Neural basis of coordinate transformations of tactile motion stimuli on the hand

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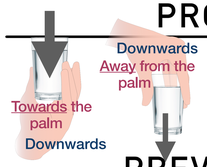
INTEGRATION OF TOUCH AND PROPRIOCEPTION

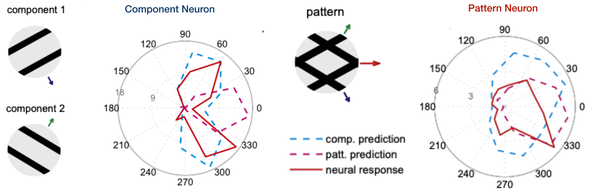


How are tactile inputs on the hand integrated with proprioceptive signals?

How is this integration controlled by the reference frame?

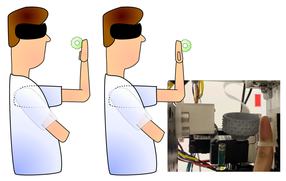
PREVIOUS RESEARCH

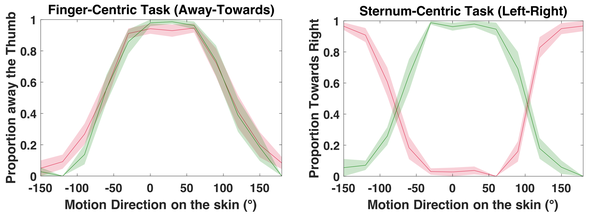
Area 1 of the Somatosensory Cortex has been shown to integrate local motion direction cues to compute a global motion percept (*Pei et. al, 2011*).



This results from these studies were derived with the **hand in only one posture, so we don't know if Area 1 neurons are modulated by proprioception.**

In our psychophysics work, we show that humans integrate posture and tactile motion direction in a reference-frame dependent manner (*Ahuja et. al 2024*)



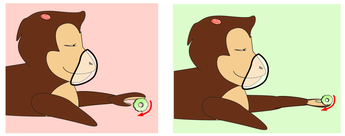


RESEARCH QUESTION

Are *tactile-motion direction sensitive* neurons in Area 1 modulated by proprioception?

Can these neurons generate readouts in non-skin-centric coordinates?

METHODOLOGY



Anesthetized NHP preparation (N=1)

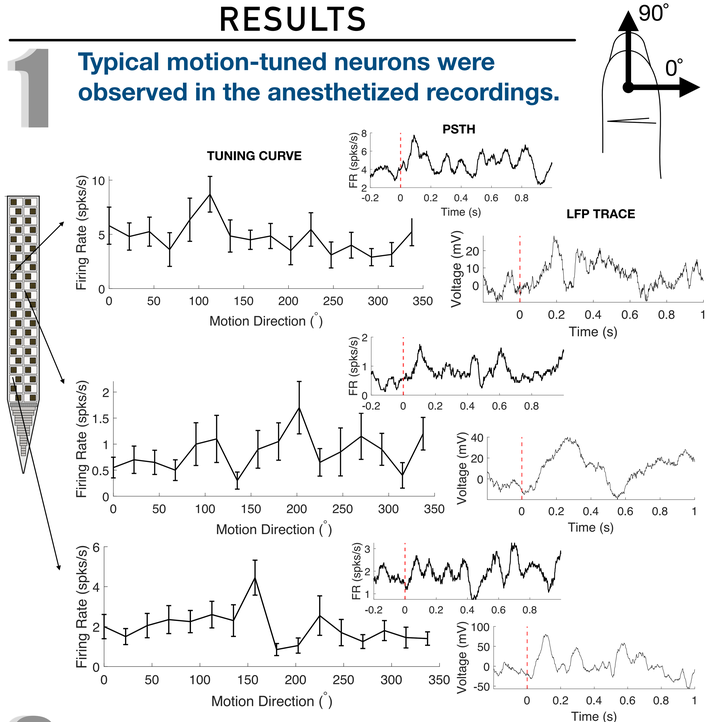
Two Postures — Supinated and Pronated roll around the elbow.

Recordings in the Somatosensory cortex using **NHP Neuropixels**.

