Evoking Behavior-Oriented Neural Population Patterns by Intracortical Microstimulation

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Core question

Can ICMS evoke a neural population state resembling natural motor behavior?

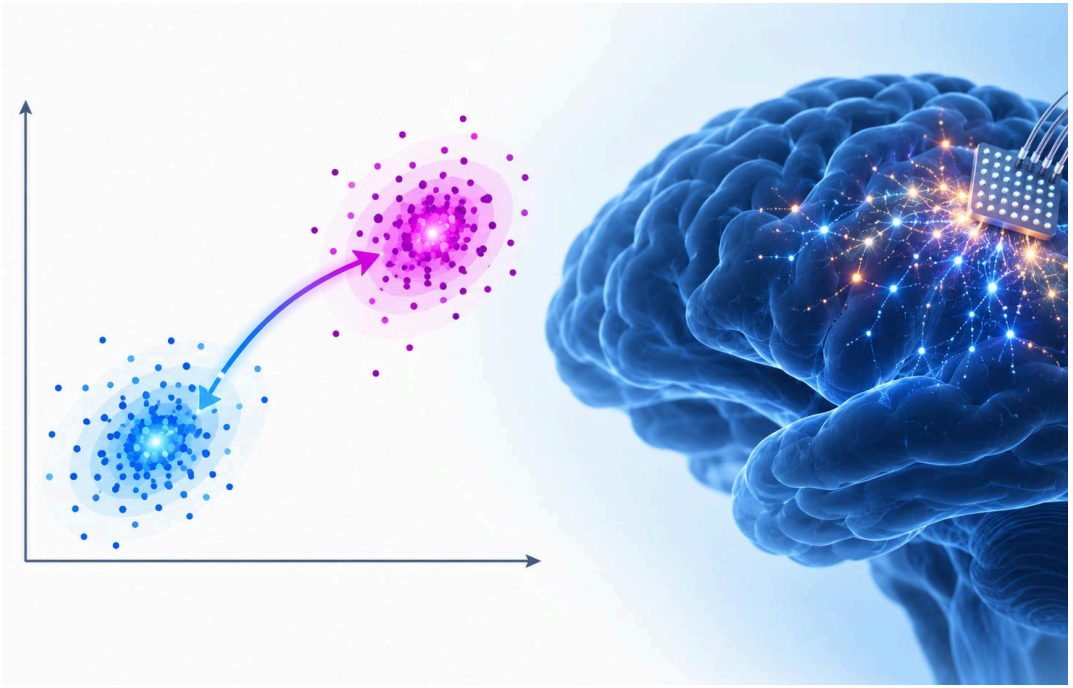
Motivation: from stimulating tissue to evoking functional neural states

Why this matters

M1 is central to voluntary motor control, and ICMS provides a direct route to modulate local cortical activity.

The missing step

Activation alone is not enough. For restoration, evoked activity should match behavior-related population patterns.



We evaluate ICMS as a way to write behavior-relevant neural states into M1.

Research gap and hypothesis

Previous evaluation of ICMS in M1

- single-pulse neural responses
- EMG / muscle activation
- peripheral-output parameter search

