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Tactile Perspective-Taking: Cognitive Process of Estimating Others' Subjective Tactile Similarity

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Abstract

Understanding how others perceive the tactile world is essential for human communication. Each individual has a unique and multidimensional tactile perceptual space, which makes it challenging to understand others' tactile perceptions within the spaces. This study investigates the cognitive ability and process of estimating another person's subjective similarity of various textures, a key aspect of tactile perceptual space. Participants performed tasks to estimate how a target individual would rate the similarity of tactile stimuli pairs. Results showed that participants could partially infer target's similarity ratings, and their estimated tactile similarity ratings converged toward an intermediate point between their own and the target's. The estimation process included exploration, adaptation, and overgeneralization phases. Moreover, participants' own similarity ratings shifted closer to those of the target after performing the task. These findings suggest that estimating another person's subjective similarity between textures involves incorporating elements of the target's tactile perceptual space into one's own.

Keywords: tactile perceptual space; tactile similarity; perspective-taking

Introduction

Understanding how others perceive the world is fundamental to human communication and social interaction. In the field of haptic research, study of the technology for conveying the tactile perceptions experienced by one person to another is an important focus (Kitamichi, Yukawa, Minamizawa, & Tanaka, 2022). It has also been reported that humans can infer the tactile perceptions experienced by others with an above chance level of accuracy by visually observing their explorative hand movements (Yokosaka, Kuroki, Watanabe, & Nishida, 2018; Wijntjes, Xiao, & Volcic, 2019). These findings suggest the existence of some underlying mechanisms for inferring others' tactile perceptions. However, little is known about the cognitive process that contributes to understanding others' tactile perceptions.

Human tactile perception is multidimensional, making it difficult to understand others' tactile perceptions. Numerous studies have reported tactile dimensions such as roughness, hardness, and stickiness, and that tactile perceptions for discrete objects can be expressed in a multidimensional space consisting of these tactile dimensions (Holliins, Faldowski, Rao, & Young, 1993; Hollins, Bensmaïa, Karlof, & Young, 2000; Picard, Dacremont, Valentin, & Giboreau, 2003; Bergmann Tiest & Kappers, 2006; Okamoto, Nagano, & Yamada, 2013). This multidimensional space is called the tactile perceptual space (Figure 1A). Due to this multidimensionality, it is difficult to grasp the full extent of another person's tactile perceptions just by comparing two people's evaluation of different stimuli in a specific tactile dimension, such as roughness. In addition, since the set of adjectives used to describe each tactile dimension (e.g., 'rough-smooth' and 'hard-soft') represents only a part of the tactile perceptual space that researchers have been able to elucidate so far, it is not able to express unexplored or difficult-to-verbalize tactile dimensions.

Researchers have adopted the similarity rating task as a method for capturing tactile perceptual space (Holliins et al., 1993; Hollins et al., 2000), and this task may also help people estimate the tactile perception of others. As shown in Figure 1A, subjective similarity ratings for stimulus pairs are based on the distance between stimuli in the tactile perceptual space held by each individual, and the similarity ratings can be used to reconstruct the tactile perceptual space using analysis methods such as multidimensional scaling. Similarity ratings contain more information on tactile dimensions that is important for individuals attempting to judge others' tactile perceptions than the ratings based on adjective-pairs mentioned above and are therefore expected to be a valuable source of information for understanding how others experience tactile perceptions.

The study by Hollins et al. (2000) shows that tactile perceptual space varies across individuals. Although their study involved only five participants, the results showed differences in dimensions of tactile perceptual space among them. We have previously conducted a study that constructed tactile perceptual space based on similarity ratings between tactile stimuli (Yokosaka, 2024). In that study, we found that some participants exhibited highly congruent tactile perceptual spaces (e.g., Participants X and Y in Figure 1B, left), while others exhibited less congruent tactile perceptual spaces (e.g., Participants X and Z in Figure 1B, right). When the tactile perceptual space between two people differs, the tactile similarity perceived for the same pair of stimuli (the distance between the stimuli in the tactile perceptual space) will also differ between them.

