Exploring Missing Grasp Force Signals in Motor Cortex During Object Transport

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Introduction

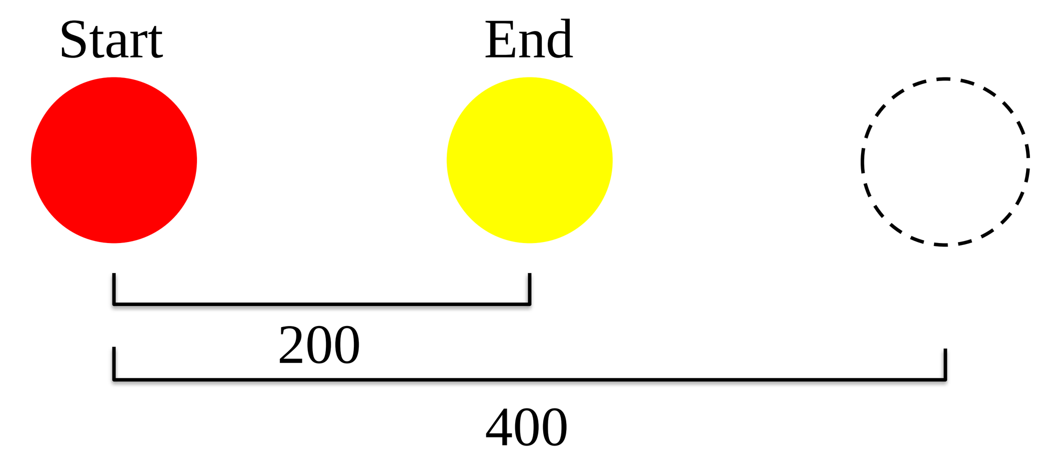
Currently, millions of people in the U.S. are living with spinal cord injury, limb loss, or limb difference, significantly impacting autonomy. Brain-computer interfaces (BCIs) offer potential solutions by translating neural signals into robotic prosthesis control. While research has primarily focused on decoding limb position and velocity, grasp force decoding remains underexplored despite its critical role: insufficient force results in object slippage, while excessive force risks breakage. Notably, preliminary studies suggest that grasp force information is lost in the motor cortex during object transport, leading to poor decoding accuracy. Given the established functional interplay between motor and somatosensory cortices, we hypothesize that this information loss stems from the absence of sensory feedback involving spinal cord injury patients. We leveraged a BCI subject with residual sensory and motor function to examine whether grasp force representation persists during object transport when using the native limb.

Experimental Setup

Clinical Trial NCT01894802 and approved by IRBs at the University of Pittsburgh and the University of Chicago. Participant C1 (male), 57 years old at the time of implant, presented with a C4-level ASIA D spinal cord injury (SCI) that occurred 35 years prior. Filament tests revealed spared deep sensation but diminished light touch in the right hand (detection thresholds ranged from 0.6 to 2.0 g across digit tips). Electrode arrays were implanted into the medial and lateral regions of the primary motor cortex (M1) and the primary somatosensory cortex (S1), comprising 96 channels per region in M1 and 32 channels per region in S1.

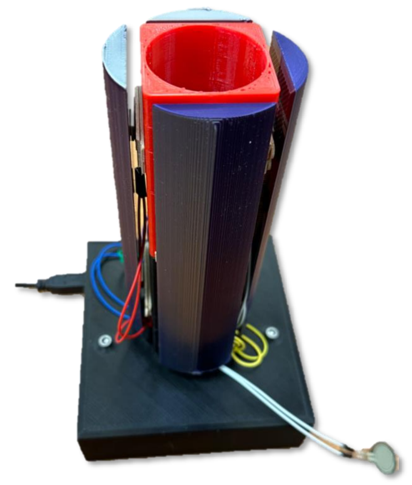
The subject was instructed to grasp and move a cylindrical object equipped internally with force-sensing resistors to measure the applied grasp force. The cylinder's weight varied between trials (ranging from 0 to 4) to elicit different grasp force levels. The subject sequentially moved the cylinder between three target locations projected onto a table surface along the same horizontal line. Concurrently, neural signals from the M1 and S1 were recorded.