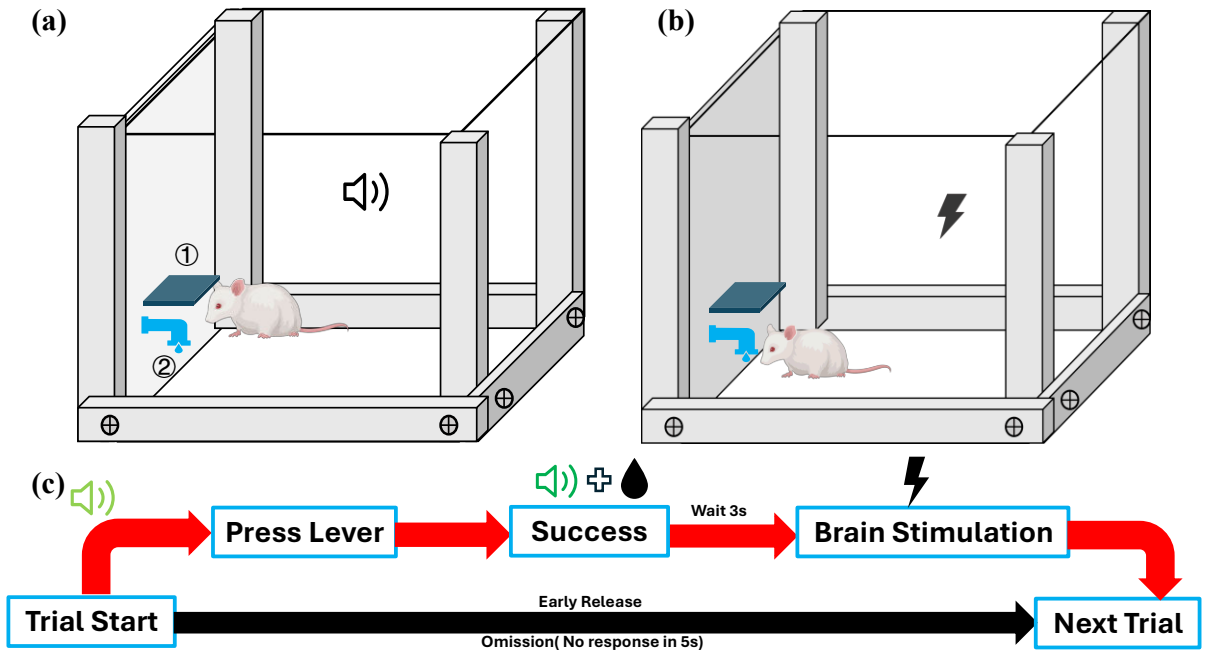
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Gap
Population-level alignment with natural behavior remains unclear.

Working hypothesis

Some stimulation parameter combinations can shift post-stimulation M1 activity from a rest-like state toward a hold-like state.

Experimental design: one-lever press task with inter-trial ICMS



One-lever press task and stimulation timing.

Behavioral task

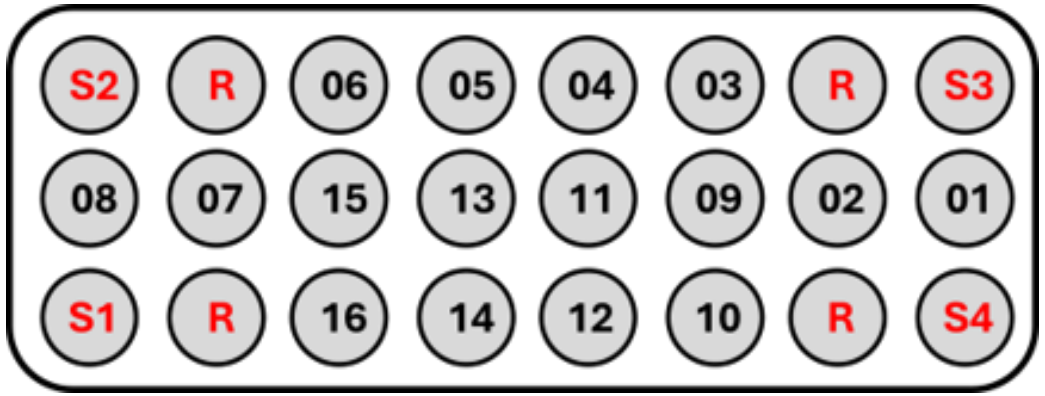
- 90 ms, 10 kHz auditory start cue
- press and hold lever for 500 ms
- correct trial → tone + water reward
- inter-trial interval: random 8–10 s

Stimulation timing

ICMS was delivered randomly during inter-trial intervals while the rat was drinking water, allowing evoked responses to be separated from active lever pressing.

Natural behavior defines the reference; inter-trial ICMS provides the evoked test response.

Stimulation and recording setup



Stimulation and neural recording contacts on the microelectrode array

Channel\Amplitude	15μA	30μA	45μA	60μA
Ch1	1	2	3	4
Ch2	5	6	7	8
Ch3	9	10	11	12
Ch4	13	14	15	16

4 amplitudes × 4 channels = 16 tested combinations

Fixed stimulation train

100 Hz | 150 ms | biphasic pulses
shuffled order across combinations
6 repetitions each → 96 stimulation trials/session

Neural recording and sorting

40 kHz acquisition; 500 Hz high-pass filtering; adaptive −4σ spike detection; offline PCA-based single-unit isolation.

