How is tactile timing information integrated-, somatotopically or spatiotopically?

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ABSTRACT

We are perceiving environment tactually in various situations. Does the consciousness of tactile timing change depending on the stimulated body parts or how we touch? In this research, we focused on how temporal information is combined under the influence of two distances-somatotopic and spatiotopic. Which distance is important for temporal processing? We provide two experiments to investigate this question. By using two stimuli with short intervals, we can judge simultaneity. With a long interval, two stimuli can be separated, and the time interval can be evaluated. As a result, we found that somatotopic coordinates clearly influence these processes. Conversely, they are not based on spatiotopic coordinates. Furthermore it was suggested that the judgment mechanism for about 1 second of timing information exists in the early stage of temporal processing, where even the coordinate frame remapping of somatotopic to spatiotopic has not yet been completed. Depends on how we touch stimuli the perceived temporal interval would be slightly changed.

INDEX TERMS: H.1.2 [MODELS AND PRINCIPLES]: User/Machine Systems—Human information processing; H.5.2 [INFORMATION INTERFACES AND PRESENTATION]: User Interfaces—Theory and methods

1 INTRODUCTION

Human beings touch and feel the environment daily in various ways. We do this not only with our fingertips, but also with our hands; sometimes we use both hands. Tactile receptors are distributed over the whole body, so in terms of nerve circuits, stimuli are come into contact with very different places on the body each time. This raises the following question: When searching for environmental information, does our perception change with how we touch? Does consciousness change depending on the stimulated body parts, even if touching same stimulus? This question can easily be expanded to incorporate the question of how the brain interprets information from a lot of sensors.

This unresolved question carries fundamental importance for developing tactile displays. Our major research question asks how space and time correlate in tactile information processing. In vision, spatiotopic position information is coded on the retina so that the retinotopic and spatiotopic coordinates are the same. On the contrary, in the tactile modality, the spatiotopic location of a stimulus can only be determined after information from proprioception and other senses is integrated. Thus, there exist two different definitions for coordinates: somatotopic and spatiotopic. Which coordinates should be paid attention when we design tactile displays?

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Each coordinate would affect perception at a different layer. We focused on temporal information processing and investigated which type of distance is a clue to this processing, the somatotopic or the spatiotopic?

There must be several layers in temporal information processing; the definition of the coordinate that influences processing is probably different in each layer. To investigate this functioning, first, we measured simultaneity, since simultaneity judgments are assumed to be fundamental to all other types of temporal judgments [1]. How much of a time interval is needed between stimulus onsets so that they do not fuse together and, rather, are identified as successive? In earlier studies, simultaneity testing involved fingers on the ipsilateral side and the bilateral side of the body. On the basis of the results from these tests, it was thought that somatotopic distance affected simultaneity because of the clear difference of simultaneity durations. Here, we have another question: How does spatiotopic distance affect the judging of simultaneity? We experimentally investigated the influence of these two distances at the same time.

2 EXPERIMENT 1: SIMULTANEITY

To our knowledge, no previous studies have compared influences on simultaneity by separating somatotopic and spatiotopic locations using the same conditions.

In Experiment 1, we examined how the window of subjective simultaneity was influenced by the distance of the stimulus points with two coordinate definitions.

2.1 Apparatus

To avoid the negative effect of finger skin vibration, we used an electric stimulus in all of our experiments. The electric stimulating method makes a potential gradient on the axon of the peripheral tactile receptor, and produces nerve activity directly. As shown in previous work, an electric stimulus has same capability as a mechanical stimulus when used in simultaneous testing [2].

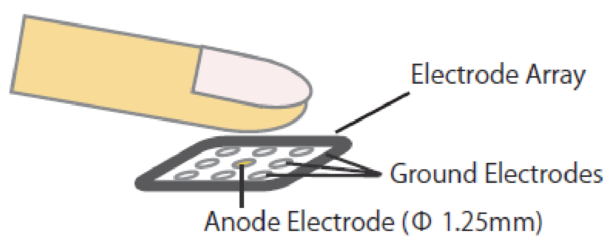


Figure 1. Experimental Equipment

Anodic stimulation, where one electrode and surrounding electrodes served as the anode and ground, respectively, was used (Fig. 1). In this experiment, stimuli were presented at equal intensities by an electric stimulator and involved quite simple impulses, so that one stimulus would not interfere with another. The subjects placed their finger pads on the electrode arrays. The electrodes were 1.25 mm in diameter and arranged at intervals of 2.5 mm each. Five shots of the current pulses, which were 20 microseconds in length and a maximum 4mA current, were added in 1 msec as one group stimuli.