Decoders were trained to predict object weight based on neural signals, aligned to force signal stages (force onset, plateau onset, plateau offset, and force offset) and grouped by target distances (0, 200, and 400).



Cylindrical Object

Two force-sensing resistors were positioned beneath each grasping surface, with an additional resistor placed at the base of the object to detect when it was completely lifted. Variable weights could be inserted into a central cavity to alter the object's mass.

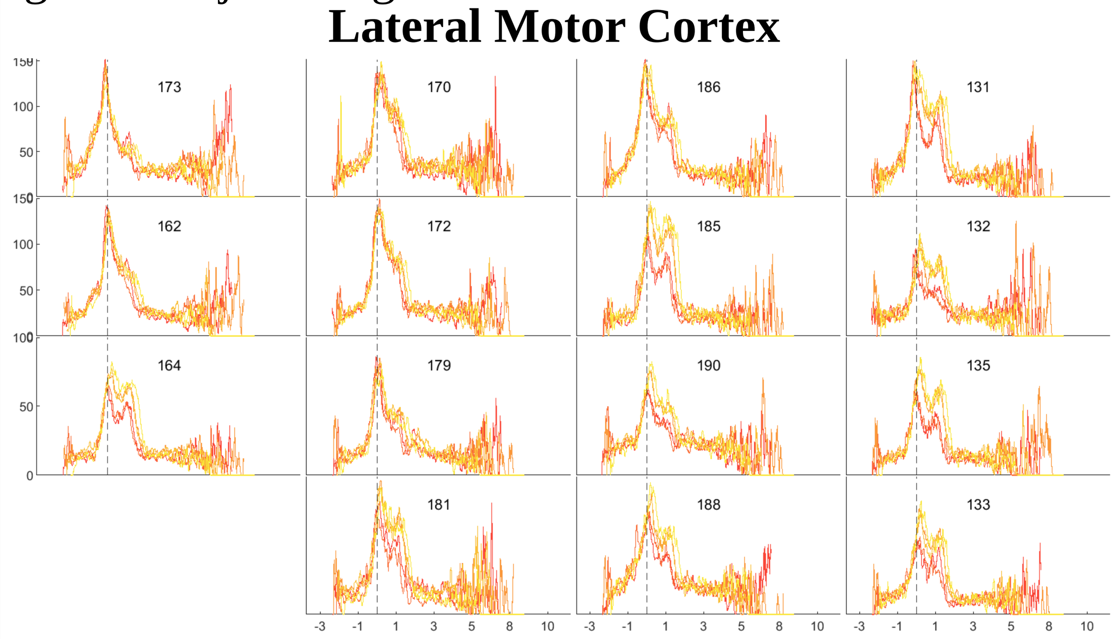


Result

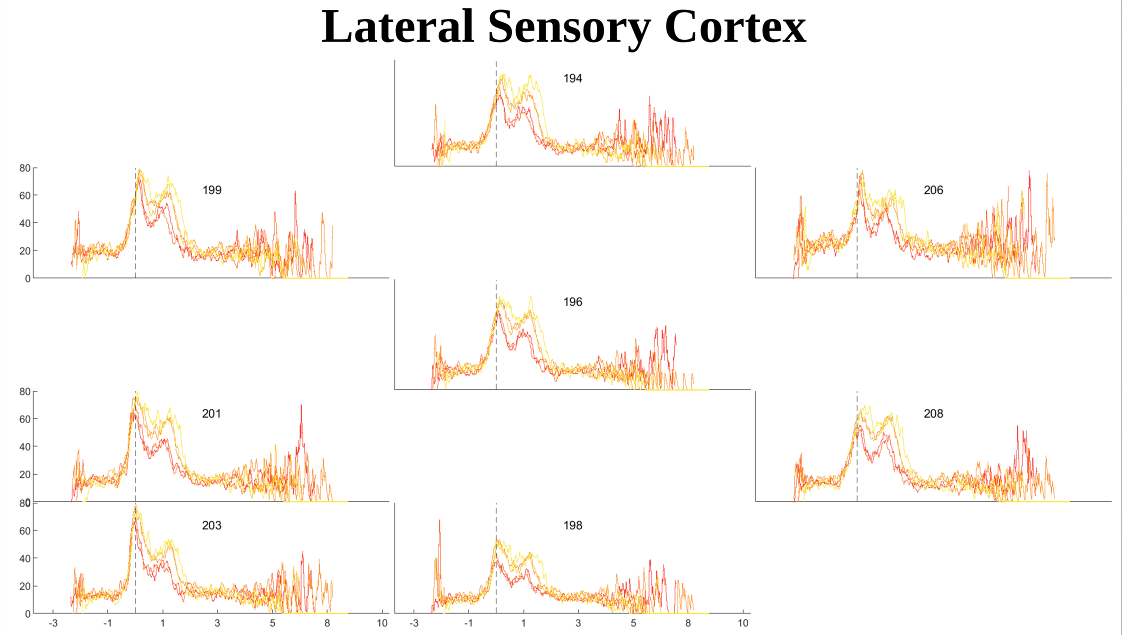
Per Channel Neural Activities

Neural data from each trial were aligned to a specific force signal stage and averaged across trials of the same weight. Representative neural activity from lateral M1 and lateral S1, distance 200, aligned to force onset, is shown. Increased neural activity was observed with greater object weight.