Data quality and neuron selection

90.6%
behavioral success

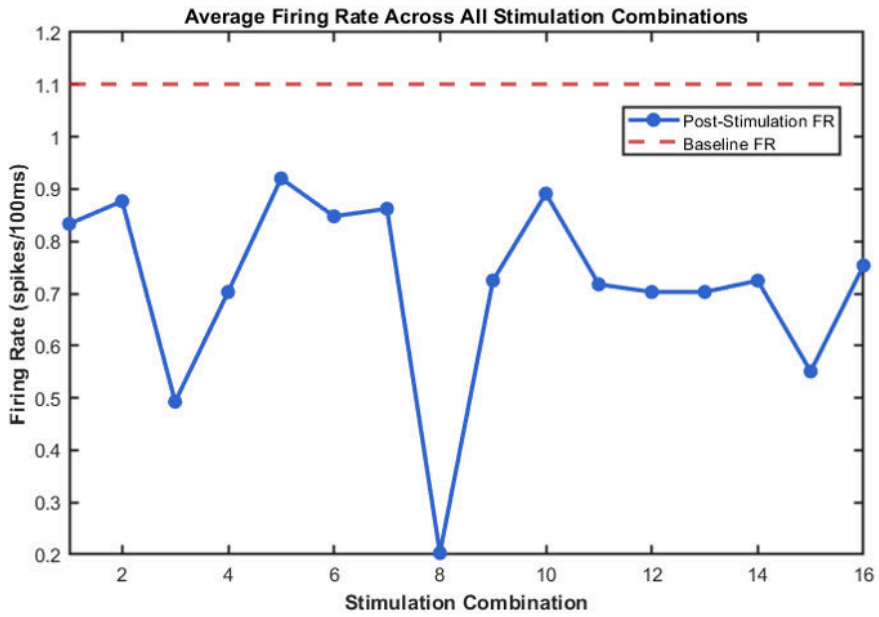
94/96
usable stimulation trials

9
neurons selected

Five of 14 initially recorded neurons were excluded because they showed consistent stimulation-induced suppression across all tested parameters.

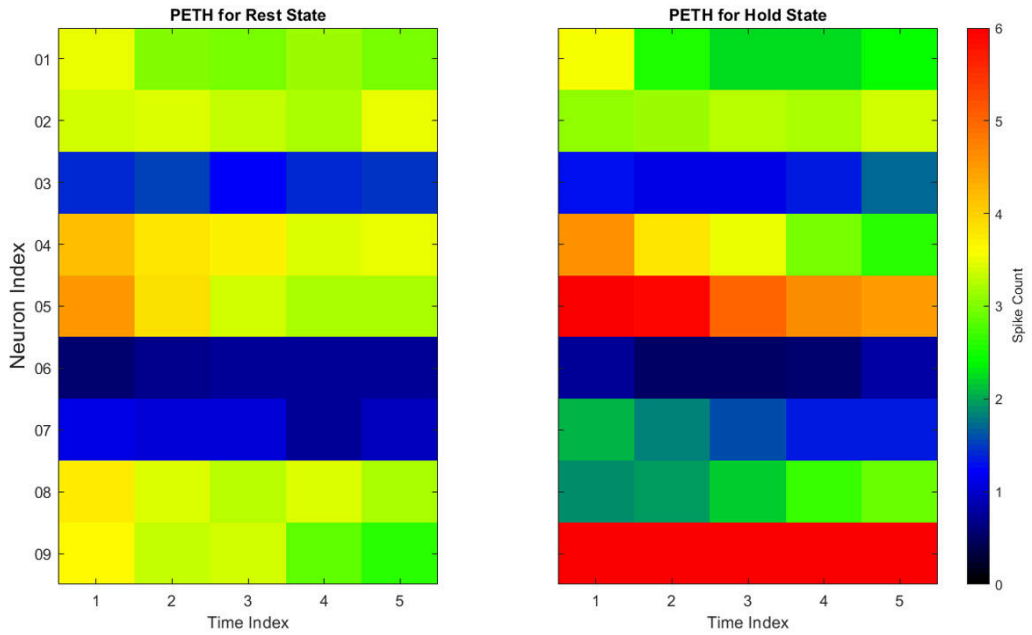
Why exclude inhibited neurons?

Because lever pressing mostly increased firing rates, the analysis focused on neurons likely to be positively recruited by stimulation.

