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Reach-to-grasp: EMG activity in both proximal and distal muscles is related to both location and object

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Introduction

In reach-to-grasp movements, proximal muscles act on the shoulder and elbow to transport the hand to its target while distal muscles shape the hand to grasp the object. However, given that shoulder angles also vary depending on the object, the activity of proximal muscles might vary depending on the object as well as its location. Conversely, given that wrist and finger angles vary to orient the hand toward the object, distal muscle activity might vary with location as well as object shape.

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. Chronic, intramuscular bipolar electrodes were implanted in 16 right forearm muscles of each animal to record electromyographic (EMG) activity. EMG signals were sampled at 1 kHz (Plexon, Inc.).

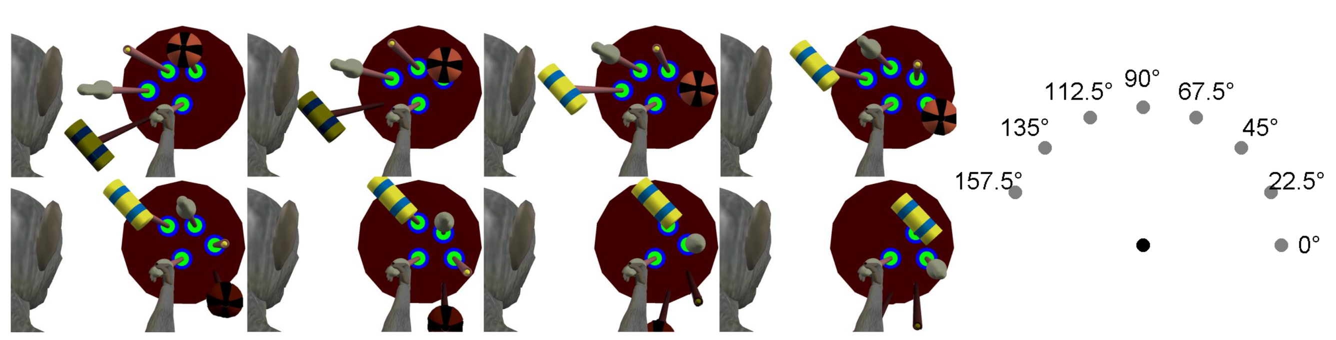


Figure 1. Reach-to-grasp task. For each block of trials, the objects were rotated to one of eight zones. The eight possible locations for a given object were 157.5° (most left location), 135°, 112.5°, 90°, 67.5°, 45°, 22.5°, and 0° (right horizontal location). Objects not located at one of these locations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

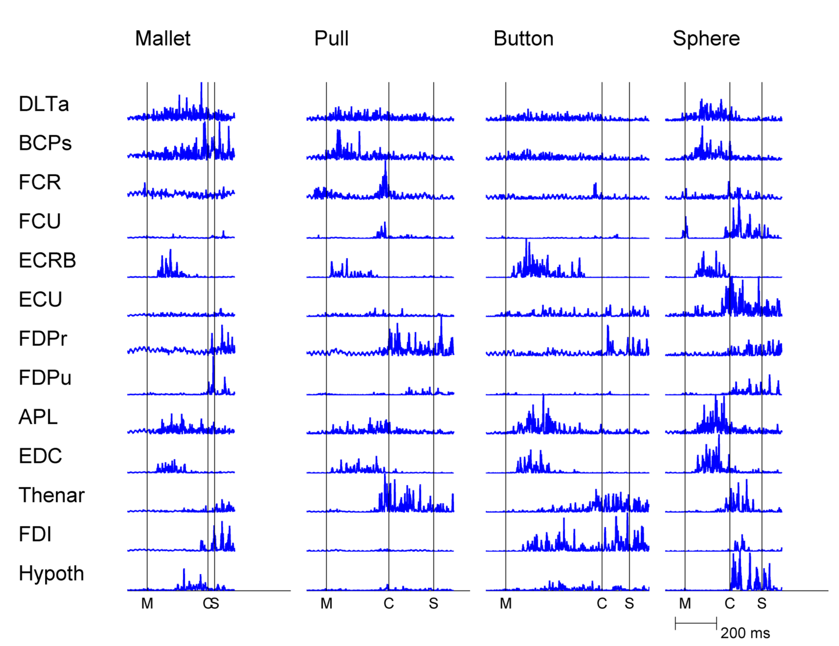


Figure 2. Examples of rectified EMG activity for a single trial of each of the four different objects when located at 45°. Activity in proximal as well as distal muscles differs across the four objects. Activity also appears to occur largely in two sequential temporal phases, with both early and late phase activity in both proximal and distal muscles. The individual trials shown here were selected because they matched the mean activity for a given reach type across the entire recording session.

