# Somatotopic distortion of tactile temporal interval estimation

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**Abstract:** Tactile timing mechanism, which is essential for accurate response to the external environment, has to compensate for the distortions of neural timing signals. Specifically, signals come from the distributed peripheral receptors and the body parts move dynamically in a space. Since an accurate visual timing encoding lacks the precision when using two widely separated photoreceptors, here we studied on how the tactile timing is encoded in relation to two distance; somatotopic representation, defined by cortical topography, and spatiotopic representation, defined in the physical world. We performed 1 second tactile interval estimation experiments, in which the spatial distance of the two stimuli was systematically changed in somatotopic and spatiotopic representations and compared. Our results showed that somatotopic nerve distance, not real-world physical distance, plays a dominant role in the tactile timing estimations.

**Keywords:** Tactile, temporal interval estimation, somatotopic

## 1. INTRODUCTION

When you look at a saliently ticking clock, you sometimes think that the second pointer takes longet than normal to move to its next position. For a short period, the clock appears to have stopped which is a famous phenomenon called chronostasis [1]. This temporal modification by voluntary action suggests that our temporal perception is not directly reflect the timing of the neural signals. In other words, our time is not caliculated by ”metaphysical central clock” in our brain. Another modification phenomena were reported that sluggish neural signal, caused by transient luminance noise [2], impaired the accuracy of timing judgment. And also, spatial separation between receptors has effects [3].

Since neural mechanisms encoding timing events are crucial for human sensory and motor system, we focused whether this modification mechanism exist in touch. Do we have metaphysical central tactile clock? Or do we have several distributed neural mechanisms of temporal estimation? Considering the latter case, it can be speculated our timing perception is distorted by stimulus condition, such as position or attention. Here, tactile modality is unique from the viewpoint of its spatial representation since receptors are distributed over the whole body, and body parts move around dynamically with our body movements. For example, signals from the receptors in the finger and toe are subject to significantly different latencies, and spatial distance between receptors in the left and right hands dramatically changes in the physical space depending on whether the arms are opened or closed. So the information processing of tactile timing can be performed through at least two spatial representations; somatotopic representation, defined by cortical topography, and spatiotopic representation, defined in the physical world. Does the perception of tactile timing change depending on the stimulus position? And if so, which coordinates should be paid attention when we design tactile displays? This question can easily be expanded to incorporate the question of how the brain interprets information from a lot of sensors. Since we have been considered this tactile coordinate problem [4], we especially focused on time interval estimation in this paper.

## 2. EXPERIMENT: 1 SEC TIME INTERVAL ESTIMATION

### 2.1 Apparatus

To avoid the negative effect of finger skin vibration, we used an electric stimulus which makes a potential gradient on the axon of the peripheral tactile receptor, and produces nerve activity directly. The participant placed his/her finger pad on the electrode arrays. The electrodes were 1.25 mm in diameter and arranged at intervals of 2.5 mm. Anodic stimulation method was used, in which one electrode and surrounding electrodes served as the anode and ground, respectively, and made a potential gradient on the axon of the peripheral tactile mechanoreceptors. As demonstrated in previous studies, electric stimulus has the same capability as a mechanical vibration [5]. The duration of one electric stimulus was about one millisecond, and it was composed of five shots of current impulses, which were 20 microseconds of duration. The magnitude of applied current was adjusted from 2 mA and 4 mA individually due to individual difference of perceived intensity.

### 2.2 Procedure

It was difficult for participants to estimate and replicate the interval of presented tactile stimuli, we used the comparative method. The tactile temporal interval was compared with auditory comparison stimuli. Four electrode arrays were arranged for the subject’s left middle