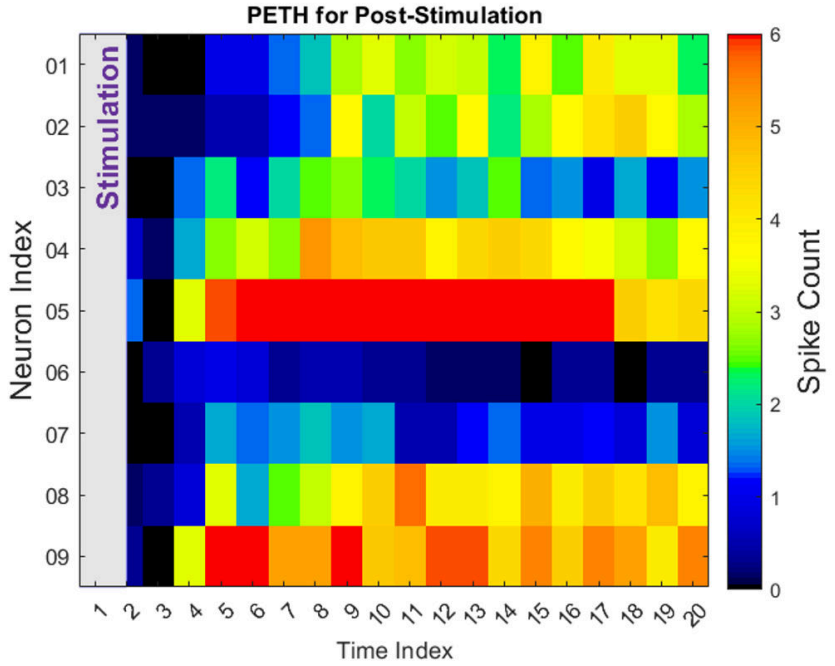


Example inhibited neuron.

Result I: post-stimulation PETHs resemble the natural hold state



Natural behavior: rest vs hold PETHs



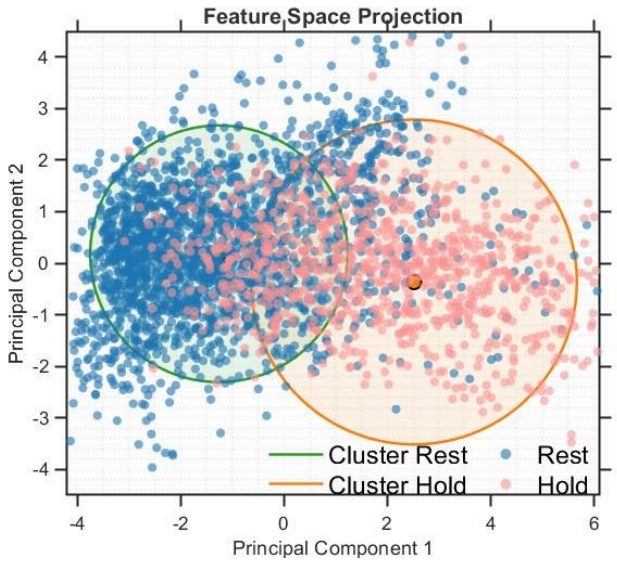
Post-stimulation PETH

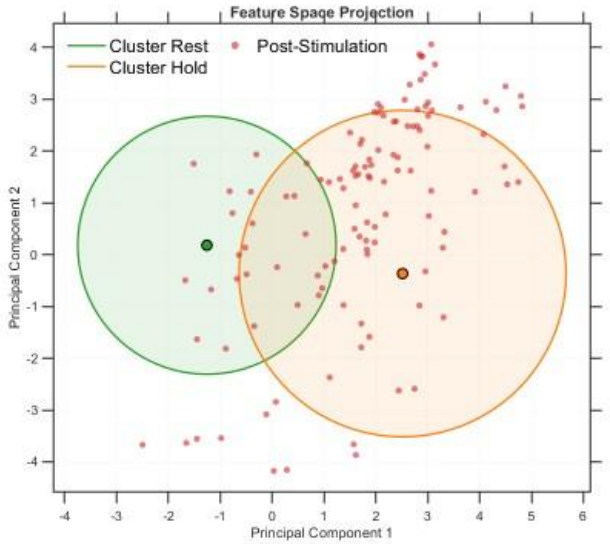
Interpretation

Rest and hold showed distinct population patterns. Post-stimulation activity deviated from rest and visually resembled the hold pattern, especially in neurons 05 and 09.

Qualitative evidence: ICMS can evoke a hold-like population pattern.

