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Biological relevance of visual stimuli modulates the temporal binding window between ICMS and vision

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Introduction: Intra-cortical microstimulation (ICMS) of primary somatosensory cortex (S1) can elicit artificial tactile sensations in humans, but there has been little work on how the brain processes this non-naturalistic input in multisensory contexts. Understanding the timing necessary for visual and ICMS stimuli to feel simultaneous (the temporal binding window) is essential for a successful closed-loop brain-machine interface (BMI).

Material, Methods and Results: A tetraplegic patient implanted with 2 microelectrode arrays (Blackrock Neurotech) in S1 received single-channel ICMS (60 or 100 µA, 300Hz, 0.5s) while observing visual cues. Visual and ICMS stimuli were delivered at varying offsets from one another (0, 150 or 300ms). Visual cues, presented in virtual reality, were either abstract (a dot moving to the end of a line) or realistic (a robotic arm tapping a first-person-perspective human arm). The participant reported whether visual contact or ICMS-evoked sensations occurred first, or if they were simultaneous. Task performance was equal across visual conditions and was not affected by learning over time. The patient was more likely to perceive an order to the stimuli (vision before ICMS or ICMS before vision) in the abstract condition, whereas in the realistic condition the patient was more likely to perceive the stimuli as simultaneous (Fig. 1). Based on behavioral data, the participant experienced ICMS at a temporal lag relative to visual input, with a larger lag in realistic trials (~100ms) than in abstract trials (~50ms) (Wilcoxon sign rank test, $p<0.05$), despite more realistic trials being reported as simultaneous overall. Electrophysiological data was recorded during the experiment. During catch trials, in which no ICMS was applied, it was possible to decode baseline vs visual contact in both conditions, and generalize this decoder across conditions.

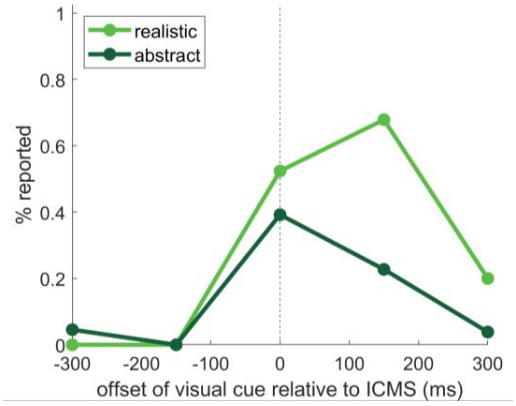

Figure 1. *Proportion of trials in which the participant reported visual contact and ICMS-evoked sensations were simultaneous, in two visual conditions.*

Discussion: The perceptual lag between visual and ICMS inputs indicates that ICMS is not well-integrated into a unified conscious experience of touch. Behavioral differences between visual conditions suggest that a more biologically relevant visual scene results in a larger temporal binding window between visual cues and ICMS. Visual content that more closely mimics biological touch allows the brain to better integrate ICMS inputs as part of a causal, multisensory environment. Additionally, decodable visual information in S1 indicates that S1 represents salient multisensory content in a context-independent fashion.

Significance: ICMS represents a potential method to restore touch and provide a closed-loop BMI to individuals with sensorimotor disorders. Uncovering how S1 encodes touch-related stimuli and how ICMS is interpreted in a multisensory context is necessary to understand uses and limitations of ICMS in real world environments.