Therefore, when one person wants to understand the tactile perceptions of another, it is important for them to understand what kind of tactile perceptual space underlies those perceptions and how the space differs from their own. Research to

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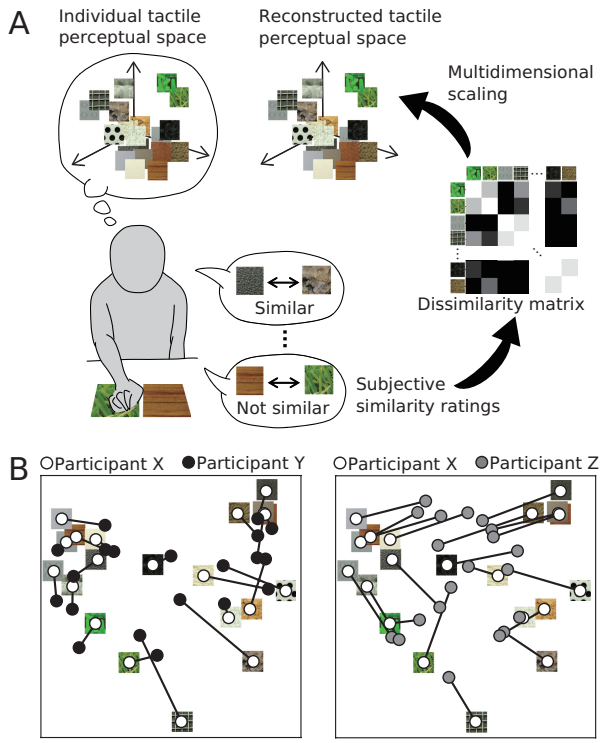

Figure 1: (A) Reconstruction of tactile perceptual space based on the similarity rating task. (B) Individual difference in the structure of tactile perceptual space (Yokosaka, 2024).

date has not clarified whether people can understand the perceptions of others with different tactile perceptual spaces nor what estimation processes underlie that understanding.

In this study, we asked participants to estimate the subjective similarity that a targeted person would feel between a given pair of tactile stimuli and investigated the nature of the estimation process. Hereafter, the term "target" will be used to refer to the individual whose similarity ratings participants attempt to estimate. This similarity estimation task was inspired by a method called the output agreement game, in which participants attempt to give the same response to a common input presented to all of them. Research using this task to label the similarity between images has shown that participants can reach a high degree of agreement in similarity evaluation (Wei et al., 2019; Wei, Paliyawan, & Thawonmas, 2022). This result suggests that participants can understand a target's similarity ratings and adjust their own similarity ratings to align more closely with the target's. Based on this suggestion, this study will test the following hypothesis.

H1: Participants can estimate a target's similarity ratings by performing a similarity estimation task.

In the context of psychology and cognitive science, the concept of perspective-taking has been widely studied as a process for inferring and sharing the emotions and thoughts of others (Davis, 1983; Galinsky, Ku, & Wang, 2005). Perspective-taking in this context refers not just to emotional empathy but to the cognitive ability to recognize and understand the perspectives and experiences of others by adopting the other person's point of view and way of thinking as one's own. Based on this idea, we hypothesized that in this estimation process, by adopting the characteristics of the target's tactile perceptual space into one's own tactile perceptual space, participants might try to understand the target's similarity ratings. In this study, the hypothesis is tested as follows.

H2: After performing the similarity estimation task, the participant's own similarity ratings more closely align with the target's.

Methods

Participants

Sixteen individuals (six female; the mean age $\pm$ SD was 23.75 $\pm$ 3.82) participated in the experiments. The participants were unaware of the specific purpose of the experiment. Ethical approval for this study was obtained from the ethics committee at Nippon Telegraph and Telephone Corporation. The experiments were conducted according to principles originating in the Helsinki Declaration, excluding the pre-registration. Written informed consent was obtained from all participants.

