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LOW FREQUENCIES IMPROVE INTENSITY DISCRIMINATION FOR ELECTROCUTANEOUS ARTIFICIAL SENSORY FEEDBACK

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Introduction: The current standard of care for those living with upper limb loss is unsatisfactory, with up to 50% of amputees abandoning their prostheses, often citing unintuitive use as well as a lack of sensory feedback as primary reasons. Electrocutaneous stimulation uses electrodes on the skin to evoke tactile sensation. Stimulation of reinnervated afferent nerves can be used to provide amputees with natural, intuitive somatosensory feedback. Conveying the magnitude of tactile stimuli is an essential characteristic of natural touch. Here, we explored the ability to modulate stimulation frequency to convey magnitude of tactile stimuli to users of sensorized prostheses.

Materials and Methods: Participants received stimulation through a custom-fabricated stimulation pad placed on the palm or residual limb. We measured the just-noticeable difference (JND) − the minimum change in stim frequency that can be identified correctly 75% of the time − to describe how well electrocutaneous stimulation conveys the magnitude of tactile stimuli. We quantified the JND using a two-alternative forced-choice paradigm in which pulse frequency was varied, and participants were asked to determine which of two pulses felt stronger.

Results and Discussion: Weber's law states that the JND is proportional to the absolute magnitude of that stimulus and that the percent change relative to the absolute magnitude (known as the Weber fraction) is consistent across stimulus magnitude (i.e., the more intense a stimulus, the greater the change must be to be detected). Here, we show that Weber's law does not hold true for electrocutaneous stimulation, where the Weber fraction is much smaller at lower stimulus frequencies (10% and 13% change needed at 25 Hz and 50 Hz, respectively, vs 28% change needed at 75 Hz vs 34% change needed at 100 Hz). This suggests that the number of perceivable sensory gradations may be closer to 34 (based on the variable Weber fractions across frequency). This is more than double the previously estimated 14 perceivable sensory gradations (based on a static Weber fraction of 0.34 obtained at 100 Hz). These results also help deepen the understanding of tactile perception across frequency, where lower frequencies may provide supplemental temporal cues that aid discrimination.

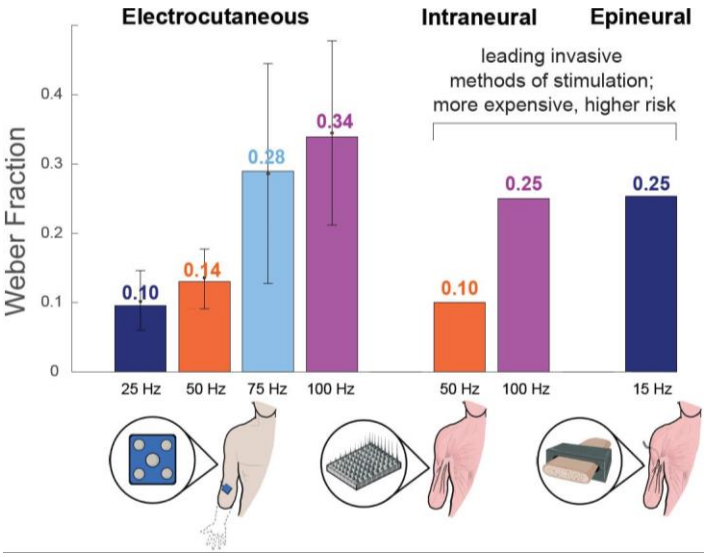

Figure 1: Weber fractions are much smaller and indicate greater discriminability at lower frequencies. The discriminability of electrocutaneous stimulation was comparable to that of the most invasive, high-resolution neural interface (via Utah Slanted Electrode Arrays) and greater than that of another invasive but lower-resolution neural interface (epineural stimulation via Flat Interface Nerve Electrode) [1,2]. This suggests electrocutaneous stimulation can serve as an effective low-cost, non-invasive surrogate for restoring high-resolution sensory feedback to amputees.

Conclusions: These results can help facilitate the implementation of electrocutaneous stimulation for restoring sensory feedback with the use of bionic arms. Improved discrimination of tactile features will benefit neural prostheses in real-world tasks that rely on somatosensory feedback.

References: [1] George, J. A., et al. *EMBC*, 2020, pp. 3893–96.
[2] Ackerley, R., et al. *J. Neurophysiol*., 2018, vol. 120, no. 1, pp. 291–95.