Injecting Arbitrary Instructions into Anterior Intraparietal Area with Low-Amplitude Intracortical Microstimulation

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Summary

Current efforts to improve brain-computer interfaces (BCIs) are focused on delivering information about the state of the BCI to the brain. Providing such information from multiple sensory modalities can improve the speed and accuracy of BMIs. Information has been successfully delivered to the cerebral cortex by exciting neurons in gray matter with intracortical microstimulation (ICMS). ICMS subthreshold for evoking muscle contraction (low-amplitude ICMS) can elicit distinguishable experiences when delivered in primary somatosensory, visual, and auditory cortex, as well as ventral premotor cortex – an association cortical region.

The anterior intraparietal cortex (AIP) is another association cortical region where information could potentially be delivered with low-amplitude ICMS. AIP extracts visual information about objects and communicates with the ventral premotor cortex to plan appropriate grasping movements. Such visuomotor transformations are critical for making natural dexterous grasps, making AIP a desirable region for interfacing with neuroprosthetics involving motor control. Here, we demonstrated that low-amplitude ICMS in AIP elicited distinguishable experiences a monkey learned to associate with arbitrarily-assigned movements. AIP offers novel cortical territory for delivering information to improve the functionality of BCIs.

Methods

Array Implantation

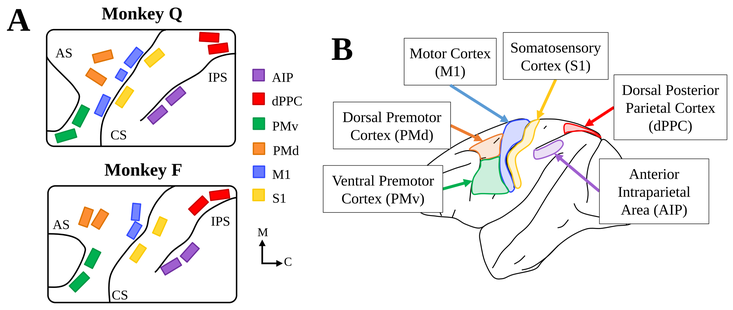


Figure 1. 1A) Floating microelectrode arrays (FMAs) implanted in anterior intraparietal area (AIP – purple), dorsal posterior parietal cortex (dPPC – red), primary somatosensory cortex (S1 – yellow), primary motor cortex (M1 – blue), ventral premotor cortex (PMv – green), and dorsal premotor cortex (PMd – orange) in monkeys Q and F. AS: Arcuate Sulcus, CS: Central Sulcus, IPS: Intraparietal Sulcus, M: Medial, C: Caudal, **1B)** Cortical diagram outlining estimated boundaries of each implanted region for rhesus macaque cortex.

Center-Out Task

We trained two rhesus macaques (Q and F) to perform a center-out task (COT). The monkeys were instructed to move a cursor from a center target to one of four instructed peripheral targets:

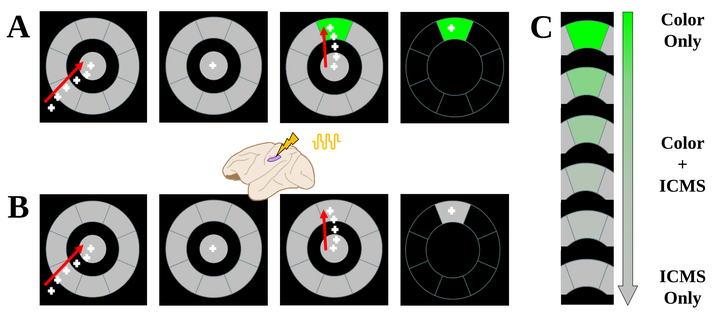


Figure 2. 2A) COT task instructed with visual cues only. **2B)** COT task instructed with ICMS only. **2C)** ICMS training progressed by pairing the ICMS with the visual cues, and then gradually removing the visual cues until ICMS served as the only instruction.

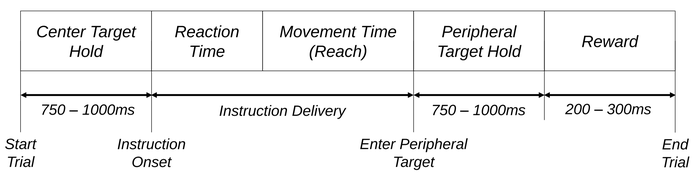


Figure 3. Breakdown of trial epochs during the center-out target task.

