction, the shoulder angles are the best predictors and decrease for the more distal joint groups.

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.

Acknowledgments

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