The number of the participants was designed before the experiments. In this study, we planned to compare the mean values of the correlation coefficients between two paired groups. Since correlation coefficients have upper and lower limits, the distribution does not necessarily follow a normal distribution. Therefore, we planned to use a bootstrap test for the comparison. Since there is no established method of sample size design for bootstrap tests, we calculated the sample size by referring to the sample size for the paired t-tests. Using a statistical calculator, the pwr package in R, we computed the number of participants based on three criteria: a large effect size (d = 0.80), a power of 80%, and an alpha of 5%. The number of participants that met these criteria was 15. Using this calculation as a reference, we recruited 16 participants.

Materials

As shown in Figure 2, participants were seated at a desk with their dominant hand in front of them. A board placed in front of the participants prevented them from seeing their hands. A wooden frame was placed in front of their hands, allowing two stimuli to be fixed to it side by side. The stimuli were a selection of 20 everyday materials such as fabric and metal, as shown in Figure 2, and they were 100 $\times$ 100 mm in size. These stimuli were equivalent to those used in previous studies (Yokosaka, 2024). White noise was presented through headphones worn by the participants to prevent them from judging the tactile texture based on the sound that occurs when they touch the surface of the stimulus.

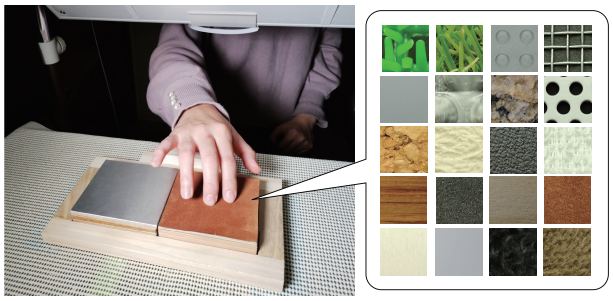

Figure 2: Experimental setup and stimuli.

Procedure

In Experiment 1, participants provided subjective similarity ratings. All possible pairs of the 20 stimuli (i.e., 190 combinations) were presented in random order. When participants heard a beep, they started to compare the two stimuli by touching them. They were instructed to use only the index and middle fingers of their dominant hand to touch the stimuli but were otherwise free to explore them in any manner they preferred. This instruction of exploration was enforced to ensure that the participants were able to engage with the stimuli under the same conditions as the targets in our previous experiment (Yokosaka, 2024). There was no time limit for touching the stimuli. Participants stopped touching the stimuli once they could judge the similarity between the two and provided the similarity ratings on a 7-point interval scale. Each pair was presented only once during the experiment.

Experiment 2 was the same as Experiment 1 except for the target's similarity estimation task. In this experiment, rather than their own subjective ratings of similarity, participants were asked to estimate how a target would rate the similarity of stimulus pairs that were presented to them (Figure 3). As candidates for the target, we used similarity rating data previously collected from a different set of 16 participants for a different purpose (Yokosaka, 2024). In that previous study, the stimuli, the way the participants touched the stimuli, and the method of specifying the similarity rating were all the same as in the current experiment. After each participant had completed Experiment 1, we calculated the correlation coefficient between their similarity ratings and the similarity ratings of each of the 16 candidates for the target. The candidate with the lowest correlation was then selected as the target for the similarity rating estimation in Experiment 2. This selection was intended to maximize the contrast in tactile perceptual space between a participant and their corresponding target, making the estimation task challenging. In each trial, participants explored a stimulus pair, made an estimation of the similarity rating given by the target by choosing a point on a 7-point interval scale, and then received feedback on the correct answer (how the target actually rated the similarity). In this experiment, since we also wanted to analyze whether the participants' estimated similarity ratings converged, we conducted the experiment for two sets of 190 pairs.

Experiment 3 was the same as Experiment 1, except that the participants were explicitly instructed to answer based on their own subjective similarity ratings without considering the target's. A total of 760 trials in all experiments were conducted over one day, with breaks in between, over a total period of six hours.