Methods

Training to use Intracortical Microstimulation Instructions

Table 1. Stimulation Parameters during Training

	AIP-ICMS	PMv-ICMS	S1-ICMS
Pulse Shape	Biphasic, 200µs, cathode-leading, symmetric		
Number of Electrodes	1 – 4	1 – 4	1 – 4
Amplitudes	35 µA	20 µA	20 – 35 µA
Period Frequencies	33 – 80 Hz	33 – 80 Hz	33 – 80 Hz
Pulse-Train Duration	Instruction onset – final hold onset		

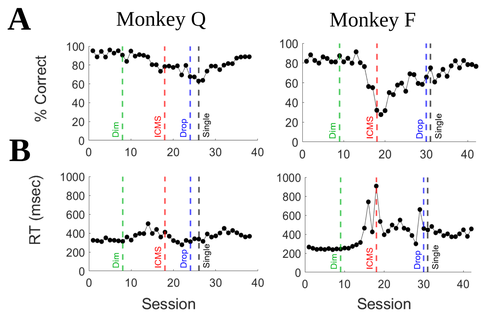
AIP-ICMS: Instructions delivered in anterior intraparietal cortex

PMv-ICMS: Instructions delivered in ventral premotor cortex

S1-ICMS: Instructions delivered in primary somatosensory cortex

Results

Training Results with AIP-ICMS



Key Takeaways

- Low-amplitude AIP-ICMS evokes distinguishable experiences that monkeys can learn to associate with specific movements
- After complete ICMS training, success percentages were comparable to baseline levels with full visual cues

Figure 4: Success percentages **4A)** and reaction times **4B)** during training to learn AIP-ICMS instructions. Vertical dashed lines demarcate the following training milestones: 1) 'Dim' (green) – color desaturation of visual-cues with paired ICMS begins, 2) 'ICMS' (red) – only ICMS instructions remain, 3) 'Drop' (blue) – dropping stimulating electrodes to reduce to one electrode per target, 4) 'Single' (black) – each instruction delivered on a single electrode. No further changes were made after single-electrode ICMS was achieved.

Sweeping Parameters of AIP-ICMS Instructions

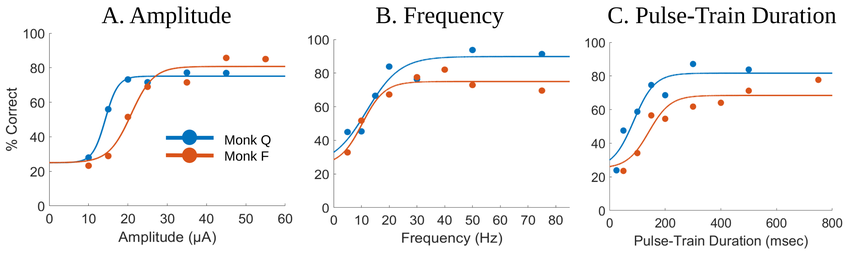


Figure 5: **5A)** Amplitude, **5B)** frequency, and **5C)** pulse-train duration of AIP-ICMS instructions were swept. Data were fit to psychometric performance functions to estimate how parameter changes affected behavior for Q (blue) and X (orange).

Psychometric Performance Function

$$Y = \frac{A-D}{1+e^{-B(x-C)}} + D$$

Y, Success percentage
x, Swept parameter
A, Scale parameter → Plateau performance
B, Slope → Sensitivity to changes in '*x*'
C, x-shift → Detection threshold (50% of *'A'*)
D, y-Shift → Chance performance (25% for 4 Targets)

Table 3. Fitted psychometric parameters for Q (blue) and F (orange).

