Exploring Electrotactile Stimulation as a Modality for Sensation Illusion on the Arm

Xinlei Yu, Xin Zhu, Xiaopan Zhang and Heather Culbertson

***Abstract*—In this study, we navigate the evolving domain of wearable haptic interfaces, spotlighting the criticality of tactile feedback in enhancing user experiences across diverse applications. Our core contribution is designing and implementing an electrotactile feedback system to bridge our knowledge gaps concerning its perception, especially individual preferences and spatial intricacies. Through a focused human subject study (N=20) centered on the forearm, we investigated the interplay of location, frequency, and skin moisture on the Detection Threshold (DTDT) and Pain Threshold (PTPT). Our data highlights the pronounced influence of stimulation location on perception within the same body area. Interestingly, factors like individual differences and skin moisture were less influential on perception as related to signal frequency. Drawing from these results, we offer a strategic calibration procedure for electrotactile stimuli, shedding light on setting frequency bounds. This research not only refines our comprehension of electrotactile feedback nuances but also sets the stage for future innovations, particularly in the realms of wearable devices and virtual reality.**

***Index Terms*—haptics, electrotactile feedback, frequency modulation, spatial distribution, perception**

I. INTRODUCTION

Electrotactile stimulation, a haptic technology, employs electrical signals to induce touch sensations on the skin and finds potential applications in areas like virtual and augmented reality [1], [2], teleoperation [3], and rehabilitation [4], [5]. Key motivations for its incorporation in haptic systems encompass its high resolution and fidelity, enabling detailed touch experiences [6]–[8], the ability for non-contact operation useful in specific scenarios [3], [9], and versatility in generating a gamut of touch sensations [9]–[11]. Moreover, it facilitates haptic interactions for those with sensory challenges or amputations [1], [4], [5] and amplifies realism in virtual environments [2], [9]. This paper delves into the impact of frequency and location on the detection ability and pain thresholds of electrotactile feedback on the forearm. Through electrodes affixed at varied forearm positions and changing signal frequencies, we scrutinize participants' feedback to understand individual tolerances, with considerations like skin moisture and personal differences. Our findings aim to optimize the future design and calibration of wearable electrotactile devices.

II. EXPERIMENT SETUP

We design a system to examine the perception of electrotactile feedback on the forearm and upper arm due to the potential for a wide coverage area of electrodes and the recent interest in wearables for this body area. For our system, we selected a set of Transcutaneous Electrical Nerve Stimulation (TENS) electrodes (AUVON) as our stimulus conduction material. This is a commercially validated product in physical therapy with pre-programmed analog signals (and also has the potential to be further developed into a wearable device at a low cost). Based on our pilot study, we found that the intensity of the elicited electrotactile sensation is positively correlated to the size of the electrode. We cut each individual electrode pair as equilateral triangles.

The electrodes were driven by an analog signal output by a PCI board (SENSORAY Model 826) in a desktop computer and modulated by a linear current amplifier using a power op-amp (LM675T) with a gain of 1 A/V. In our experiment, we leveraged the library of the PCI board to program signals sent to each electrode.

We fixed the output current (pulses' amplitude) at 0.05 A. We chose a frequency range of our device from 1 Hz to 200 Hz to ensure safe and painless electrotactile stimulation. We determined this range from our pilot study; the pilot participants did not perceive the lower bound (1 Hz), and the upper bound (200 Hz) was the limit we found at which participants began to feel skin irritation or finger twitching.

[xinleiyu, xinzhu, xiaopanz, hculbert]@usc.edu, Department of Computer Science, University of Southern California, Los Angeles, CA, USA.

III. STUDY AND DESIGN

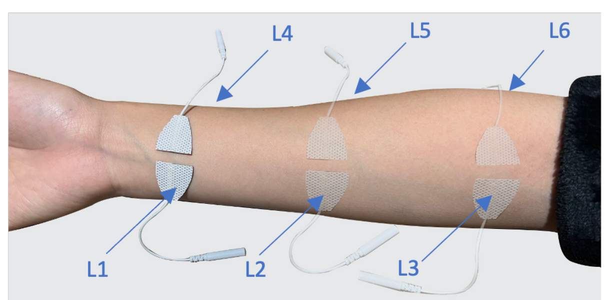

Fig. 1. Placement of electrode pairs on the arm, L1 - L3 are on the ventral side, L4 - L6 are on the dorsal side.

In this work, we designed and implemented an electrotactile feedback system to fill in the gaps in our understanding of the perception of electrotactile feedback, focusing on individual preferences and spatial differences. We conducted a human subject study (N=20) displaying electrotactile feedback on the forearm (Fig. 1) to examine the effect of location, frequency, and skin moisture level on the stimuli's Detection Threshold (DT) (Fig.2) and Pain Threshold (PT) (Fig. 3). Our results showed that the location of the electrotactile stimulation sig-

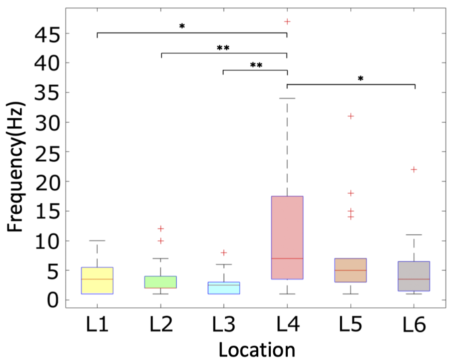

Fig. 2. Detection Threshold DT separated by different locations.