Analysis

One motivation for this research was to investigate whether people understand the tactile perceptual space of others based on their own tactile perceptual space. Therefore, we designed an analysis method that reflects the process of estimating the similarity ratings of the target by gradually modifying the similarity ratings of the participants themselves.

For the purposes of explanation, we define the similarity ratings of the participants and the target using symbols (Table 1). The similarity ratings for all 190 stimulus pairs provided by the participants in Experiments 1 and 3 are called $\mathbb{A}_{I}$ and $\mathbb{A}_{III}$, respectively. The estimated similarity ratings for each trial i in Experiment 2 are expressed as $\mathbb{A}_{II,i}$ (note that, unlike $\mathbb{A}_{I}$ and $\mathbb{A}_{III}$, $\mathbb{A}_{II,i}$ does not refer to the participants' subjective similarity ratings, but to the similarity ratings of the targets as estimated by the participants). We calculate the estimated similarity ratings for each trial because we want to understand the process by which participants come to understand the target's similarity ratings. $\mathbb{A}_{II,0}$ is the same as $\mathbb{A}_{I}$. When a particular pair of stimuli is presented in trial i, $\mathbb{A}_{II,i}$ is created by taking the similarity ratings from the previous trial, $\mathbb{A}_{II,i-1}$, and updating the entry corresponding to that stimulus pair with the participant's estimated rating (as indicated by the red cross marks in Figure 3). For example, consider the case where the stimuli 'Japanese paper' and 'stone' are presented in the 10th trial. When the participant answers that the target would have rated the similarity of these stimuli as a 2 on the 7-point scale, the similarity rating of 'Japanese paper' and 'stone' in $\mathbb{A}_{II,9}$ is replaced with the value 2, and this is set as $\mathbb{A}_{II,10}$. This method allows us to calculate the sequential correlation coefficients $r_{II,i}$ between participants' estimated similarity ratings and the target's similarity ratings. For convenience, we denote the estimated similarity ratings for the final trial N as $\mathbb{A}_{II,N}$. The target's similarity ratings are represented by $\mathbb{B}$.

Two statistical tests were planned. The first was a test to see whether the correlation coefficient $r_{II,N}$ between the estimated similarity rating $\mathbb{A}_{II,N}$ and the target similarity ratings $\mathbb{B}$ is significantly larger than the correlation coefficient r_{I} between the participant's similarity ratings $\mathbb{A}_{I}$ before the estimation task and the target similarity ratings $\mathbb{B}$. Here, the correlation r between $\mathbb{A}$ and $\mathbb{B}$ refers to calculating the correlation coefficient by pairing all similarity ratings (i.e., 190 pairs) belonging to $\mathbb{A}$ and $\mathbb{B}$. If the participants can understand the similarity structure of the target (i.e., If H1 is true), then $r_{II,N} > r_{I}$ is expected.

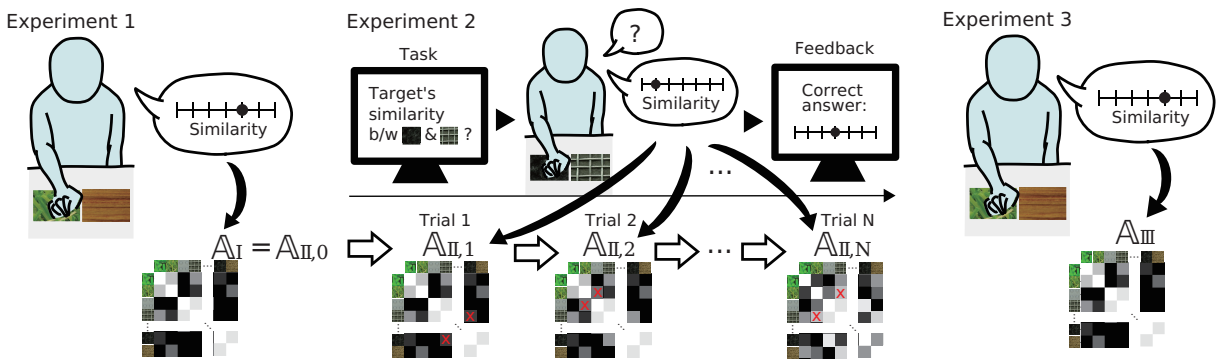

Figure 3: Experimental protocol.

