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Tactile Localization in Forearm-Mounted Multi-Tactor Displays: The Effect of Tactor Number and Position

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I. Introduction

Wearable vibrotactile displays have gained attention as an effective means of conveying information through touch, particularly when visual or auditory channels are unavailable. To deliver richer information, researchers have developed wearable displays using multiple tactile actuators positioned at various body sites [1]–[3]. Among these sites, the forearm is considered practical due to its high tactile sensitivity and minimal movement constraints, making it well-suited for mounting tactors to deliver haptic stimuli.

To convey more complex tactile information, a key question arises: whether users can accurately localize individual vibrotactile stimuli delivered through multi-tactor arrays. Several studies have shown that localization performance is influenced by the number and placement of tactors [1], and that performance degrades when more tactors are activated simultaneously [2]. Huang et al. also examined how intensity and frequency affect spatial acuity, although they did not systematically compare different anatomical regions [3].

However, most prior work focused on arbitrary configurations, leaving the effects of spatial layouts underexplored. Thus, no clear guidelines exist on how to arrange tactors to maximize localization accuracy. This limitation restricts the design of applications requiring precise tactile spatial cues, such as tactile communication.

In this study, we evaluate localization performance for different tactor configurations, varying in number (four, six, or eight) and position (near the wrist or elbow) on the forearm. We expect our results to offer practical insights for designing forearm-mounted vibrotactile interfaces with high identification accuracy.

II. Methods

The experiment aimed to evaluate how accurately humans can identify localized haptic stimuli from multiple actuators arranged in different configurations on the forearm.

A. Apparatus

We used several eccentric rotating mass (ERM) motors (Seeed Technology, 10.00 mm diameter) in our system due to their higher perceived intensity compared to linear resonant actuators (LRAs) [4]. The tactors were actuated via PWM signals by an Arduino Due. These tactors were mounted on a velcro band, which allows for adjustable positioning based on the user's forearm size, as shown in Fig. 1(a). This setup ensured consistent tactor placement across participants. The band was worn either on the distal or proximal region of the forearm to evaluate localization performance at two anatomically distinct sites. In this experiment, up to eight tactors were arranged in two rows of four.

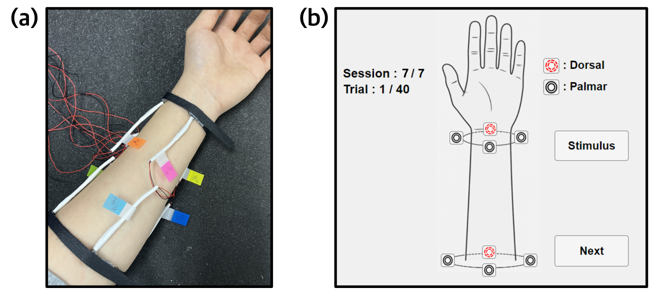

Fig. 1. (a) Example setup showing placement of tactors on the distal and proximal regions of the forearm using a velcro band. (b) Graphical user interface (GUI) displaying the positions of tactors during the experiment.

B. Experimental Conditions

Seven tactor configurations were tested across seven sessions, varying in the number and placement of actuators, as illustrated in Fig.2. In Sessions 1 and 2, four tactors were placed along either the palmar–dorsal or medial–lateral axis on a single region of the forearm. Sessions 3 and 4 used six tactors, with three on the distal region and three on the proximal region. In Session 3, tactors were placed on the medial, lateral, and palmar sides within each region, whereas in Session 4, they were placed on the medial, lateral, and dorsal sides. In Sessions 5 and 6, the same number of tactors were used, but the arrangement varied: two tactors were placed on the palmar side and one on the dorsal side in Session 5, and vice versa in Session 6, to manipulate inter-tactor spacing. Session 7 used eight tactors placed on the dorsal, palmar, medial, and lateral sides of both distal and proximal regions, representing the most spatially dense configuration. Each tactor was labeled anatomically (DX for distal and PX for proximal, where X indicates the number within each region), as shown in Fig.2(b).

