Learned dissociation of cortical activity for 2D cursor control

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Introduction

In persons with nervous system injury, restoration of function using neural prostheses is affected by plastic adaptation of cortical activity. This adaptation confounds the design of transfer functions that *decode* acquired neural activity into prosthesis control signals. Rather than approach cortical plasticity as problematic for prosthesis control, we are investigating the extent to which cortical adaptation can be harnessed to *encode* prosthesis control.

Previous studies have shown that non-human primates (NHPs) can be operantly conditioned to modulate motor cortical activity voluntarily. We are operantly conditioning non-human primates to voluntarily modulate motor cortex neuronal activity to control a simple prosthesis – a 2D computer cursor. We show that non-human primates can improve performance in a cursor prosthesis task through changes in the correlated discharge patterns of motor cortical neurons.

Methods

Experimental Setup

We recorded neural activity from the primary motor cortex (M1) in a male rhesus macaque using four, sixteen-channel microelectrode arrays. The NHP was seated head-restrained in a primate chair, facing a 17-inch LCD computer monitor. Two well-isolated single units recorded on different electrodes were used to control a 2D cursor on the computer screen. Through linear transfer functions, one unit controlled the cursor's x-position (c_x) and the other unit controlled the y-position (c_y). The firing rates for each single unit (f_1 and f_2) were determined using overlapping 500msec bins, incremented by 10msec. The transfer function coefficients (α_x, α_y, β_x, β_y) were defined at the beginning of the first experimental session, such that the range of cursor positions spanned the entire task space. These coefficients remained fixed for all subsequent experimental sessions. No specific properties of the single units' activity, such as directional tuning, were used for their selection or for transfer function definition.

Assigned transfer functions:

$$c_x = \alpha_x f_1 + \beta_x$$
$$c_y = \alpha_y f_2 + \beta_y$$

Task

To earn rewards, the NHP moved the cursor to pseudo-randomly presented targets within 7500 msec of target presentation and held the cursor within that location for ≥100msec, entirely by modulating the discharge of the two selected single units (Figure 1a-c). Because co-modulation of the two units moved the cursor along a diagonal, we picked target locations along the x- and y- axes (Figure 1d), requiring the NHP to dissociate the activity of the two M1 neurons chosen for cursor control.

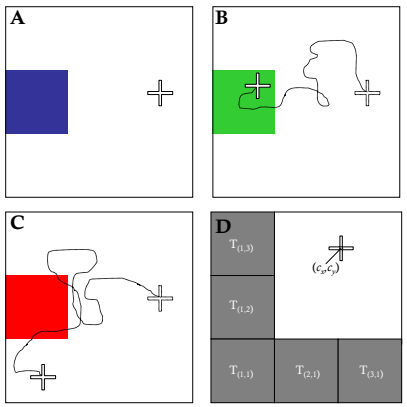

Figure 1: (**a**) Trial start. (**b**) Trial success. (**c**) Trial failure. (**d**) Locations of presented targets.

Results

The non-human primate exhibited improved performance across experimental sessions in many facets of the cursor-target task. Over the course of 15 experimental sessions, the non-human primate learned to confine the location of the cursor primarily to the target locations, improve success rates for all targets, and reduce response times to all targets.

Cursor Position

Throughout each experimental session, continuously displayed cursor positions—at trial start, between trial start and trial success/failure, and during inter-trial intervals—were unrestricted. As the non-human primate learned to improve performance in this task, however, the cursor position within and between trials became restricted primarily to the target locations (task space). Figures 2a and 2b show the cursor positions across Session 1 and Session 15, respectively.

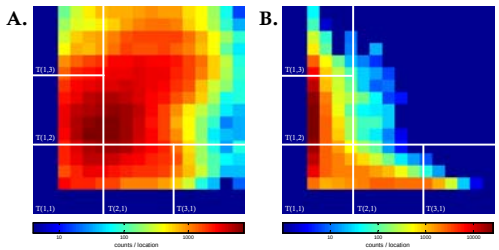

Figure 2: Cursor positions over the entire experimental session. (**a**) Session 1. (**b**) Session 15.

Success Rates

Improvements in success rates for all targets occurred primarily during the third week of experimental sessions. Figure 3 shows the success rates for all targets for all 15 sessions. The black trace shows the trend in average success rate for all targets.