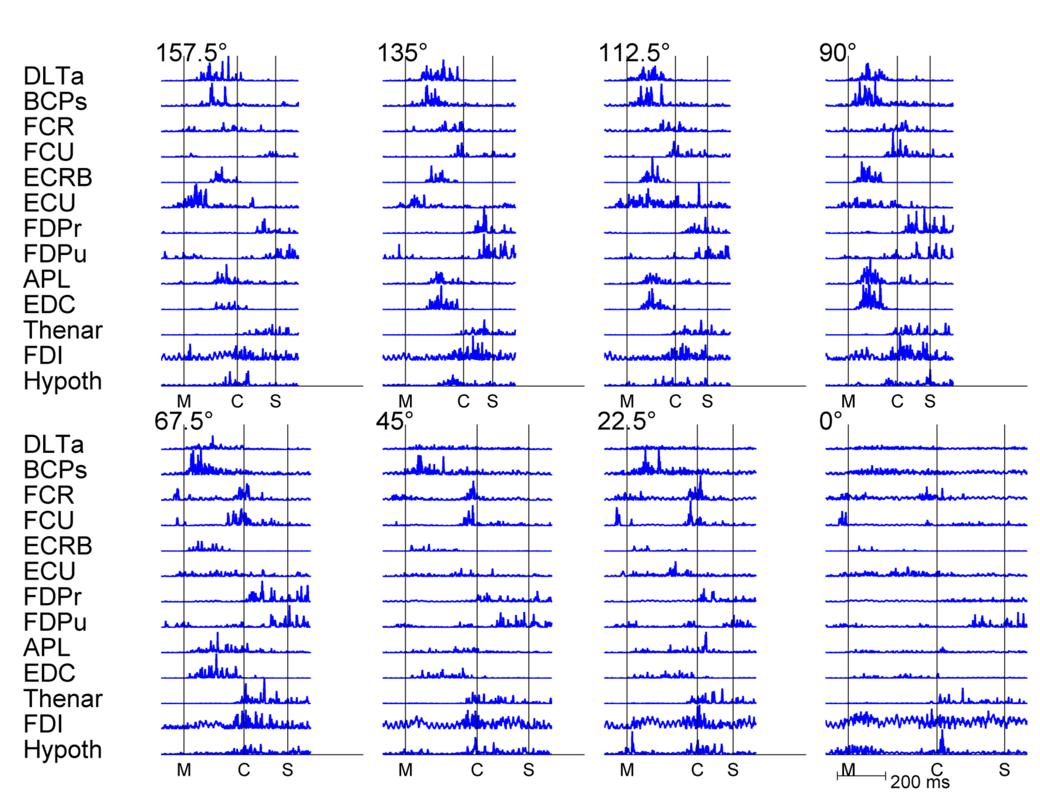


Figure 3. Example rectified EMG activity during reach and grasp of the pull handle at each of the eight locations. Gradual changes in individual muscle activity as a function of location are observed.