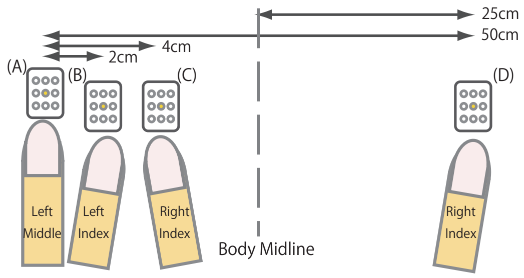


Fig. 1 Finger place conditions

finger (A), left index finger (B), and right index finger (C), with 2 cm distance between them. The subject could only move the right index finger to the right (D), so that the distance from left middle finger to right index finger was 50 cm, as shown in Fig.1. Four place conditions with pair of fingers were examined. One was referred to as the "same site condition," in which the two stimuli were added on (A). This "same site condition" was tested as a control condition. The "ipsilateral condition" used (A) and (B), and the two "bilateral conditions" used (A) and (C) or (A) and (D). The difference between the two bilateral conditions was the distance of the subject's hands. Two beeps with stimulus-onset asynchronies (SOA) were provided, then left side arrays was presented first stimulus and the other was stimulated with exactly 1 second interval. The auditory stimuli presented with an interval chosen from 5 values between 850 and 1150 ms. Participants were asked to compare the temporal interval of auditory stimuli with that of tactile stimuli, which was always one second, and answered which interval was longer as shown in Fig. 2.

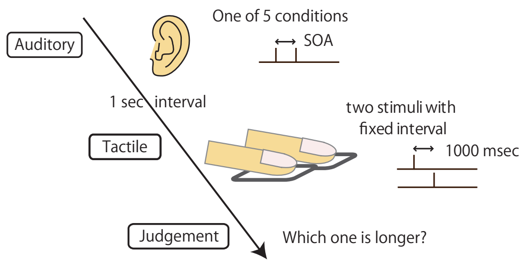


Fig. 2 Procedure

Each condition was tested 20 times. The SOAs and place conditions were tested in random order. Five subjects were tested individually.

### 2.3 Result

Fig.3 shows the result obtained with participant MT. The horizontal and vertical axes represent SOA of Audio signal, and the rate of a participant's response of "Audio was longer", respectively. The rates in the both bilateral conditions fell to zero with smaller SOAs than those in the same site and ipsilateral conditions. As the SOA increased, the rate increased to one. In this case, the same site and ipsilateral conditions increase with smaller SOAs than those in the bilateral conditions.

Point of Subjective Equalities (PSEs) where each par-

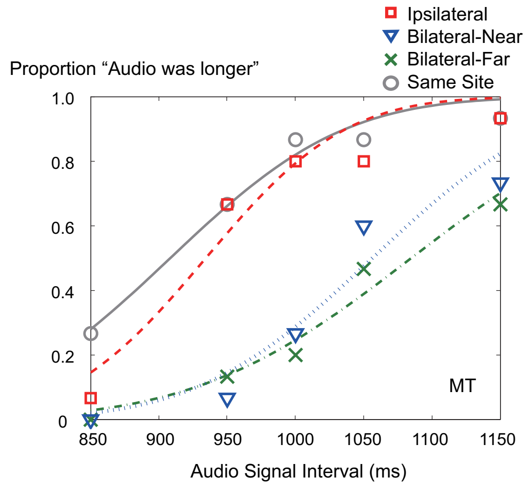


Fig. 3 Psychometric functions obtained with participant MT

ticipant perceives two intervals to be the same was calculated. We consider that shift of the same site condition's PSE from the audio stimuli interval as a corollary of modality difference. Because each subject showed different PSE shift of same site condition, we normalized each subject's results by each PSE of same site condition as shown in Fig.4.

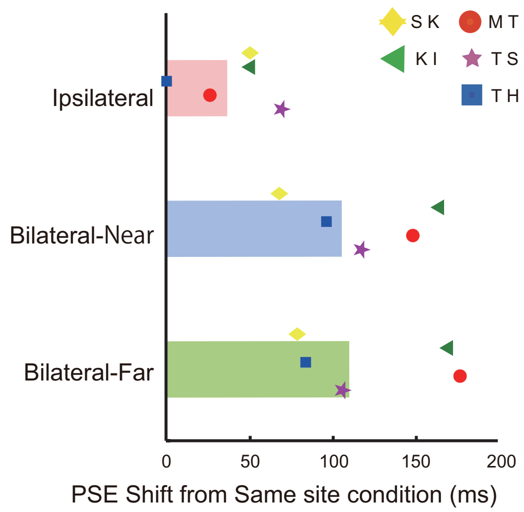


Fig. 4 PSE shift of temporal interval from same site condition

Surprisingly, the shift of PSE in the ipsilateral condition is significantly small than bilateral conditions ($t=-3.951$, $p<0.05$) which were more than sixty milliseconds. In addition, there were no significant differences between the two bilateral conditions ($t=0.536$, p<n.s.). This means that temporal interval perception around one second is distorted by the difference in the stimulus position on the body, and the difference in the body positions in the real-world does not make sense.