Lateral Motor Cortex

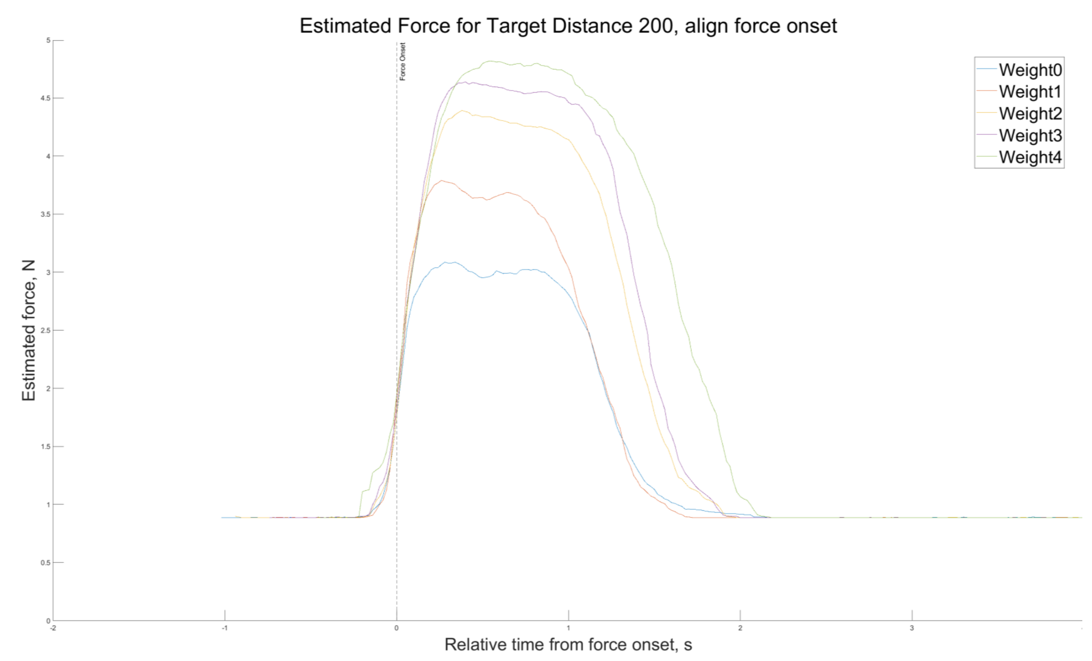


Lateral Sensory Cortex



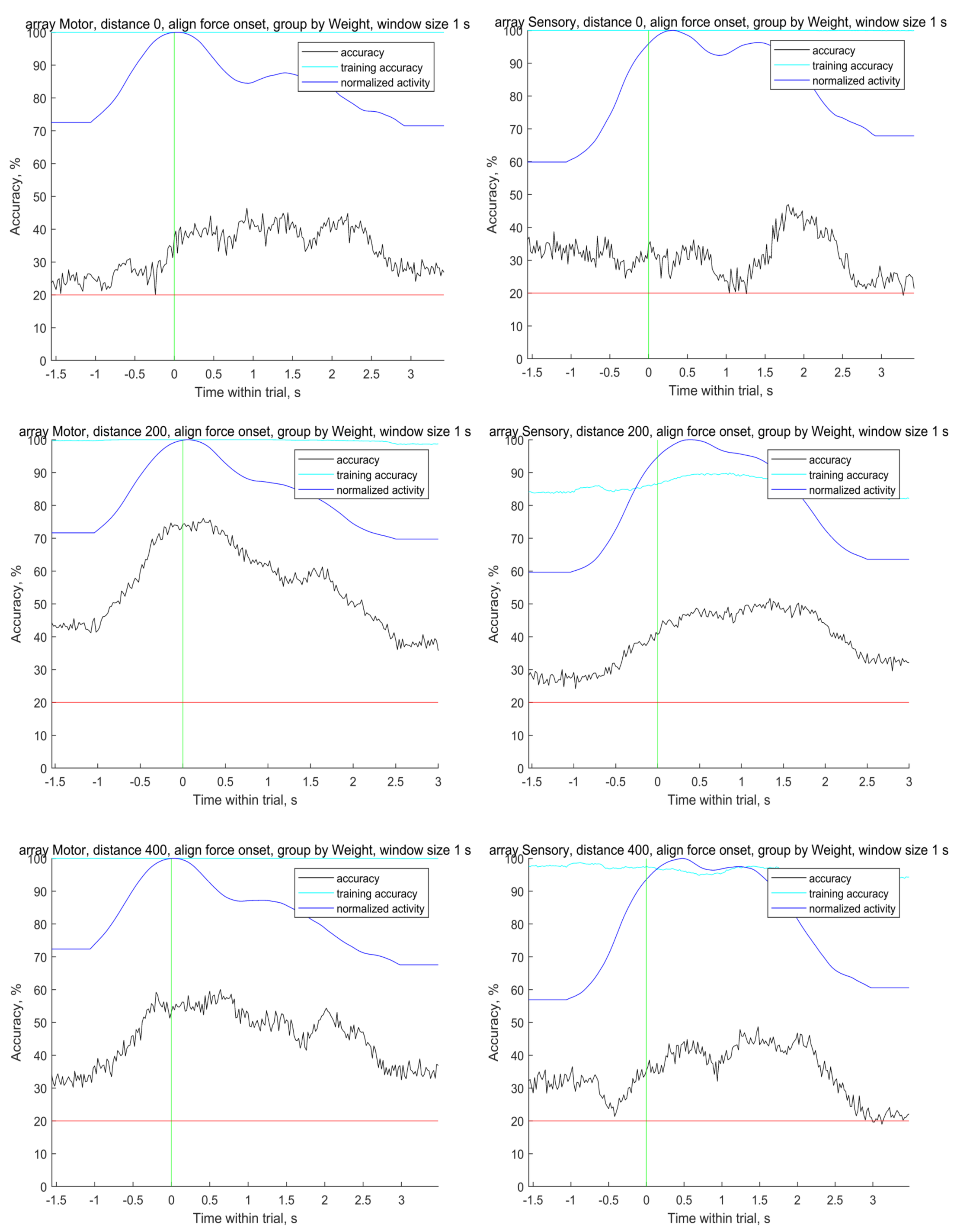
Grasp Force

As object weight increased, a greater magnitude of grasp force was consistently applied. Therefore, object weight serves as a valid proxy for grasp force and was used as the labeling variable for training the neural decoder.