Results

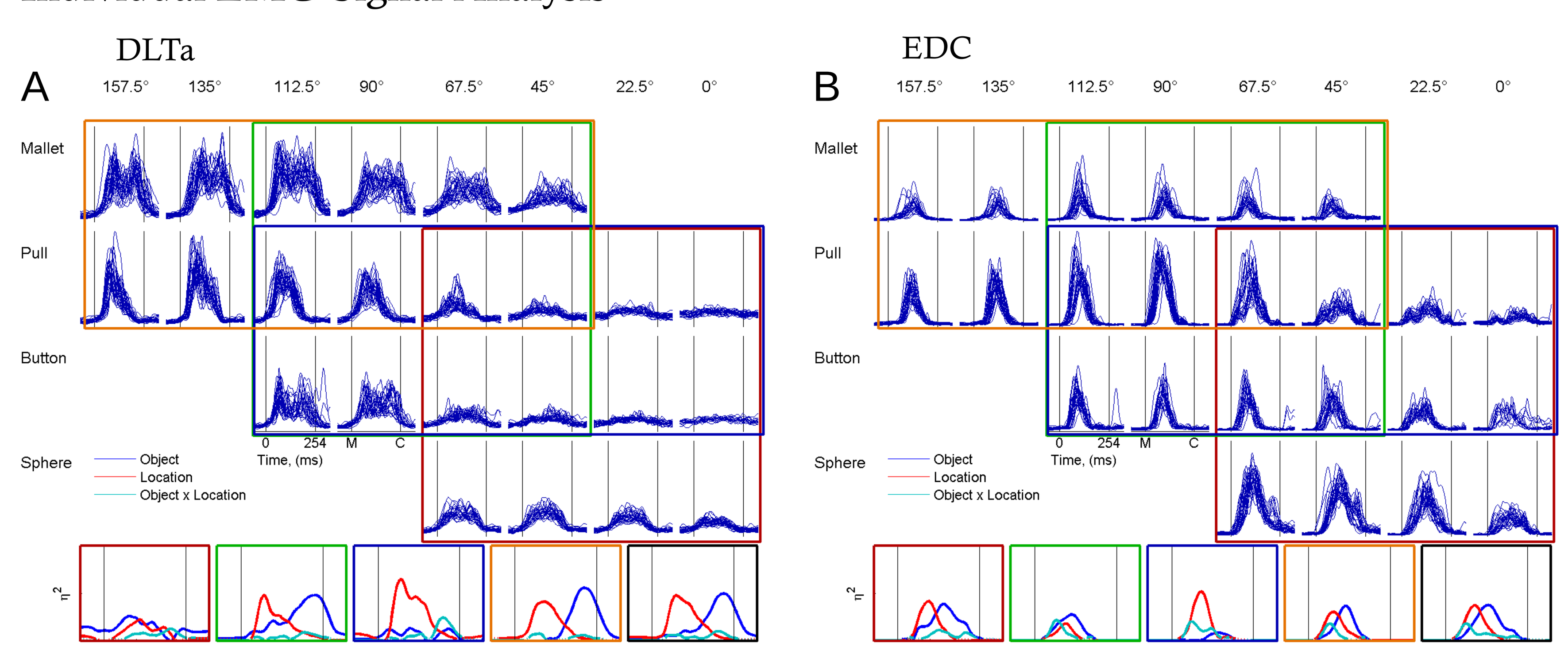
The EMG signals were full-wave rectified and low-pass filtered at 20 Hz for analysis. For each monkey, all trials then were linearly interpolated to time align the data to two time points: the onset of movement and peripheral object contact. Two separate analyses were performed on the EMG data. First, two-way ANOVA was performed with the type of object (Object) and its location (Location) used as factors, as well as an interaction term (Object x Location). To more accurately compare the effect size across time points, η^2 was normalized by using the maximum error variation over all time points, rather than the error variation at each time point (Eqn. 1). Second, linear discriminant analysis (LDA) using selected combinations of muscles was performed to assess the ability to discriminate object and location based on EMG activity. LDA was performed separately to predict i) object type for a known location, and ii) 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 $\widehat{Obj}|Loc = LDA(\boldsymbol{Angles_{1...N}})$ *and* $\widehat{Loc}|Obj = LDA(\boldsymbol{Angles_{1...N}})$