## 3. CONTROL EXPERIMENT: 3 SEC TIME INTERVAL ESTIMATION

How can the difference in the stimulus position be explained? Although there must be neural latency difference between ipsilateral and bilateral conditions, it seems that this interval distortion we observed is different scale (see discussion). If so, the dissociation of the estimated time interval between the two fingers should be ascribed not to the difference in the timing information of the sensory input but to higher processes difference such as filtering or memory mechanism. In next experiment, we test for a possible influence of tactile memory on the longer time interval estimation to look more closely at the somatotopic effects of tactile timing mechanism.

The same experimental procedures as in the case of the 1 sec time interval estimation without SOA variations were used. Here we prolonged stimulus interval from 1 second to 3 seconds so that participants surely use tactile short term memory to judge. The interval of auditory stimuli were varied 5 values between 2700 and 3300 ms. The results are shown in Fig.5.

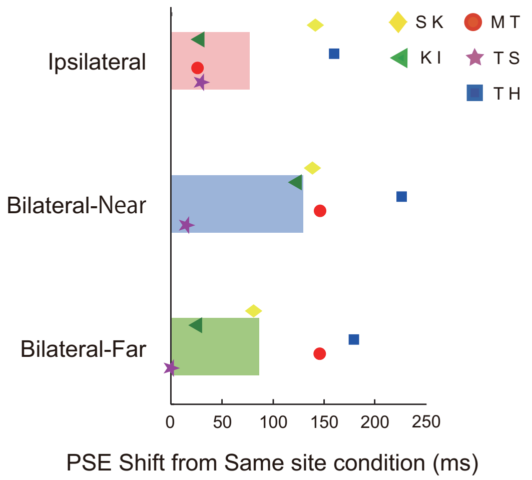


Fig. 5 PSE shift of temporal interval from audio signal

The same site condition also showed obviously shorter result than other conditions, however, no significant difference was observed between ipsilateral and bilateral conditions in this 3 second estimation case. Again, no somatotopic distortion in this control experiment. The PSE of bilateral near condition looked taking bigger than other condition, however, this difference is not significant and considering the percentage of variance, it was much more smaller than the result of 1 sec experiment.

## 4. DISCUSSION

The somatotopic distortion of tactile temporal interval estimation we report have at least three possible origins. First possibility is that the somatotopy we observed could be simply a consequence of the neural latency difference. Second, we may have measured a truly somatotopic effect, in that the time interval estimation is linked to the somatotopic position where we receive the pair of stimuli. A third possibility insists that our short memory itself, which memorizes estimated tactile interval is swayed by stimulated position.

According to the first hypothesis, the somatotopic effects we measured would arise from the other tactile temporal tasks such as simultaneity judgment. Actually, this somatotopic distortion is well reported by previous studies[6], showing that the ranges of simultaneity were wider in the bilateral conditions than that in the ipsilateral condition. Most of previous tactile simultaneity studies explained this somatotopic distortion of simultaneity judgment by neural transduction latencies. In the ipsilateral stimulation, the two stimuli are delivered to the same cerebral hemisphere, while in the bilateral stimulation they are presented to each hemisphere and interhemispheric transmission time (IHTT) is needed for the task. So are these tactile temporal estimation distortions perfectly explained by neural latency such as IHTT? We experimentally measured somatotopic distortion in simultaneity judgment with using same experimental setup as our time interval estimation. The result is shown in Fig.6.