Table 1: Summary of symbols used in this study.

$\mathbb{A}_I$	Participants' similarity ratings in Exp. 1
$\mathbb{A}_{II,i}$	Estimated similarity ratings at trial i in Exp. 2
$\mathbb{A}_{III}$	Participants' similarity ratings in Exp. 3
$\mathbb{B}$	Target's similarity ratings
r_I	Correlation coefficient between $\mathbb{A}_I$ and $\mathbb{B}$
$r_{II,i}$	Correlation coefficient between $\mathbb{A}_{II,i}$ and $\mathbb{B}$
r_{III}	Correlation coefficient between $\mathbb{A}_{III}$ and $\mathbb{B}$
ω	Weight indicating convergence toward target

The second was a test to see whether the correlation coefficient r_{III} between the participants' similarity ratings $\mathbb{A}_{III}$ after the estimation task and the target similarity ratings $\mathbb{B}$ is significantly larger than the correlation coefficient r_I. If participants estimate the similarity structure of the target by referring to their own similarity structure, then even if they are instructed to make ratings 'without considering the target's similarity ratings' (i.e., If H2 is true), $r_{III} > r_I$ is expected.

We were also interested in how the estimated similarity ratings $\mathbb{A}_{II,i}$ of the participants in Experiment 2 would finally converge. Ideally, $\mathbb{A}_{II,i}$ should change from $\mathbb{A}_I$ to $\mathbb{B}$, but in practice it may converge to intermediate ratings between $\mathbb{A}_I$ and $\mathbb{B}$, namely $(1-\omega)\mathbb{A}_I + \omega\mathbb{B}$. When $\omega = 0$, $\mathbb{A}_{II,i}$ is the same as $\mathbb{A}_I$, and when $\omega = 1$, $\mathbb{A}_{II,i}$ is the same as $\mathbb{B}$. We varied ω from 0 to 1 in increments of 0.001 and computed the correlation coefficients between $\mathbb{A}_{II,i}$ and $(1-\omega)\mathbb{A}_I + \omega\mathbb{B}$ for all ω values. The value of ω that had the highest correlation coefficient with $\mathbb{A}_{II,i}$ was taken as the estimated value of ω_i for trial i.

Results

Experiment 1: Results of Participants' Similarity Ratings

To examine the fundamental characteristics of similarity ratings and compare them with previous studies, we analyzed the similarity ratings provided by the participants in Experiment 1. The mean and standard deviation of correlation coefficients of $\mathbb{A}_I$ among participants were 0.64 ± 0.09. Next, we compared the tactile perceptual space reconstructed from the averaged similarity ratings obtained in this study with the tactile perceptual space obtained from the authors' previous research (Yokosaka, 2024). The similarity ratings for each stimulus pair were normalized to a range of 0–1 for each participant, averaged across participants, and then subtracted from 1 to obtain a dissimilarity matrix. Multidimensional scaling analysis was applied to the dissimilarity matrix to construct the tactile perceptual space. Then, we performed a Procrustes transformation to align the stimuli positions in the tactile perceptual space obtained in this study with those from the authors' previous study. The results are shown in Figure 4A. This figure demonstrates that the average structure of the tactile perceptual space obtained in this study (black circles) closely resembles that obtained in the previous study (white circles). This finding suggests that the stimuli used in this study enable the reconstruction of a relatively robust tactile perceptual space, at least when the ratings are averaged across participants. Prior to Experiment 2, we calculated the correlation coefficients of similarity ratings between each participant, $\mathbb{A}_I$, and all candidates. The average minimum and maximum correlation coefficients across participants were 0.46 and 0.72, respectively. For each participant, the candidate with the lowest correlation was selected as the target. The correlation coefficients r_I between participants' similarity ratings $\mathbb{A}_I$ and the target's similarity ratings $\mathbb{B}$ are shown in Figure 4B.