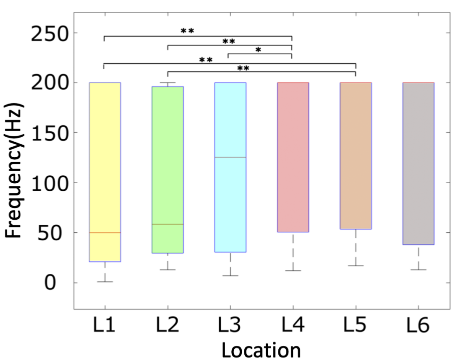

Fig. 3. Pain Threshold PT separated by different locations.

nificantly affects electrotactile perception (both DT and PT) even within the same body area (the forearm).

The significant spatial differences in electrotactile perception across different contact areas that we observed indicate the need for location-based customization of electrotactile experiences. These findings can inform the design of our arm-worn electrotactile device by allowing us to optimize electrode placement for enhanced perception and signal calibration.

IV. Conclusion

In conclusion, we designed and conducted a study investigating electrotactile perception on the forearm. The results affirm that electrotactile feedback systems can achieve precise control through signal frequency modulation. Notably, we identified substantial spatial variances in perception across diverse contact zones, underscoring the necessity for tailoring electrotactile experiences based on location. While our research highlights this domain, further exploration into individual predilections for electrotactile stimulation remains paramount. Our findings lay a robust groundwork for ensuing research in electrotactile feedback, especially concerning the development of wearable devices and immersive virtual reality environments where tactile nuances play a critical role.

V. Future Work

We plan to extend our research to explore how multiple electrotactile actuators can collaboratively generate intricate sensations, specifically in simulating illusory motion along the forearm. As part of this endeavor, we are currently developing a sophisticated electrotactile system. Our next phase will involve recruiting 20 participants to participate in a thorough study, aiding our understanding of these complex interactions.

VI. Vision

By unraveling how humans perceive and respond to electrotactile cues, we aim to provide valuable insights that can shape future haptic device design. The knowledge we gain through this study can be applied to the future development of electrostatic-based touch devices. Our study exhibits immense potential in various domains. Electrotactile feedback enhances operator interactions with robotics in intricate environments in teleoperation, seamlessly connecting remote and direct tactile experiences. In entertainment, especially VR, AR, and gaming, electrotactile interfaces heighten immersion and give virtual experiences a palpable authenticity. These systems introduce innovative emotive and tactile communication methods for distant social engagements, overcoming spatial constraints.

References

[1] H. Kajimoto, "Electrotactile display with real-time impedance feedback using pulse width modulation," IEEE Transactions on Haptics, vol. 5, no. 2, pp. 184–188, 2011. https://doi.org/10.1109/TOH.2011.39

[2] P. Kourtesis, F. Argelaguet, S. Vizcay, M. Marchal, and C. Pacchierotti, "Electrotactile feedback applications for hand and arm interactions: A systematic review, meta-analysis, and future directions," IEEE Transactions on Haptics, 2022. https://doi.org/10.1109/TOH.2022.3189866

[3] V. G. Chouvardas, A. N. Miliou, and M. K. Hatalis, "Tactile displays: Overview and recent advances," Displays, vol. 29, no. 3, pp. 185–194, 2008. https://doi.org/10.1016/j.displa.2007.07.003

[4] H. Kajimoto, N. Kawakami, T. Maeda, and S. Tachi, "Electro-tactile display with tactile primary color approach," Graduate School of Information and Technology, The University of Tokyo, 2004.

[5] H. Chen, L. Shuai, W. Zhu, and M. Miao, "An investigation of stimuli- current thresholds on the non-steady contact condition," Industrial Robot, vol. 46, no. 3, pp. 351–359, 2019. https://doi.org/10.1109/TOH.2022.3189866

[6] M. Li, D. Zhang, Y. Chen, X. Chai, L. He, Y. Chen, J. Guo, and X. Sui, "Discrimination and recognition of phantom finger sensation through transcutaneous electrical nerve stimulation," Frontiers in Neuroscience, vol. 12, p. 283, 2018. https://doi.org/10.3389/fnins.2018.00283

[7] R. K. Ray and M. Manivannan, "Reduction of electrotactile perception threshold using background thermal stimulation," in International Conference on Human Interaction and Emerging Technologies. Springer, 2021, pp. 331–338. https://doi.org/10.1007/978-3-030-85540-6-42

[8] K. A. Kaczmarek, J. G. Webster, P. Bach-y Rita, and W. J. Tompkins, "Electrotactile and vibrotactile displays for sensory substitution systems," IEEE Transactions on Biomedical Engineering, vol. 38, no. 1, pp. 1–16, 1991.

[9] Z. Zhou, Y. Yang, J. Liu, J. Zeng, X. Wang, and H. Liu, "Electrotactile perception properties and its applications: A review," IEEE Transactions on Haptics, 2022. https://doi.org/10.1109/TOH.2022.3170723

[10] H. Kajimoto, "Electro-tactile display: principle and hardware," in Pervasive Haptics. Springer, 2016, pp. 79–96.

[11] S. Brummer and M. Turner, "Electrical stimulation of the nervous system: the principle of safe charge injection with noble metal electrodes," Bioelectrochemistry and Bioenergetics, vol. 2, no. 1, pp. 13–25, 1975. https://doi.org/10.1016/0302-4598(75)80002-X