2.2 Procedure

Four electrode arrays were arranged for the subject's left middle 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. 2.

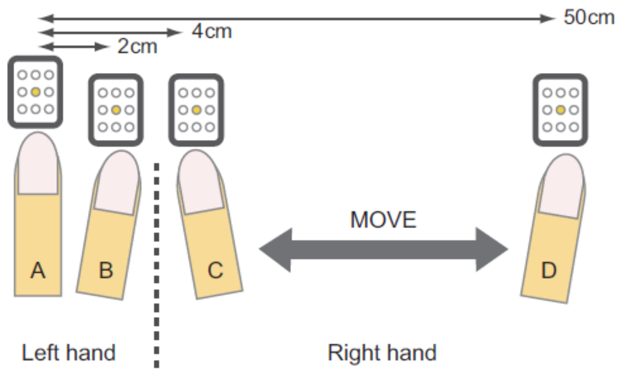


Figure 2. Place Conditions

Four place conditions were examined. One was referred to as the "same site condition," in which the two patterns were generated on one electrode array (A) and presented to the subject's left middle finger pad. The other three conditions used two arrays: the "ipsilateral condition" used (A) and (B), and the two "bilateral conditions" used (A) and (C) or (A) and (D). For the ipsilateral condition, the subject's left middle finger pad rested on one of the two electrode arrays, and the subject's left index finger pad rested on the other array. For the bilateral condition, the subject's left middle finger pad rested on one, and the right index finger pad rested on the other. The difference between the two bilateral conditions was the distance of the subject's hands. These fingers were chosen because the index and middle fingers are innervated by the same spinal nerve [3]. One of the two arrays was randomly selected and presented first stimulus and the other was stimulated after brief stimulus-onset asynchronies (SOA). In both the same site and the separate-site conditions, the subject's task was to indicate whether the stimuli were simultaneous or successive. Seven SOAs, 0, 15, 30, 45, 60, 90, and 135 msec, were tested.
Simultaneity tasks generally require the participant to judge whether a pair of stimuli are presented simultaneously or sequentially. However, this judgment is easily influenced by participants' bias. The definition of simultaneity varies among different individuals and erratic. What we want to investigate here is whether the output of peripheral sensors in connection with simultaneity judgment is influenced according to the distance between sensors. To avoid the effect of bias, two simultaneous stimuli were shown to the same two arrays used in the test stimulus as in the comparison stimulus. The subject was presented with two groups of stimulus, then answered which group tended to be simultaneous within a two alternative forced choice. The interval between the two groups was 2 seconds, long enough to reduce the masking effect. Which group was presented first, the comparison stimulus group or test stimulus group, was changed randomly. This procedure, shown in Fig. 3. might enable the subjects to pick up any possible difference between stimuli, and thus might show relatively low thresholds.

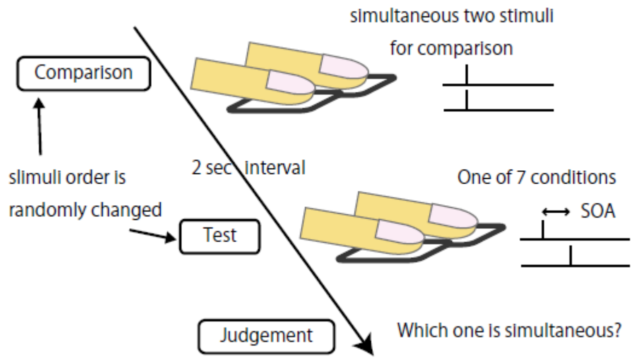


Figure 3. Experimental Procedure

Here, we have another problem to be considered. Even if the equipment shows exactly simultaneous stimuli, there is a possibility that a subject feels successive sensation because of his or her information processing. To avoid this bias also, we fixed stimulus order. In every test stimulus in separate-site condition, left side stimulus came first. Subject was told of stimulus order as criterion to make decision. Each condition was tested 20 times. The SOAs and place conditions were tested in random order, and an experimental session consisted of 4 blocks of 140 trials. Subjects were one of the authors (S.K.) and three volunteers who were unaware of the purpose of the experiments.