Experiment 2: Results of Estimation Task of Target's Similarity Ratings

Figure 4B illustrates the correlation coefficients $r_{II,N}$ between the similarity ratings obtained as a result of completing the similarity estimation task $\mathbb{A}_{II,N}$ in Experiment 2 and the target's similarity ratings $\mathbb{B}$. A bootstrap test revealed that $r_{II,N}$ was significantly greater than r_I ($p = 0.008, Hedges'g = 0.65$). These results suggest that the participants were able to estimate the similarity ratings made by their corresponding target through the similarity estimation task, which supports Hypothesis H1.

To investigate how participants' estimated similarity rat-

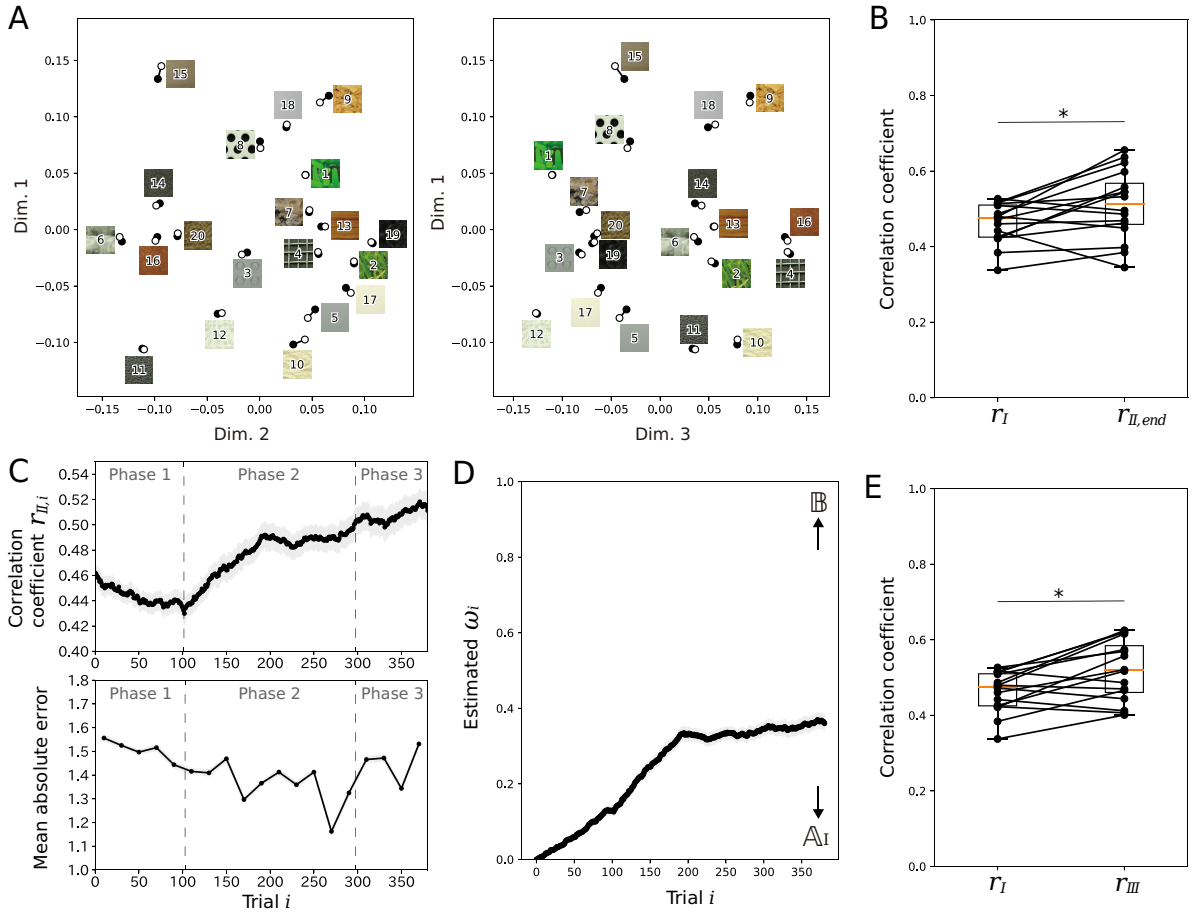

Figure 4: Results of experiments. (A) Comparison of the tactile perceptual space based on the participant-averaged similarity ratings obtained in this study with those obtained in our previous study (Yokosaka, 2024). The black and white circles represent the positions of stimuli in the present study and the previous study, respectively. The line segments connecting the black and white circles indicate that they correspond to the same stimuli. (B) Correlation coefficients r_I and $r_{II,N}$. (C) Top: Dynamics of the correlation coefficient $r_{II,i}$ over trials. Bottom: Dynamics of the mean absolute error between participants' estimated ratings and the target's actual ratings over trials. The error was averaged every 20 trials to smooth variability in difficulty across stimulus pairs. Shaded areas denote the standard error. (D) Dynamics of the estimated ω_i value over trials. Shaded areas denote the standard error. (E) Correlation coefficients r_I and r_{III}.

ings $\mathbb{A}_{II,i}$ in each trial i approached the target's similarity ratings $\mathbb{B}$ in Experiment 2, the correlation coefficient $r_{II,i}$ between $\mathbb{A}_{II,i}$ and $\mathbb{B}$ was calculated for each trial i. The results averaged across participants for each trial are shown in the top panel of Figure 4C. In addition, the bottom panel shows the mean absolute error between $\mathbb{A}_{II,i}$ and $\mathbb{B}$ as a function of trial i. These figures reveal three distinct phases: immediately after the start of the