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Using transient, modality-specific neural responses to enhance decoding

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Introduction: The real-world implementation of brain-computer interfaces (BCI) for use in e.g. computer access should ideally rely on fully asynchronous decoding approaches. That is, the decoding algorithm should continuously update its output by estimating the user's intended actions from real-time neural activity, without any temporal alignment to an external cue. This kind of open-ended temporal flexibility is necessary to achieve naturalistic control, but presents a challenge: how do we know when it is appropriate to decode anything at all? Activity in motor cortex is dynamic and contains a heterogeneous mix of different control modalities (proximal arm, hand, speech, etc.) that can interfere with each other. Because of this, the "decodability" of any given action type (amount of relevant information present in the activity) fluctuates over time based on motor intent as well as intrinsic network dynamics. Here we present a method for simplifying the problem of decoder generalization that uses transient, modality-specific neural responses to first identify periods of modality engagement (e.g. "hand-related"). Only then do we decode specific features of that modality (e.g. digit or force). By using this two-stage approach, decoding models can be simpler (owing to local linearity) and are less sensitive to cross-modality interference.

Material, Methods and Results: We recorded intracortical activity from chronic microelectrode arrays (Blackrock Microsystems) in the primary motor cortex (M1) of two human participants with tetraplegia as they attempted arm- and hand-related tasks. The tasks included a mixture of covert proximal arm translation, individual finger presses, and full-hand grasp at different force levels. We found widespread transient responses at the onset and offset of all hand-related gestures that were nonspecific to the digit or force level (Figure 1a, top). We also found that the amount of available information regarding the specific digit(s) used and/or grasp force level peaked at the onset of a gesture and then steadily decreased until offset (Figure 1b). Based on these findings, we created a multi-level decoding approach for hand gestures that engages decoders for digit and/or force only after identifying a hand-related onset transient (Figure 1a, bottom). By restricting the decoder to operate only on relevant temporal epochs (indicated in Figure 1b), simple linear methods for both digit and force decoding were able to provide high quality control (0.1 errors per decoded gesture for both digit and force, compared to 3.6 and 16.2 errors per decoded gesture when using standard classification).

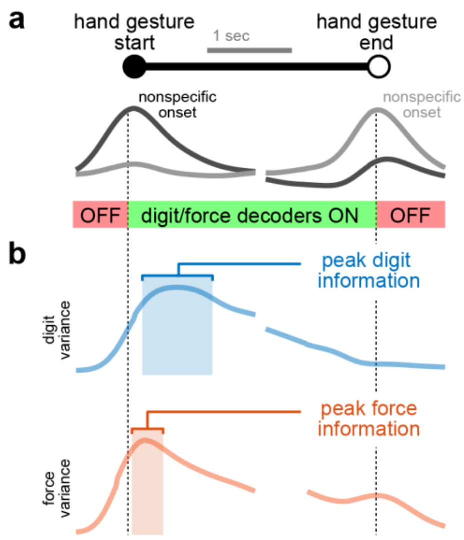

*Figure 1. Modality-specific transients indicate upcoming periods of high information content. **a** The participant performed tasks involving finger and grasp force gestures. Transient hand-specific responses—nonspecific to either digit or force level—existed at the onset and offset of gestures, which were used to enable and disable detailed decoding **b** The population activity contained decreasing information about finger and force throughout the gestures*

Discussion: Under controlled conditions, motor cortical activity often contains linear relationships with kinetic and kinematic variables. However, these simple relationships often break down during complex, free-behavior (like during real-world control). Here we show a nested, multi-layer method for dealing with nonlinearities during multi-modal BCI decoding.

Significance: Reliable control spanning multiple modalities (e.g. arm and hand) is essential for successful BCI application. We found that nonspecific transient responses related to modality engagement can be used to supplement decoding approaches and improve performance.

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