Function Parameter	*A*, Plateau (%)	*B*, Sensitivity (Δ% / Δx)	*C*, Threshold (µA, Hz, or ms)
Amplitude (µA)	75.1	0.62	14.3
	80.7	0.35	20.8
Frequency (Hz)	89.8	0.17	11.9
	75.0	0.25	10.3
Pulse-Train Duration (ms)	81.7	0.03	87.1
	68.4	0.03	141.0

Key Takeaways

- Behavior most sensitive to changes in amplitude
- ICMS detection thresholds are very low
  - *Amplitude: 14µA*
  - *Frequency: 10Hz (1 pulse every 100ms)*
  - *Pulse-Train Duration: 87ms (3-4 pulses)*

Results

Stimulus-triggered Averaging Shows No Evoked Muscle Activity

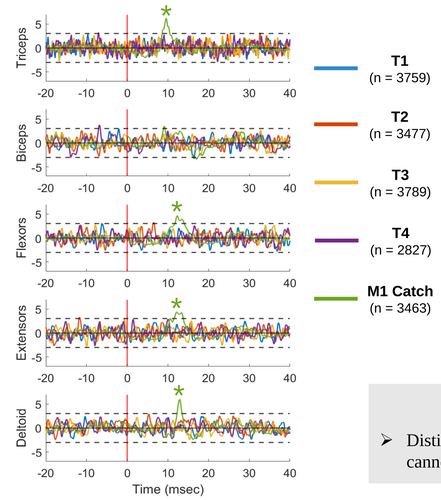


Figure 6: Stimulus-triggered averages of EMG activity from five upper extremity muscle groups of monkey Q – Triceps, Biceps, Forearm Extensors, Forearm Flexors, and Deltoid – were triggered on individual ICMS pulses (t = 0, red vertical line) delivered in AIP to instruct each target (T1, T2, T3, T4) and M1 (catch trials). EMG signals were sampled at 30kHz, rectified, smoothed with a flat 10-point finite impulse response filter, and averaged across 'n' ICMS pulses (see legend). Smoothed, averaged EMG traces rising above 3 standard deviations for longer than 1ms were deemed significant (color-coded * in EMG traces). Data is only shown for monkey Q, but no significant AIP-ICMS triggered EMG averages were found in monkey X either.

Key Takeaway

- Distinguishable experiences elicited by AIP-ICMS cannot be attributed to different muscle contractions

Comparing Performance with AIP-, PMv-, and S1-ICMS

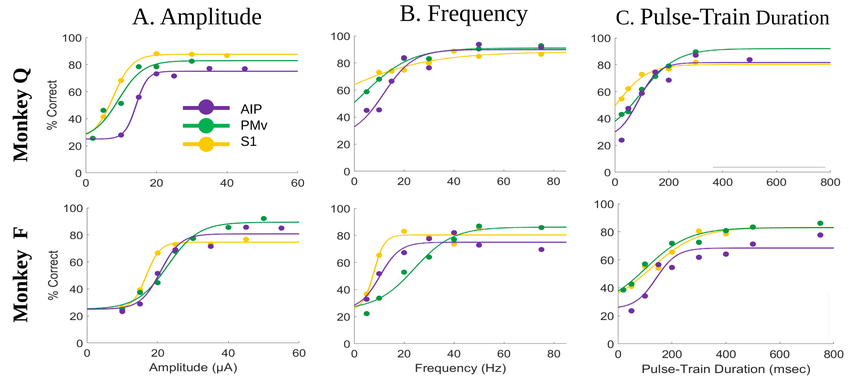


Figure 7: Comparing behavioral sensitivity to changing 7**A)** amplitude, **7B)** frequency, and 7**C)** pulse-train duration of ICMS instructions delivered in AIP (purple), ventral premotor cortex (green), and primary somatosensory cortex (yellow).

Key Takeaway

- Sensitivity to changing parameters of ICMS delivered on single electrodes was similar in AIP, PMv, and S1

Discussion

- AIP-ICMS produced distinguishable experiences with amplitudes as low as 14µA, frequencies as low as 10Hz, and pulse-train durations as short as 3-4 pulses
- AIP-ICMS instructions were clear and distinguishable enough for both monkeys to achieve performance similar to that obtained with visual instructions
- Experiences elicited by ICMS delivered via nearby electrodes in AIP can be distinguished from one another (note that in both monkeys, two different instructions were delivered on the same array)
- AIP-ICMS did not emulate natural cortical activity

Future Work

- What is the spatial resolution for delivering distinguishable information in AIP?
- How does AIP-ICMS affect neural activity in distant cortical regions?
- In what other association regions can ICMS be used to deliver information?

Acknowledgments

- Supported by NINDS grant R01NS107271 to MHS and F31NS129099 to BMR