similarity estimation task, both the correlation and the error decrease (Phase 1); around Trial 100, the correlation begins to increase and the error continues to decrease (Phase 2); after approximately Trial 300, the correlation continues to increase, but the error starts to increase (Phase 3). Phase 1 can be interpreted as an exploration period where participants begin to move away from their original perceptual space while gradually improving the accuracy of their predictions for individual pairs. Phase 2 can be interpreted as an adaptive period where participants begin to grasp the target's perceptual space and make more accurate and consistent predictions across pairs. Finally, Phase 3 may represent an overgeneralization (or fatigue) period where participants capture the overall ranking of the target's ratings while their estimates for individual pairs become less accurate, suggesting a shift toward rule-based generalization.

To investigate the structure of the similarity ratings into which $\mathbb{A}_{II,i}$ converges, we calculated the trial-by-trial progression of ω_i values, which showed the highest correlation between $\mathbb{A}_{II,i}$ and $(1-\omega_i)\mathbb{A}_I + \omega_i\mathbb{B}$ at each trial i. The results are shown in Figure 4D. The final mean and standard deviation of ω_N across participants were 0.36 ± 0.16. This result suggests that participants' estimated similarity ratings $\mathbb{A}_{II,i}$ do

not fully replicate $\mathbb{B}$, but rather converge to a structure represented by $0.64\mathbb{A}_I + 0.36\mathbb{B}$.

Experiment 3: Results of Participants' Similarity Ratings After the Similarity Estimation Task

Figure 4E illustrates the correlation coefficient r_{III} between participants' similarity ratings $\mathbb{A}_{III}$ after the estimation task (i.e., in Experiment 3) and the target's similarity ratings $\mathbb{B}$ as well as r_I. A bootstrap test revealed that r_{III} was significantly greater than r_I ($p = 0.0004, Hedges'g = 0.83$). This result suggests that performing the estimation of the target's similarity ratings influences participants' own similarity ratings, causing them to shift closer to the target's similarity ratings. This result supports Hypothesis H2.

