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An efficient protocol to optimize ICMS encoding of artificial sensation

Samuel Senneka[1*], **Maria Dadarlat**[2]
[1] *Weldon School of Biomedical Engineering, Purdue University, West Lafayette, IN, USA*
*3164 Pheasant Run Dr. Apt 407, West Lafayette, IN 47909,USA. Email: ssenneka@purdue.edu

Introduction: Most prosthetic limbs lack proprioceptive feedback, which is essential for making complex movements [1, 2]. Intracortical microstimulation (ICMS) of the somatosensory cortex can be used to elicit sensory perceptions and guide active movements, which could serve as an artificial proprioceptive signal [3, 4]. However, movements guided by ICMS remain slower and less accurate than those guided by natural sensation. To improve sensory encoding via ICMS, we have developed a behavioral paradigm in freely moving mice to efficiently evaluate algorithms for encoding artificial sensory information via spatial and temporal patterns of ICMS.

Material, Methods and Results: C57BL/6J mice between 3-4 months were implanted with a TDT 8x2 microwire electrode array (N = 5). ICMS stimulation was controlled by a Ripple Neuro Grapevine Processor and behavioral data was tracked with DeepLabCut Live. Mice were trained to navigate to targets within the training cage guided by combined visual and ICMS feedback (Fig. 1a). Target location (distance and direction relative to mouse's heading) was encoded via patterned ICMS across all sixteen electrodes. For electrode i, stimulation frequency at time t was set to $f_i(t) = \delta(t) * e^{\kappa * cos(\phi_i - \theta(t))}$, where $\theta(t)$ is animal's heading relative to the target direction, $\delta(t)$ scales with distance to the target, and ϕ_i is fixed for each electrode. Stimulation pulses were cathode-leading biphasic symmetric pulses with a fixed amplitude between 10-20 μA and pulse frequency ranging from 10-200 Hz; stimulation parameters were updated at 10 Hz. Once subjects became proficient in the behavioral task, probe trials were introduced: ICMS-only, visual-only, and sham (no inputs). Mice quickly learned the task, achieving $\geq$80% accuracy on combined trials in 4-6 training sessions (400-600 trials). Mice could complete ICMS-only trials with $\tilde{7}0\%$ accuracy, which was statistically equivalent to their performance on visual-only trials (Fig. 1b). Animal performance on combined trials was statistically better than on unimodal trials (ICMS-only or dim visual-only), suggesting that the two signals were integrated (Fig. 1c).

Conclusion: Mice quickly learn the behavioral task and perform many trials (150-200) per training session. The speed and extent of learning that we present here support this approach for communicating multivariate sensory information (direction and distance) to the central nervous system. This behavioral paradigm can be easily adapted to further investigate how specific parameters of ICMS (such as the number of electrodes used) impact encoding accuracy. Using this approach, we can aim to delineate the limits and capabilities of using ICMS to provide artificial sensation.

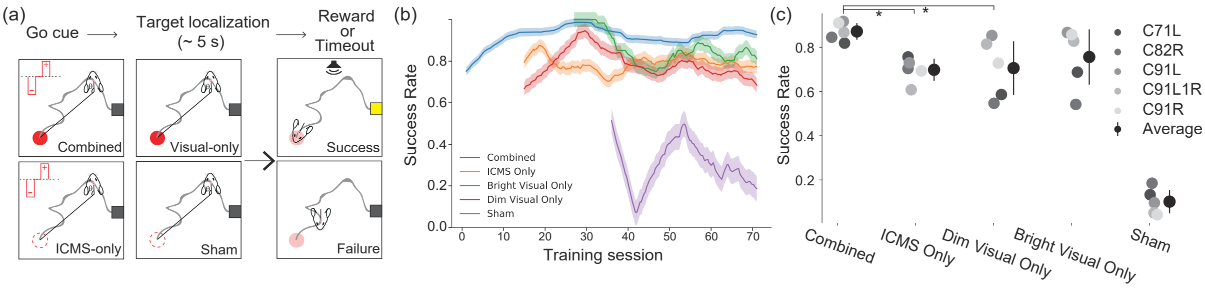

Figure 1: *(a) Trial structure: Target is randomly selected and trial start is indicated by go cue. Subject receives either combined visual-ICMS, visual only, ICMS only, or no feedback (sham) and have 5 seconds to reach the target. Successful trials are indicated by a success tone and rewarded with juice. A new trial starts 5-7 seconds after reward is collected or at the end of a failure trial. (b) Learning of task structure and ICMS, shown as the (smoothed) fraction of correct trials across training sessions for one subject. (c) Success rates for all subjects for each trial type over last five training sessions for each subject. Asterisks indicate significant difference in success rates between paradigms. Performance on sham trials was significantly worse than all others.*

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