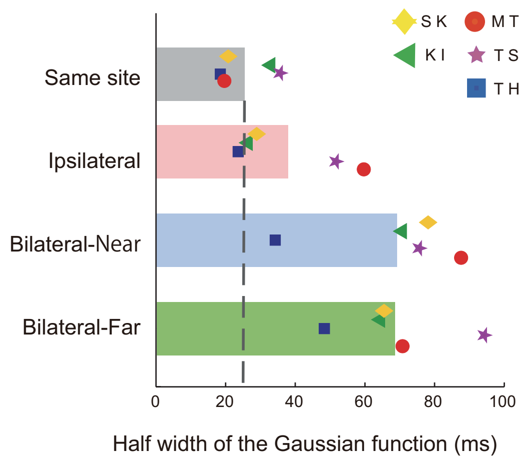


Fig. 6 Mean ranges of subjective simultaneity

What is interesting here is that although one-second time perception seems at a glance to be a complicated process for neural filtering, the simultaneous perception showed the same tendency. No spatiotopic effect, but only somatotopic distance had effect again. From the view of information encoding, the accuracy of signal/noise segregation becomes worse for bilateral stimuli. In visual psychophysical studies, it was reported that sluggish neural signal, caused by spatial separation between receptors [3] or by transient luminance noise [2], impaired the accuracy of timing judgment. The reduced accuracy in the tactile simultaneous task can also be explained from the view of information encoding as in the visual timing tasks. However, the IHTT estimated in our simultaneity experiment was around 30 milliseconds. The mean value of the IHTT reported in previous study was around 20 milliseconds, which was equivalent or even shorter than our results, and it was too short to explain the difference in the time interval estimation, around 80 milliseconds.

When the time interval of two stimuli is short, the information can be processed by a low level mechanism such as a spatiotemporal filter. However, our experiment used enough long interval so memory mechanism should be involved in judgement. To verify the third hypothesis ”whether stimulated position does have effect on memory or not” we made control experiment with more long interval. In a control experiment where 3 seconds interval was used instead of 1 second, the somatotopic distortion is disappeared, indicating that this somatotopic effect on time interval estimation is due to the estimation mechanism itself rather than the memory distortion.

Here, we support the second hypothesis. Although the same perception such as ”1 sec” is obtained, encoding levels between ipsilateral task and bilateral task can be different. Temporal relationship task with bilateral stimuli may be judged in higher order process than task with ipsilateral stimuli and/or may be cognitive level. It is, however, unclear at which level the difference could be generated; it could be in the level of neural signal, encoding, or higher cognitive strategy. So why do we have parallel temporal estimation mechanisms? Is there any validity or demand in our daily life? There is a famous trend called simultaneity constancy, which insists that the perceived timing of sensory events is not determined exclusively by the transduction latencies of the neural signals [9]. This flexible mechanism enables us to compensate some temporal differences between sensory processes and accurately decide whether they originated from a single event. For example, when two distant lights flick together, we can judge true simultaneity despite differences in the neural latency. This was widely demonstrated in vision, however, it was reported that this constancy was not perfect in touch. When the different parts of the body were touched simultaneously, they were successively perceived [7]. When the foot stimulus was touched earlier than the hand, they came to be perceived simultaneous. Apparently it means lack of compensation mechanism. However, the observed time differences of simultaneity in their experiments cannot fully be explained by the differences of neural latencies. The compensation mechanism somehow works but is not perfect [10]. We also hypothesize there is a compensation mechanism of tactile temporal perception, which resulted in our experimental observation.

Not only somatotopic but also spatiotopic effect is well reported in vision, so there might be a strategy difference between tactile and vision. This discrepancy which is also observed in constancy system may be raised from difference of spatio-temporal resolution of the receptors and dynamics of the sensory organs. In touch, the temporal resolutions of mechanoreceptors are high enough comparing the duration of the limb movement, while the temporal resolution of photoreceptors and the duration of rapid eye movements are in the same time scale. Therefore the complicated information process such as coordinate transformation may be needed in touch. In addition, if we dynamically change our strategy by position of body parts in space for better estimation of objects, recognize of our own body may collapse.

## 5. CONCLUSION

Perception information processing in a short time (around 1 second) is important for humans' sensation and movement mechanisms. Our major research question asks how information about the time of a tactile sense is integrated. In this paper, we tested the influence of finger position on temporal interval judgments. From our experiment, 1 sec temporal interval estimation is affected by somatotopic distance, not by spatiotopic distance. The judgment mechanism might exist in earlier stage, though in a location where coordinate frame remapping of somatotopic to spatiotopic is not completed. Following the addition of other tasks, further careful studies investigating the efficiency limit of somatotopic distance are required. After though investigation of temporal sensation, we will be able to sort out the stages of temporal judgments, and this will lead to the reasonable design of tactile displays.

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