C. Procedure

Ten participants (6M and 4F, mean age: 25.1 $\pm$ 2.4 years) took part in the experiment. All procedures were approved

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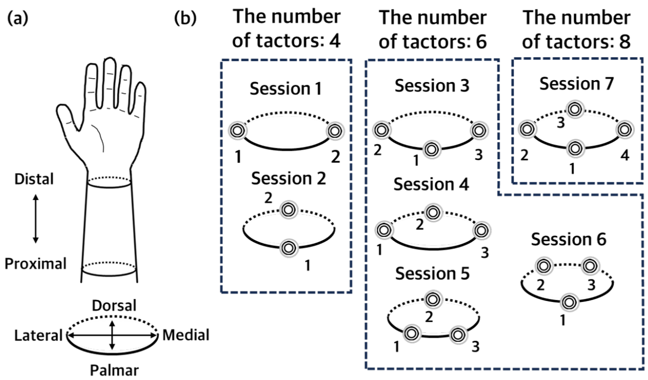

Fig. 2. (a) Anatomical reference for the distal and proximal regions of the forearm used in the experiment. (b) Tactor configurations for each session. The cross-sectional diagrams illustrate the spatial configuration of tactors, and the numbers indicate the label assigned to each tactor during the corresponding session.

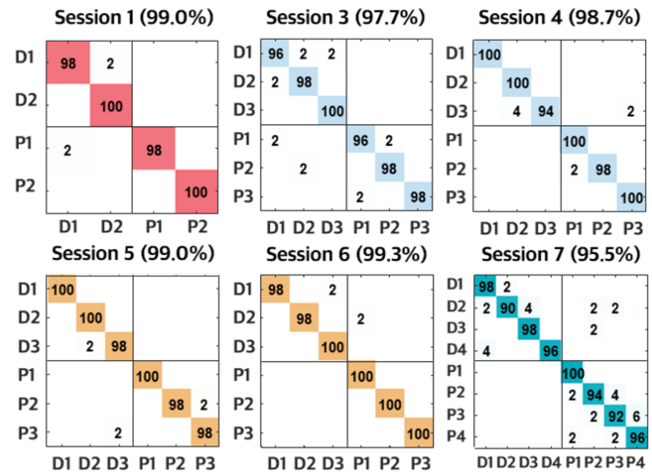

Fig. 3. Confusion matrices for each session. The x- and y-axis labels indicate tactor locations using anatomical codes: D and P refer to the distal and proximal regions of the forearm, respectively, and the numbers, X, represent the tactor labels assigned in each configuration. The matrix for Session 2 is not shown, as its accuracy was 100%.

by the institutional review board (PIRB-2023-E025).

Before each session, participants were shown the tactor arrangement layout via a graphical user interface (GUI), as illustrated in Fig. 1(b). When they pressed the "Stimulus" button, a 2 second vibrotactile stimulus was delivered among the N mounted tactors, selected at random. Participants indicated the perceived location by clicking the corresponding position icon on the GUI. They then proceeded to the next trial by pressing a "Next" button.

III. Results and Discussion

We evaluated the identification accuracy of various actuator mounting configurations with different numbers and spatial distributions of tactors. The confusion matrices for each session are shown in Fig. 3. Accuracies exceeded 95% in all sessions, indicating reliable identification of spatial tactile cues on the forearm.

Sessions 1 and 2, which used four tactors, identification accuracies were near-perfect at 99.0% and 100.0%, respectively. These results suggest that using four tactors on the forearm can ensure high information transfer, regardless of the mounting configuration.

Sessions 3 to 6 with six tactors showed consistently high accuracy, ranging from 97.7% to 99.3%. Although the differences were not statistically significant, a tendency was observed in which configurations using the medial and lateral sides resulted in slightly lower accuracy. This may be due to vibrotactile propagation along skeletal structures in these areas, potentially reducing cue separability. However, this remains a hypothesis and requires further investigation under more controlled spatial conditions.

Session 7, which used eight tactors, resulted in 95.5% accuracy. Despite the decrease, localization accuracy remained within a usable range for eight-tactor configurations. A repeated-measures ANOVA revealed a significant main effect of configuration ($F(6, 54) = 3.57$, $p = .0047$), with post-hoc Tukey HSD tests showing a significant difference only between Sessions 2 and 7. This result suggests that increasing the number of tactors may slightly reduce localization performance.

Overall, the results showed that as the number of actuators increased, the accuracy slightly decreased, and different identification results were observed depending on the actuator arrangement. These findings confirm that high localization accuracy is achievable with up to eight tactors.

IV. Future Work

First, we plan to evaluate the localization performance with a higher density of mounted tactors, using more than eight tactors. To cover the entire forearm, we can add more tactors to a single region and introduce additional regions with multiple tactors between the distal and proximal areas.

Additionally, we can investigate identification ability by modulating the temporal parameters of the mounted tactors, such as intensity and duration, in conjunction with tactile localization across various spatial configurations. We expect that this spatio-temporal modulation could enhance identification ability.

Ultimately, based on the high identification ability of these wearable haptic interfaces with multiple tactors, we plan to apply these methods to tactile communication, such as tactile languages, to convey complex information.

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