Result II: PCA subspace alignment quantifies hold-like recruitment





Behavioral and stimulation-evoked activity in the same PCA subspace

Key numbers

72.71%
rest cluster coverage

69.85%
hold cluster coverage

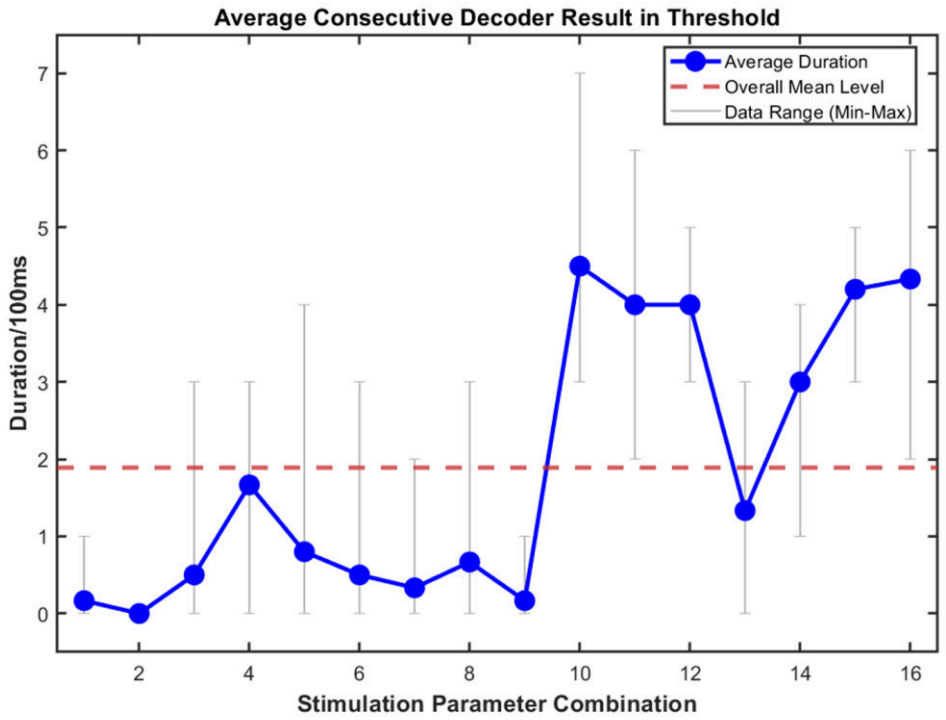
Post-stimulation alignment

64.17%

of post-stimulation points fall inside the natural hold-state cluster.

Quantitative evidence: ICMS recruits activity within the behavioral hold-state distribution.

Result III: Kalman filter decoding shows parameter-specific effects

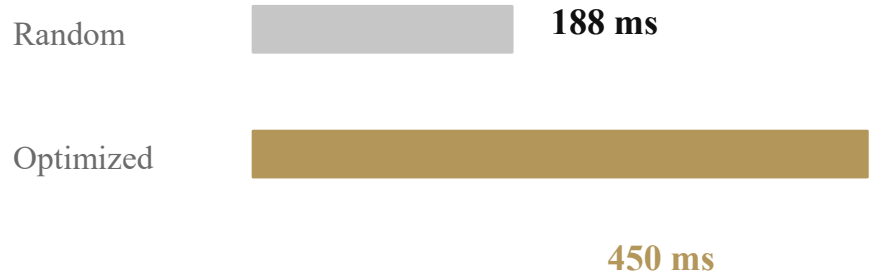


Consecutive duration within hold-like decoder threshold across stimulation parameters

Decoder criterion

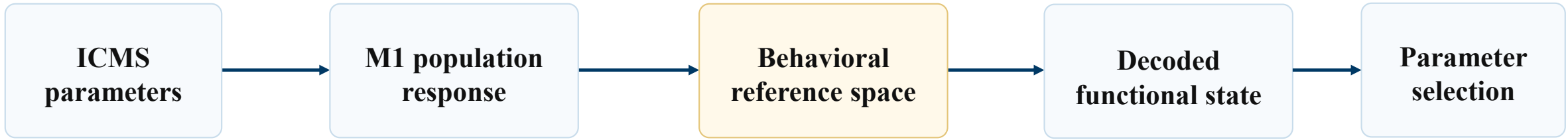
A decoded state was considered hold-like when it stayed within 0.7–1.3.

Duration comparison



Optimized stimulation sustained hold-like decoding for more than twice as long as random stimulation.

Toward behavior-oriented neuromodulation



Main contribution

This work evaluates ICMS by whether it evokes a population pattern aligned with a target behavioral state, not by activation strength alone.

Implication Future ICMS systems could select parameters that place neural activity into desired behavior-related states.

Limitations Current limits: small parameter space and offline evaluation; closed-loop optimization remains future work.