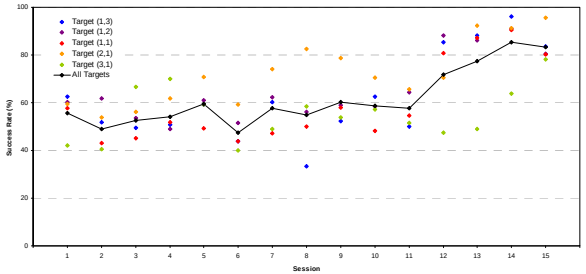

Figure 3: Success rates for all 15 sessions.

Response Times

A gradual reduction in average response time was observed across all 15 sessions as shown in Figure 4. For targets (2,1) and (3,1), however, response times increased during the last week of sessions due to a change in cursor trajectory strategies.

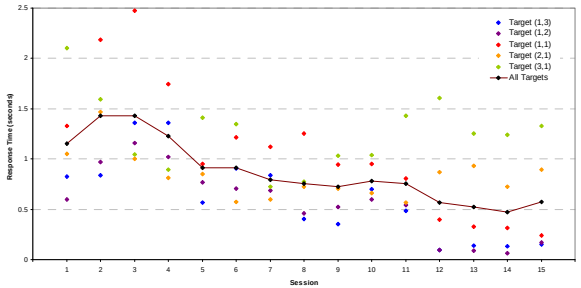

Figure 4: Response times for all 15 sessions.

Dissociation of cortical activity

Improvements in task performance indicate that the activity of the neurons selected for cursor control became dissociated. The correlated discharge patterns of these selected neurons are analyzed by quantifying changes in their coincidence histograms. The coincidence histogram is derived from the joint-perievent histogram as shown in Figure 5. Figure 6 shows coincidence histograms for Sessions 1 and 15 for target (2,1). Figure 7 shows the mean of the coincidence histograms for all targets across all 15 sessions.

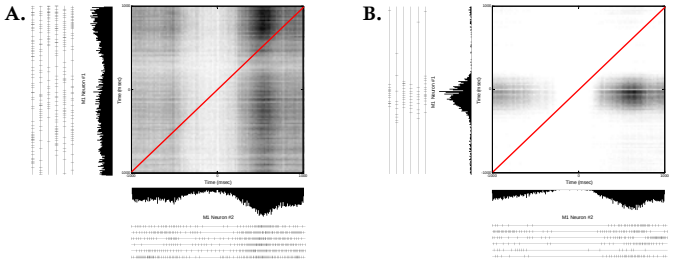

Figure 5: Joint peri-event histograms (JPEH) for selected neurons for (**a**) Session 1 and (**b**) Session 15. Histograms are aligned on the acquisition of Target (2,1). The region of JPEH highlighted in red corresponds to the coincidence histogram for the two units.

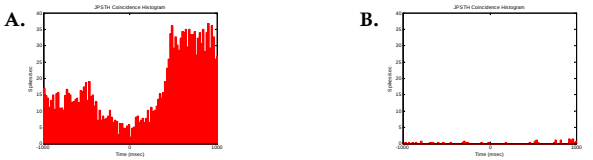

Figure 6: Coincidence histograms for selected neurons in (**a**) Session 1 and (**b**) Session 15.

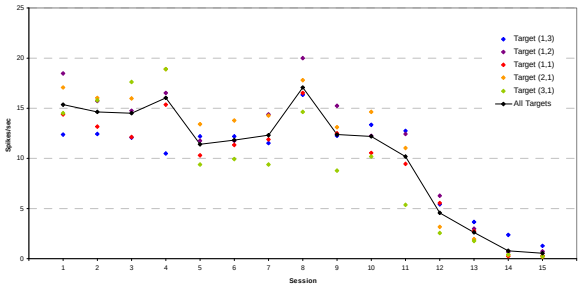

Figure 7: Mean of coincidence histograms for five targets across all sessions.

Discussion

1. In these experimental sessions, improved performance in the task required the dissociation of the activity of two M1 neurons. The activity of the two neurons selected for this task became increasingly dissociated across the experimental sessions.

2. Observations of the non-human primate's behavior during these experimental sessions revealed that he learned characteristic movements or muscle contractions which were correlated to the discharge of the neurons selected for this task. Though not obligatory for successful task performance, the primate resorted to these movements and muscle contractions when frustrated with the task.

3. These data indicate that primates can learn to encode prosthesis control through plastic adaptation of discharge patterns in primary motor cortex.

Acknowledgements

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