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Funnelectro: Electrotactile Funneling Illusion and Localization Performance on the Forearm

While tactile feedback is ubiquitous and an essential component of mobile systems, traditional mechanical actuators, like vibration motors, are often limited due to their weight or form factor. Electrotactile stimulation offers a high-density, lightweight, and energy-efficient alternative. However, rendering high-resolution spatial tactile patterns usually requires an impractical number of actuators. To address this challenge, sensory illusions like the funneling illusion can be leveraged. The funneling illusion is a phenomenon in which two stimuli are perceived as a single, centralized stimulus at small distances between actuators. By modulating the relative intensity of adjacent actuators, we can evoke a continuous perceived sensation at arbitrary points between the actuators, increasing the resolution of the system without increasing the bulk. To analyze the occurrence of the funneling illusion, we designed a custom prototype embedding 18 rubber electrodes within silicone. This ensures equal spacing between electrodes and prevents the electrodes from shifting. To prevent visual biases, the prototype was covered, and measurement tape was utilized to accurately record perceived stimulus locations. We conducted a user study with 16 participants using a within-subject design, counterbalanced via balanced Latin Square. Participants completed an informed consent form before participation. Due to the highly variable nature of electrotactile perception, we calibrated the prototype for each participant, ensuring all adjacent electrode pairs were set to a strong but not hurtful intensity with a subjectively equal perceived stimulation. Our results show that the electrotactile funneling illusion behaves similarly to its vibrotactile counterpart, achieving comparable effective distances and occurrence frequencies of up to 7.2 cm and 60%, respectively. Furthermore, qualitative data gathered via post-study questionnaires showed distinct perceptual differences across the forearm. Participants reported higher skin sensitivity near the elbow compared to the wrist. Additionally, participants reported that the perceived texture of the stimulation varied in different parts of the forearm, with “Vibrating” being the most frequently reported textural sensation. While our study was unable to elicit a moving sensation, it successfully established a baseline for a static sensation. Future work will investigate different approaches to create convincing apparent tactile motion.