N subset of angles

Individual EMG Signal Analysis



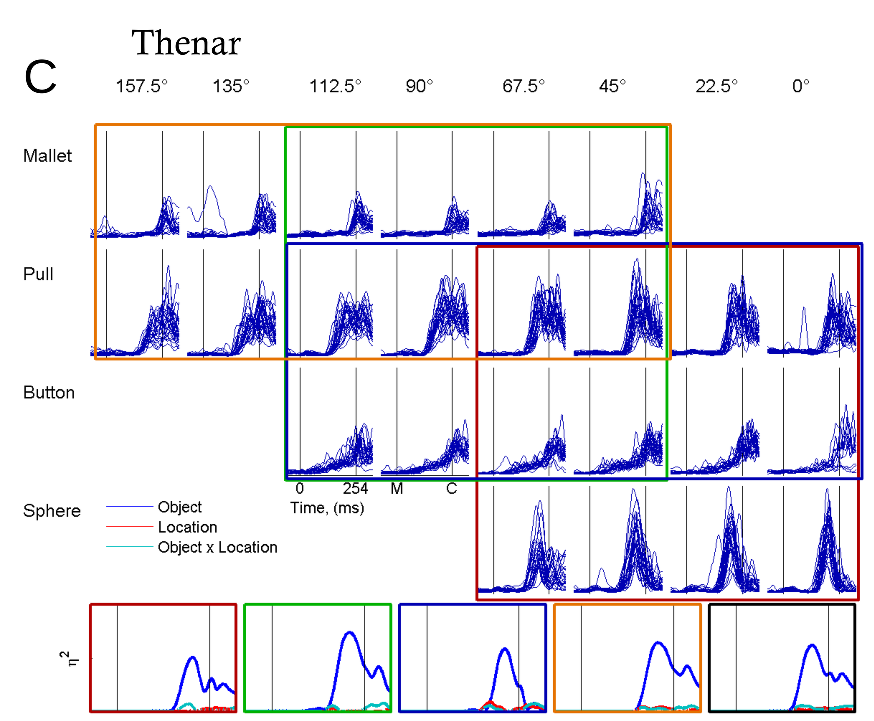


Figure 4. The amplitude of rectified EMG activity for all trials from a single recording session. The three example muscles are A) anterior deltoid (DLTa), B) extensor digitorum communis (EDC), and C) thenar muscle group. For DLTa (A), there is an initial rise in activity that varies primarily with location, but is followed by activity that depends primarily on object type. EDC (B) shows activity that appears in a single burst and has nearly equal effects of object and location. The thenar activity (C) depends primarily on object type and has little variation with location. Effect size, η^2, was calculated as a function of time separately for four balanced subsets of object/location combinations (colored boxes) and for all (unbalanced) object/location combinations (black box).

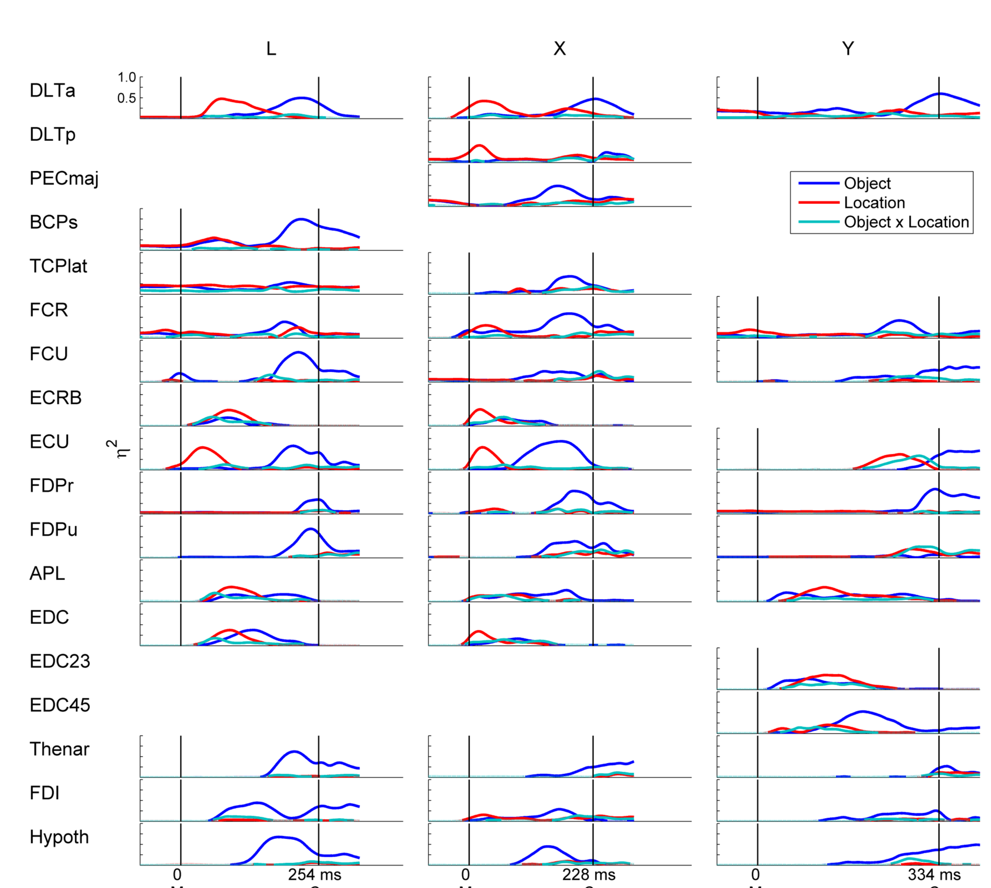


Figure 5. Effect size, η^2, plotted for all muscles for the three monkeys--L, X and Y. In general, early EMG activity depends on either location or both location and object (with little interaction). This early activity appears in most muscles, with the exception of the intrinsic hand muscles. Later activity depends primarily on object type. This late, object-related EMG activity occurs not only in distal muscles, but in shoulder and elbow muscles as well.