Discussion

In this study, we investigated the ability to estimate the tactile similarity between two textures as perceived by a target individual, and the process involved. The results showed that participants were able to estimate the target's similarity ratings better after completing the similarity estimation task than before, which supports H1. Since tactile similarity estimation is based on the distance representation between tactile perceptions (i.e., in the tactile perceptual space), our findings suggest that humans may be able to understand the structure of others' tactile perceptual space. The finding that the correlation between participants' estimated similarity ratings and the target's similarity ratings begins to increase, even though no combination is repeated until the 190th trial, cannot be attributed to a strategy of memorizing the similarity ratings for each combination. However, we also found that the estimated similarity ratings did not completely correspond to the target's similarity ratings but tended to converge to an intermediate point between the participant's and target's similarity ratings. There are two possible explanations for this. One possibility is that the person chosen as a target had a very different tactile ability and/or judgment strategy from the participants (we will discuss this later). Another possibility is egocentric bias. When understanding the knowledge and experience of others, people tend to bring in their own perspectives and standards (Nickerson, 1999). If this egocentric bias also exists in tactile similarity estimation, it will be difficult for participants to completely understand the tactile perceptual space of others.

Our results might be explained by regression to the mean. Since we chose the candidate with whom the participant had the lowest initial correlation, this selection might cause the values to move closer to the average when measured again, even without learning. Future studies should disentangle learning effects from changes caused by regression to the mean.

The possibility that the participants estimated the target's similarity ratings while referring to their own tactile perceptual space is also supported by the result that the participants' own similarity ratings were more closely aligned with the target ratings after the similarity estimation task (i.e., Exp. 3) than before (i.e., Exp. 1). However, we cannot rule out the possibility that the results are influenced by memory. For example, when participants encountered stimulus pairs that were difficult to rate for similarity, they might have recalled the target's rating of the stimulus pair and used it as their evaluation. One way to eliminate this possibility would be to use a completely different set of tactile stimuli for the similarity estimation task (Exp. 2) and the participant's own similarity rating task (Exp. 1 and Exp. 3). If the participant's own similarity ratings after the similarity estimation task align more closely with the target's similarity rating even when different stimuli are used, it is more likely that the participant's tactile perceptual space itself is being affected rather than that the participant is remembering and using the target's similarity ratings.

An important future direction for study will be to elucidate which tactile dimensions (e.g., roughness and hardness) each participant used to estimate the target's similarity ratings. The original difference in similarity ratings between the participants and the target could be attributed to differences in tactile abilities and perceptual strategies. For example, previous studies have reported that tactile discrimination performance differs depending on the mechanical properties of the skin, such as the coefficient of friction and moisture content (Gueorguiev, Bochereau, Mouraux, Hayward, & Thonnard, 2016; Skedung et al., 2018; Kawai & Tanaka, 2022). In addition, exploratory procedures (e.g., stroking motions, pushing motions, and so on) change depending on which tactile dimensions the participants want to know about, such as roughness or hardness (Lederman & Klatzky, 1987), and the difference in exploratory procedures can produce different tactile perception (Yokosaka, Inubushi, Kuroki, & Watanabe, 2020). Obtaining evaluations of tactile dimensions for stimulus by conducting an additional experiment will allow us to elucidate which tactile dimensions participants understand through the similarity estimation task.

In the future, clarifying the process of tactile similarity estimation from the perspective of tactile dimensions will contribute to the scientific elucidation of tactile perception, the technological foundation of haptic engineering, and the proposal of new communication methods. The methodology proposed in this research could be used to investigate human tactile abilities, tactile representations in the brain, and individual differences in tactile perception. Our findings could also be useful for developing a technological foundation for converting one person's tactile perceptions into tactile perceptions that others can understand. Finally, the paradigm of the similarity estimation task may provide a new communication method for people who need to understand how others feel, such as product designers.

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