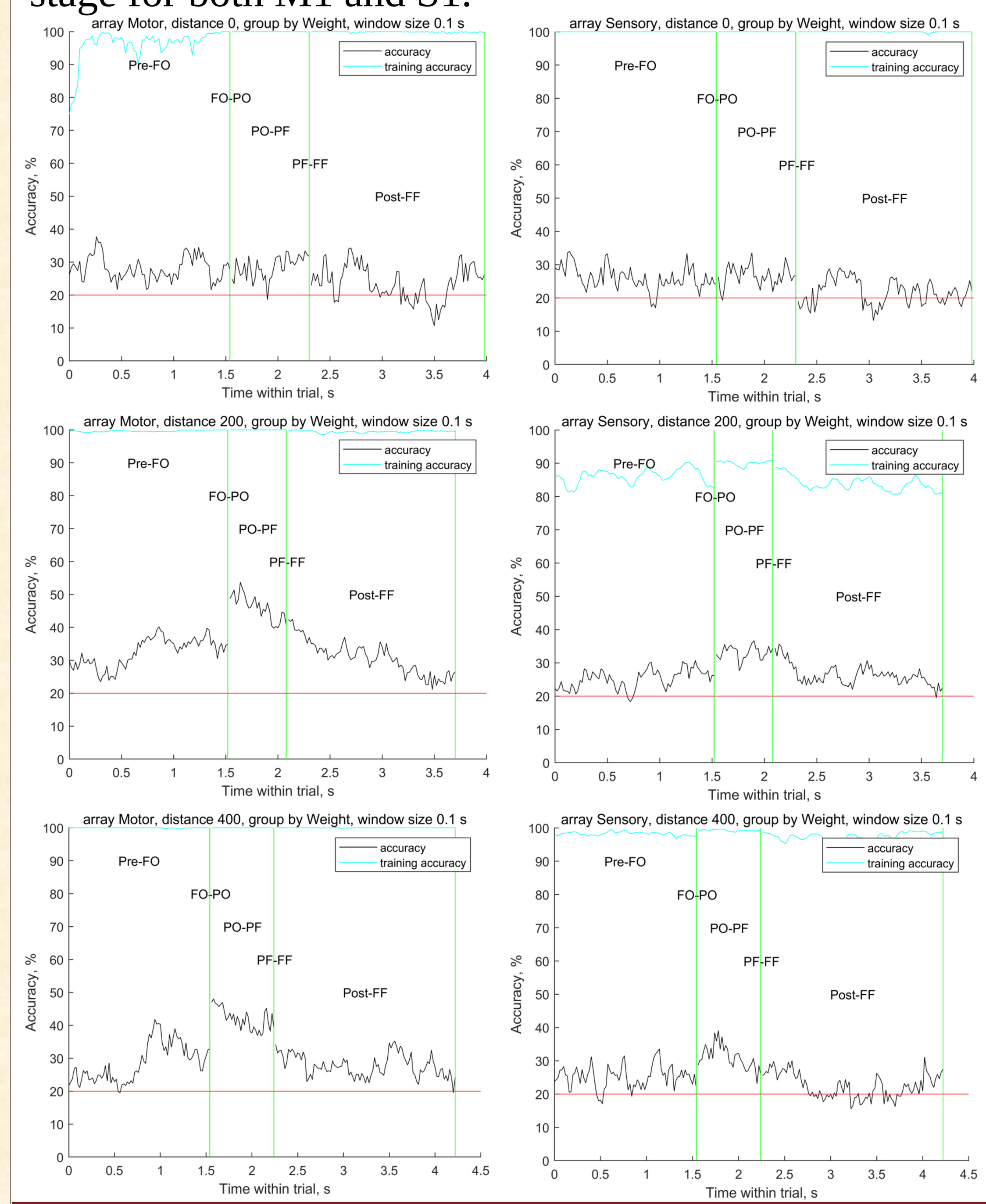
Decoder Aligned to a Single Stage

Neural data from each trial were aligned to a force signal stage. Representative results from a decoder trained on neural activity aligned to force onset, using a 1-second averaging window, are presented. Decoding performance near the force onset was significantly above chance for both M1 and S1.



Decoder Aligned to Multiple Stages

Neural data from each trial were segmented into five stages based on force signal stages: pre-force onset (Pre-FO), force onset to plateau onset (FO-PO), plateau onset to plateau offset (PO-PF), plateau offset to force offset (PF-FF), and post-force offset (Post-FF). Higher decoding performance was observed during the PO-PF stage for both M1 and S1.



Conclusions

While further validation is needed, preliminary results show that the decoder predicted object weight—correlated with grasp force amplitude—significantly above chance, suggesting that somatosensory feedback plays a critical role in encoding grasp force, particularly during object transport.

Acknowledgements

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