EMG Analysis Summary

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

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

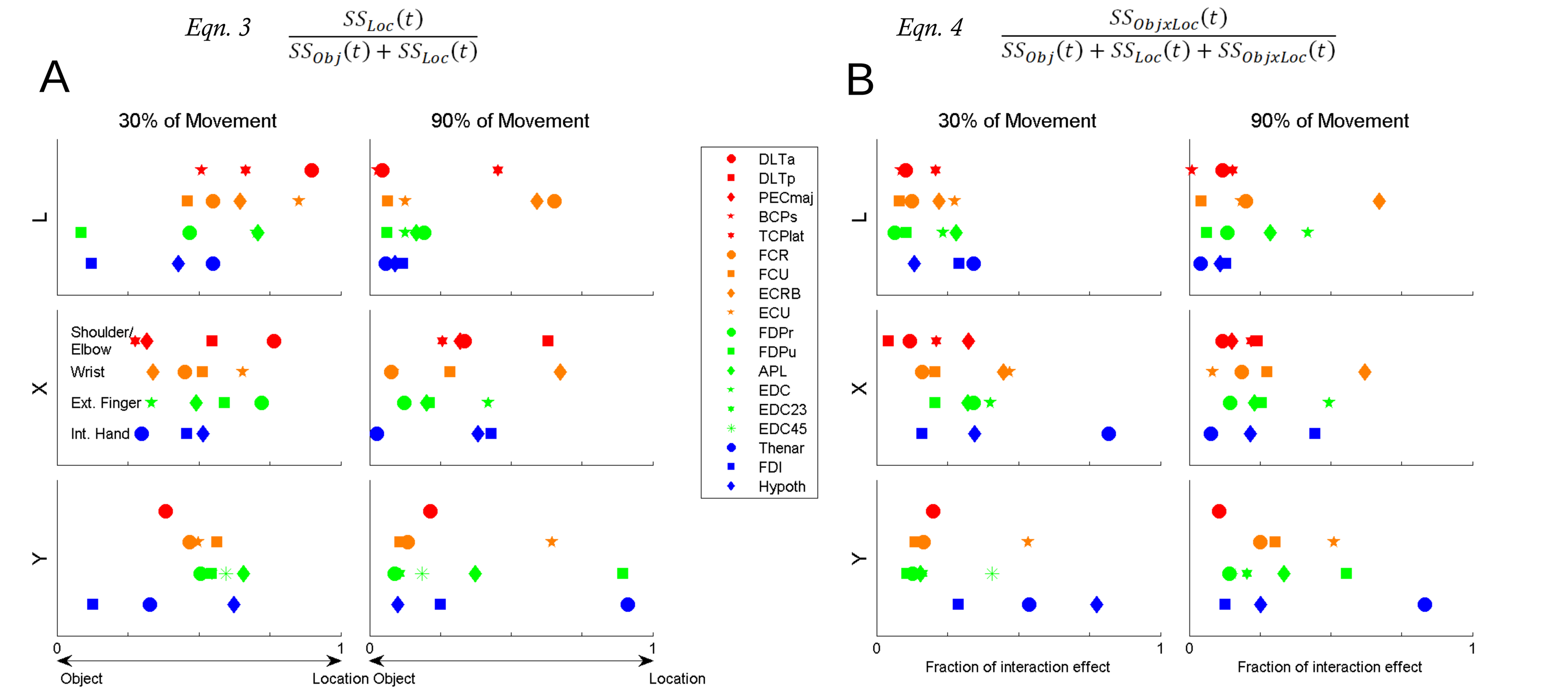


Figure 6. The relative ratio of object, location, and interaction effects at two points in time. The ratios of η^2 values at 30% and 90% of movement were compared. A) The ratio of location to object η^2 values (Eqn. 3) was calculated. During the early portion of the movement, object and location effects are similar in size. Late in the movement, the EMG activity is more object-related for most muscles. B) The ratio of interaction to separate object and location η^2 values (Eqn. 4) was calculated. Most muscles show modest interaction effects and thus depend primarily on the independent main effects of object and location.