The subjects were tested individually.

2.3 Results and Discussion

Figure 4 shows the rates of "Simultaneous" responses obtained. The horizontal and vertical axes represent the SOA of the test stimulus, and the rate of a subject's response of "Simultaneous." Since we used a comparative method, a rate of 0.5 represented the subject's complete confusion of simultaneous and successive stimuli. The red circles, blue squares, green inverted triangles, and brown crosses represent the averages of each of 20 trials in same-site (AA), ipsilateral (AB), bilateral-near (AC) and bilateral-far (AD) conditions, respectively. The thin red line, broken blue line, dotted green line and short-dotted brown line indicate the fitted line with cumulative normal distribution. As the SOA increased, the rate declined to zero. First the red and blue lines, then the green and brown lines approach asymptotically to zero. These tendencies were observed for all subjects.

As a measure of the range width of subjective simultaneity, the standard deviation of the Gaussian function is shown in Fig.5. for each of the place conditions. Symbols indicate individual data, and the bars indicate the average (n = 4). When the SOA was 0, the rate of an answer of "Simultaneous" was about 0.5.

Performance in the same site condition was significantly better than in the other three conditions for all subjects, except for subject K.I. In addition, in the three separate-site conditions, both bilateral performances lagged behind ipsilateral performance for all subjects. This accorded with a previous study [4]. In which the researchers said that ipsilateral stimulation delivered stimuli to the same cerebral hemisphere, while bilateral stimulation resulted in the delivery of one stimulus to each hemisphere, therefore requiring interhemispheric transmission (IHHT) before judging simultaneity. Our experiment showed that the somatotopic distance between two stimulus points produced a large deleterious effect on bilateral-site performance. On the other hand, spatiotopic distance had relatively no effect, such as an improvement, on either the near-site condition or on the far-site condition.

