2025 IEEE World Haptics Conference (WHC)
Suwon Convention Center, Suwon, Korea
July 8 ~ 11, 2025

Reducing Corner Perception Loss in Electrotactile Presentation of Square-Shaped Motion

A. Yamada[1], H. Kajimoto[2], H. Yano[1] and V. Yem[1]

I. Introduction

While visual and auditory modalities are predominantly used in communication, we occasionally exchange information through the sense of touch. Accurate transmission of information via tactile means can enrich human communication. In particular, when presenting shapes to the fingertips, accurately reproducing features such as corners of a square is essential for correct shape recognition.

In this study, we focus on electrotactile stimulation, a method that directly activates tactile receptors using electrical current. There are two types of this stimulation: anodic stimulation, which primarily excites Meissner corpuscles and induces a vibratory sensation, and cathodic stimulation, which mainly stimulates Merkel cells and evokes a pressure sensation [1]. However, cathodic stimulation has the disadvantage of often causing a spatial mismatch between the location of stimulation and the perceived sensation, compared to anodic stimulation [2]. Nevertheless, when using only anodic stimulation to sequentially activate a series of points at equal time intervals—effectively tracing a square on the fingertip—participants frequently perceive an illusory shape with rounded or missing corners. This suggests the need to explore methods for preventing the perceived loss of corners.

To address this issue, we propose two hypotheses. First, we hypothesize that using both anodic and cathodic stimulation may improve square-shape perception. By selectively applying the appropriate type of stimulation to the underlying receptors, it may be possible to convey shapes more accurately. Second, we hypothesize that introducing a pause at the corners of the square may help preserve the perception of corners. This hypothesis is based on the natural behavior observed when humans draw squares—briefly pausing at the corners to change the direction of motion.

II. Experiment

Fig. 1 shows the experimental setup and two examples of electrode polarity arrangements of square shape stimulation. The circuit of the electrotactile kit is described in [3]. The electrodes are circular with a diameter of 1.4 mm, and the distance between adjacent electrodes is 2.54 mm.

This work was partially supported by Japan Science and Technology Agency (JST) A-STEP, under Grant JPMJTR23RC, and Organization of Advanced Teaching and Learning, University of Tsukuba.

[1]A. Yamada, H. Yano, and V. Yem are with Degree Programs in Systems and Information Engineering at Tsukuba University, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan.

[2]H. Kajimoto, is with The University of Electro-Communications, 1-5-1, Chofugaoka, Chofu, Tokyo, Japan.

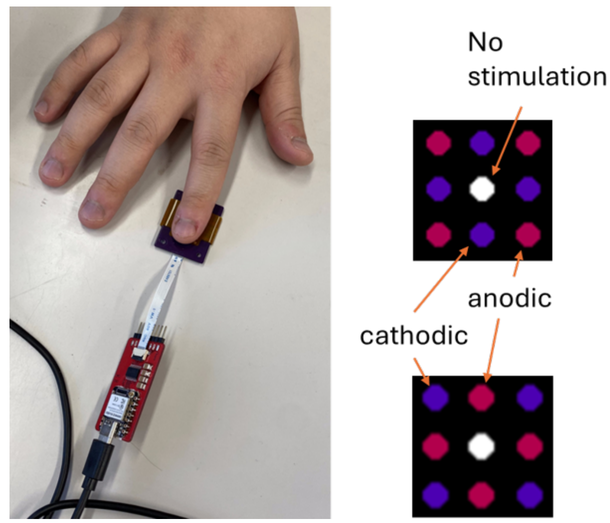

Fig. 1. Electrotactile device (left), and electrode polarity arrangements for cathodic or anodic stimulation presented at the corners of a square-shaped trace (right)

The tracing direction was set to a clockwise sequence, and the time interval between two electrodes for stimulated point motion perception was 0.1 seconds, except for the corner pause condition, where the stimulation time at each corner was 0.5 seconds.

As shown in Table I, there were 2 [polarity at corner (A: anodic, C: cathodic)] $\times 2$ [polarity at side (A, C)] $\times 2$ [corner pause (Y: yes, paused; N: no, not paused)] conditions. Therefore, there were eight conditions in total, and the order of presentation was randomized across participants. For each condition, participants were asked to report whether the perceived shape felt more like a square or a circle. Importantly, the intended shape (a square) was disclosed to participants prior to each trial to ensure consistent interpretation.

TABLE I
List of Experimental Conditions and Abbreviations(A:Anode, C:Cathode, Y:Yes , N:No)

No.	at corners	at sides	corner pause	Abbreviation
1	A	C	Y	ACY
2	C	A	Y	CAY
3	A	C	N	ACN
4	C	A	N	CAN
5	A	A	Y	AAY
6	C	C	Y	CCY
7	A	A	N	AAN
8	C	C	N	CCN

The participants consisted of three healthy individuals: a 22-year-old right-handed male, a 25-year-old left-handed male, and a 51-year-old right-handed female. Each participant completed four sets of trials, experiencing each condition once per set. This study was granted by Research Ethics Committee of the Institute of Systems and Information Engineering, University of Tsukuba (approval number: 2024R842).