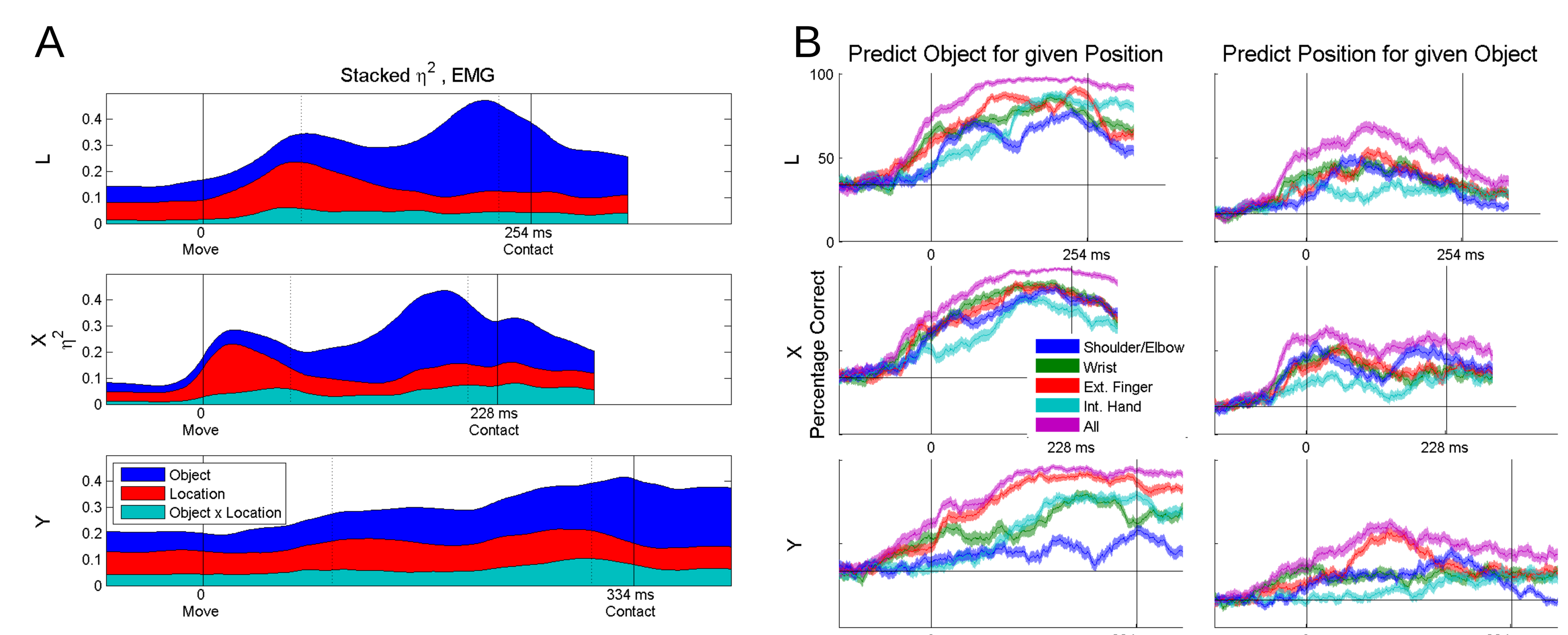


Figure 7. The effects of object and location averaged across muscles. A) The η^2 values were averaged across all recorded muscles and stacked to represent the cumulative explained variance. There are two main peaks at which times variation in EMG activity is maximally accounted for by the two factors. The first tends to show more location than object effect, while the second shows more object than location effect. B) Linear discriminant analysis shows the ability to predict object (left) or location (right) when the other factor is known, using a muscle group. The ability to predict object rises continously until the point of peripheral object contact. In contrast, the peak location prediction occurs shortly after the onset of movement. Proximal versus distal muscles differ little in their ability to predict either object or location.

Discussion

- Muscle activity occurred primarily in two temporal phases: one at the onset of movement and one preceding peripheral object contact.
- Early EMG activity was related to both object and location.
- Later activity was related largely to object, even for proximal muscles.
- All muscle groups from proximal to distal predict both object and location with similar accuracies and time courses.
- Muscle activity in both proximal and distal muscles varies with both reach location and object grasp.

Acknowledgments

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