Quantifying the spatial stability of sensory stimulation projected fields for neuroprostheses

Keqin Ding[1*], Mark Iskarous[1,5], Luke Osborn[6,7], Breanne Christie[6], Dayann D'Almeida[2], Kaichen Yu[1], Matthew Fifer[6], Pablo Celnik[8], Francesco Tenore[6], Brian Caffo[3], Nitish Thakor[1,4]

[1]*Department of Biomedical Engineering,* [2]*Department of Computer Science,* [3]*Department of Biostatistics,* [4]*Department of Electrical and Computer Engineering, Johns Hopkins University, Baltimore, MD;* [5]*Department of Organismal Biology and Anatomy, University of Chicago, Chicago, IL;* [6]*Research and Exploratory Development Department, Johns Hopkins University Applied Physics Laboratory, Laurel, MD;* [7]*Department of Biomedical Engineering, Case Western Reserve University, Cleveland, OH;* [8]*Shirley Ryan AbilityLab, Chicago, IL*

[*] Traylor 701, 720 Rutland Ave, Baltimore, MD 21205, USA. E-mail: kding3@jhu.edu

Introduction: Cutting edge research done in the field of neuroprostheses has demonstrated that electrical stimulation elicits somatosensory percepts in the phantom or paralyzed limbs of individuals with amputations or spinal cord injuries. As the goal is to provide long-term sensory feedback, stability of the percepts has become a key objective for translation to the clinic and users' home. Nevertheless, only a few studies have quantitatively characterized the projected fields (PFs), the locations of perceived sensations elicited by stimulation, and their spatial stability [1–3]. Investigating PF spatial stability over time will confirm that the stimulation design properly serves long-term goals, thus advancing translation for independent use. Here, we present a quantitative framework that determines the spatial stability of PFs and can generalize to PFs collected from different electrical stimulation paradigms.

Material, Methods and Results: We design a graph-based average hand model to represent the recorded PF data. Each node represents a PF element, while each edge represents the average 2-point discrimination threshold at the corresponding region of the human hand. To quantify spatial stability, we combine the frequency of activation of each PF element and its co-occurrence with other PF elements. This characterization reveals percept regions that were consistently elicited together. We use the model to represent PFs obtained from two different electrical stimulation paradigms. The first used non-invasive transcutaneous electrical nerve stimulation (TENS) [2]. Surface electrodes were placed on the residual limb of an individual with upper limb amputation to activate their underlying nerves. The second applied intracortical microstimulation (ICMS) to the primary somatosensory cortex of an individual with spinal cord injury [4]. There were 96 electrodes (3 microelectrode arrays, 32 electrodes each) across the left and right somatosensory cortices.

We find that for PFs that were not frequently elicited, the framework properly distinguished between when PFs co-occurred with other PFs versus when they did not. While co-occurrence values vary for different PFs and electrodes, we use statistical null models to identify PFs that show statistically significant levels of co-occurrence with other PFs. Furthermore, we investigate the spatial stability of functionally relevant PFs, hand contact areas involved in exploration and manipulation tasks. We demonstrate that our method can identify stimulating electrode(s) that elicit percepts in specific regions, such as the fingertips.

Discussion and Significance: The graph model enables representing PFs collected from different sensory stimulation paradigms with the same approach. Therefore, our method can generalize to PFs elicited from different sensory stimulation paradigms. Our framework bridges the gap between the intuition of PF stability and the experimental data towards a more systematic assessment of the efficacy of sensory neuroprostheses for long-term use.

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