To evaluate square-shape recognition accuracy, we calculated the proportion of trials in which the participant reported perceiving a square. This was done by dividing the total number of ”square” responses by the total number of stimulus presentations (i.e., eight conditions × number of participants) for each condition.

III. Results and Discussion

The experimental results are presented in Fig. 2. When comparing CAN and AAN or CAY and AAY, it is evident that using both anodic and cathodic stimulation results in a higher square-shape recognition rate than using anodic stimulation alone. Participant comments consistently indicated that cathodic stimulation produces a broader sensation than anodic stimulation. It is presumed that the positional accuracy of stimulation points is primarily determined by the vibratory sensation induced by anodic stimulation, while the directional movement between points is more clearly conveyed through the pressure sensation induced by cathodic stimulation. This combination likely clarifies the linear transitions from one corner to another.

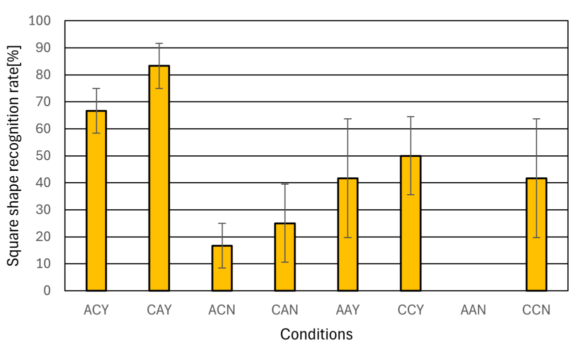

Fig. 2. Experimental result. Error bars indicate standard error.

Next, a comparison between AAY and AAN reveals that incorporating a pause at the corners improves the accuracy of square-shape recognition. This is likely because the temporary cessation of the stimulation vector at the corners allows participants to perceive the vertices of the square more distinctly. Then, the combined conditions ACY and CAY exhibited significantly higher recognition rates compared to all other conditions. These results suggest that the simultaneous use of anodic and cathodic stimulation, along with a pause at each corner, effectively prevents the perceptual omission of the square's corners and enhances the clarity of shape representation.

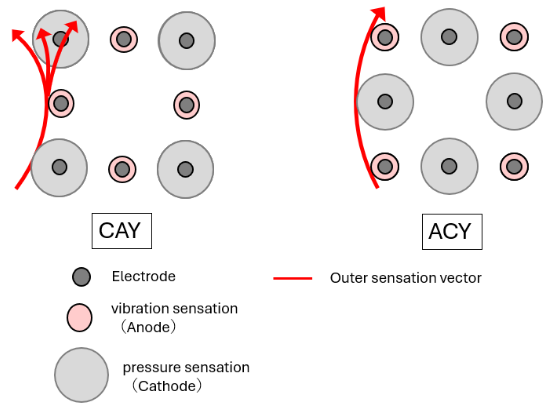

Fig. 3. Electrode configuration and outer sensation vectors in ACY and CAY conditions

Finally, the reason why the square-shape recognition rate was higher for CAY than for ACY is discussed with reference to Fig. 3. A critical issue identified in this study is the discrepancy between the intended movement vector of the stimulation points and the perceived vector of tactile sensation. When cathodic stimulation is applied at the corners, the broader pressure sensation helps disperse the perceived vector, even if the sensation vector tends to spread outward along the edges. As a result, the transition from one edge to the next becomes smoother, which may enable clearer perception of the corners. In contrast, when anodic stimulation is used at the corners—as in ACY—the stimulation tends to produce a more concentrated vibratory sensation. However, due to its narrower spatial range, it may cause the perceived vector to expand outward at the midpoint of each edge. This could lead to a distortion in the perceived shape, making it more difficult to distinguish the square corners accurately.

IV. Future Work

In future studies, we plan to investigate the accuracy of shape recognition when the size and form of the presented shapes are varied. Moreover, similar to the study in [4] that examined the effect of pulse width, we aim to assess two-point discrimination capabilities using a combination of anodic and cathodic stimulation, specifically to determine the minimum distance at which participants can perceive the two stimulation points as distinct.

References

[1] V. Yem, H. Kajimoto, ”Comparative Evaluation of Tactile Sensation by Electrical and Mechanical Stimulation.” IEEE Transaction on Haptics, Vol.10, pp.130-134, 2017.

[2] H. Kajimoto, N. Kawakami, T. Maeda, S. Tachi, ”Electro-Tactile Display with Force Feedback,” Proc.World Multiconf. on Systemics

[3] H. Kajimoto, “Electro-tactile Display: Principleand Hardware,” In: Kajimoto H., Saga S., KonyoM. (eds) Pervasive Haptics. Springer, 79-96, 2016

[4] M. Solomonow, L. Raplee, and J. Lyman, “Electrotactile two point discrimination as a function of frequency, pulse width and pulse time delay,” Ann. of Biomed. Eng., vol. 6, no. 2, pp. 117–125, 1978.