Stimulator: Rotating wheel in 16 directions (0°-360°) steps of 22.5°

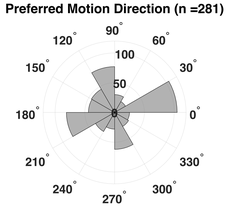
RESULTS

1 Typical motion-tuned neurons were observed in the anesthetized recordings.

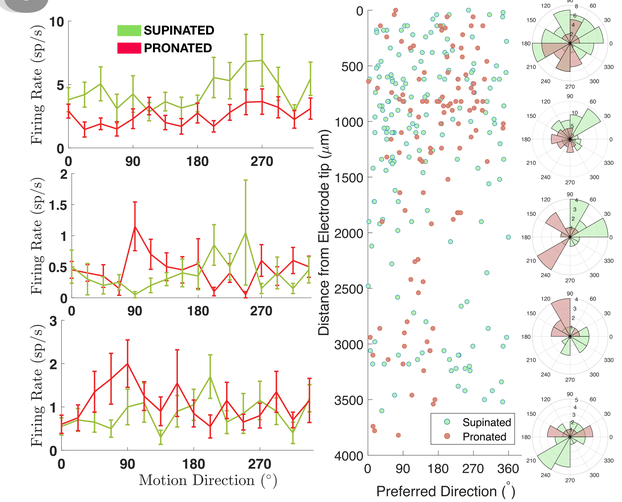


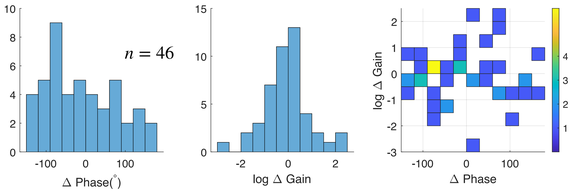
2 Population Statistics

Neuron Type	Number of Units
Isolated Single Unit	582
Responsive	376
Motion Selective	281
Traditional	112

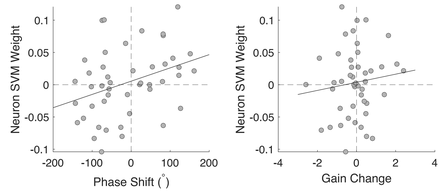


3 Proprioception modulates the tuning properties of motion-sensitive neurons



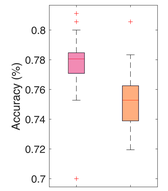


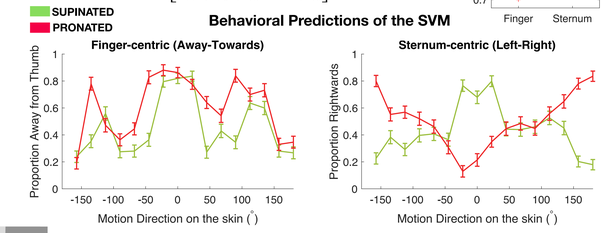
SVM Readout Weights Compared Against Neuron Phase and Gain Changes



4 Linear SVM Decoder trained on neural data matches human behavior in multiple reference frames

$$X = \begin{bmatrix} fr_{11} & fr_{12} & fr_{13} & \dots & fr_{1n} \\ fr_{21} & fr_{22} & fr_{23} & \dots & fr_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ fr_{T1} & fr_{T2} & fr_{T3} & \dots & fr_{Tn} \end{bmatrix} \quad y \in \{0,1\}^T$$





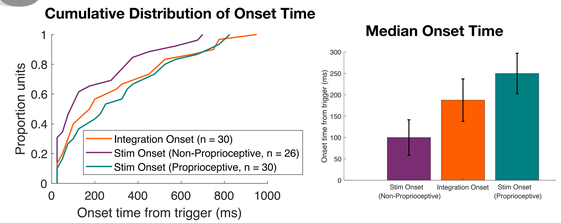
5 Traditional neurons have independent gain change and phase changes

$$\mathrm{FR}(\theta; g, \mu, \sigma) = g \cdot exp\left(\frac{-2 \cdot (1 - cos(\theta - \mu))}{\sigma^2}\right)$$

$$\Delta\text{Phase} = \mu_{\text{Pro}} - \mu_{\text{Sup}}$$

$$\log \Delta\text{Gain} = \log \frac{g_{\text{Pro}}}{g_{\text{Sup}}}$$

6 Onset effects for Integration of Proprioception and Tactile motion



CONCLUSION

Proprioception modulates the preferred direction of tactile motion of neurons in the somatosensory cortex. This modulation can be characterized with phase shift and gain change mechanisms

Changes in phase-shift by proprioception appear more prominent in deeper brain regions of SI (e.g., Area 3b, or deeper layers of Area 1)

The effects of proprioception on tactile motion tuning functions are delayed, indicating that that proprioceptive-dependent changes on neurons' preferred direction emerge from feedback mechanisms.

Neural responses can predict human behavioral response in finger and body-centric reference frames.

In general, our experiment showcases a feasible paradigm to study neural interactions between proprioceptive and tactile signals in somatosensory cortical neurons of non-human primates.

ACKNOWLEDGEMENTS

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