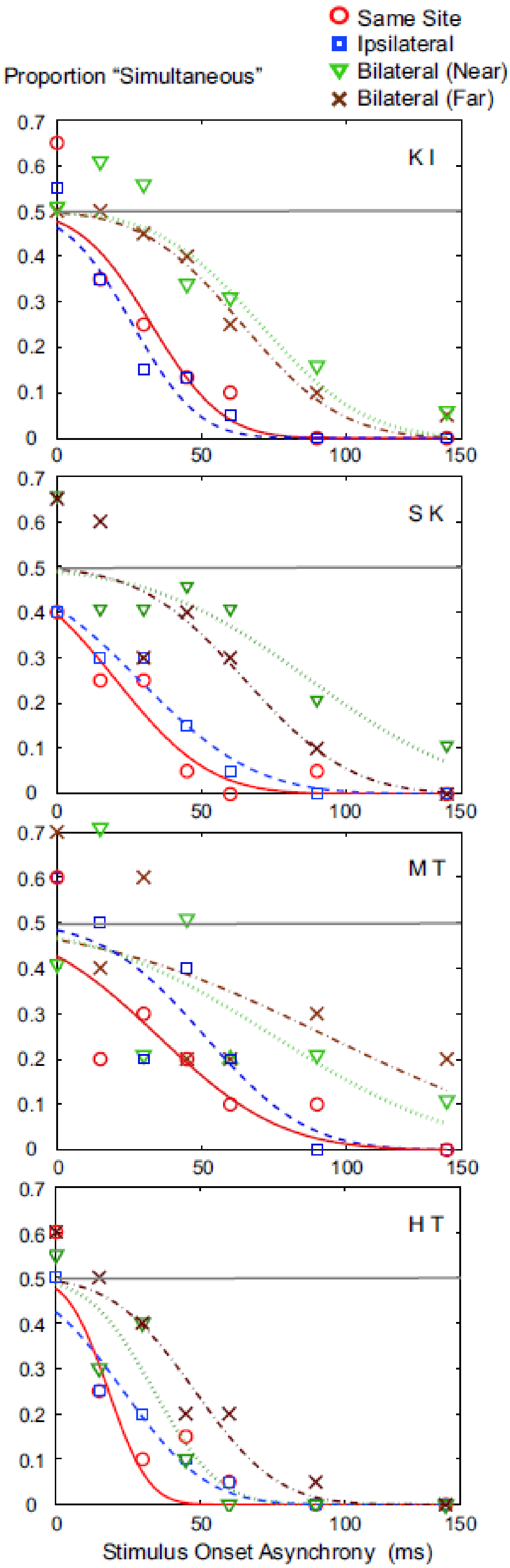


Figure 4. Experiment 1 (Simultaneity)

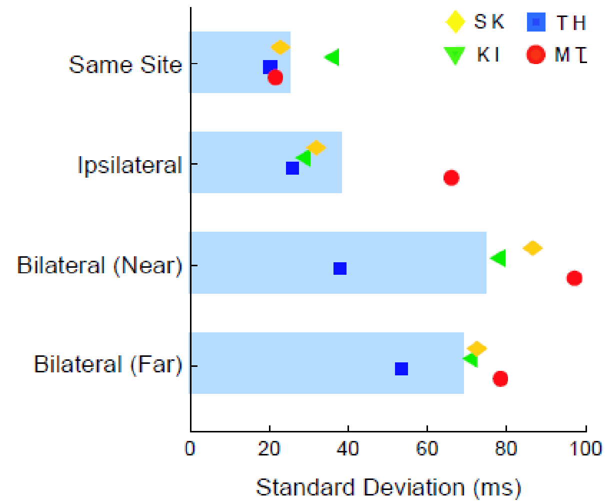


Figure 5. The Range Width of Subjective Simultaneity

Comparing two bilateral conditions, some participants even showed shorter standard deviation in far condition than near condition. This was caused by participant's attention bias probably.

What accounts for the irrelevance of spatiotopic coordinates in simultaneity? As is well known, changing stimulus points' spatiotopic coordinates, such as through crossing hands, certainly affects the judgment of tactile temporal order [5, 6]. The tactile stimuli are remapped into a spatiotopic frame of reference as a final form for our perception. Perhaps the two available somatotopic and spatiotopic frames are integrated, and both contribute to performance equally in higher order processes. We hypothesize that judging simultaneity is a primitive process in tactile information flow, which maybe occur before the remapping process. There are two foundations for this hypothesis. One is that, considering the advantage of ipsilateral conditions, simultaneity must be judged before the integration of both hemispheres' information. The other is the accuracy of the simultaneity judgment: we can recognize successiveness with such a small SOA difference as shown in Fig. 5.

To ensure consistency with the results of TOJ, we need to ensure careful consideration; however, some other researchers have argued that although the two tasks superficially appear to be similar, they may actually be qualitatively different [1]. When judging temporal order tasks, we have to change the coordinates to answer "which side" was stimulated first. What is more, with simultaneity judgments, no deficit in temporal processing is seen when the hands are crossed [4]. For these reasons, we again suppose that simultaneity is primitive enough that only somatotopic distance has an influence on it.

3 Experiment 2: Time interval

The results of Experiment 1 suggest that simultaneity is judged at each hemisphere, and can be called a primitive judgment. In Experiment 2, we examined two coordinates' effect on a more complicated temporal judgment. By setting a second-scale interval, two stimuli can be totally separated, and a time interval can be evaluated. In all cases, subjects judged the interval of two stimuli.

Generally, when checking the interval sensations, the subject's task was to reproduce the interval by using the push button or Morse keys. The use of such a contact device results in fatigue by physical touch or in change of condition and, what is more, lacks accuracy. Here, we use a second (not so long) interval and try to clarify the small difference between different placement conditions; thus, we again chose a comparative method in

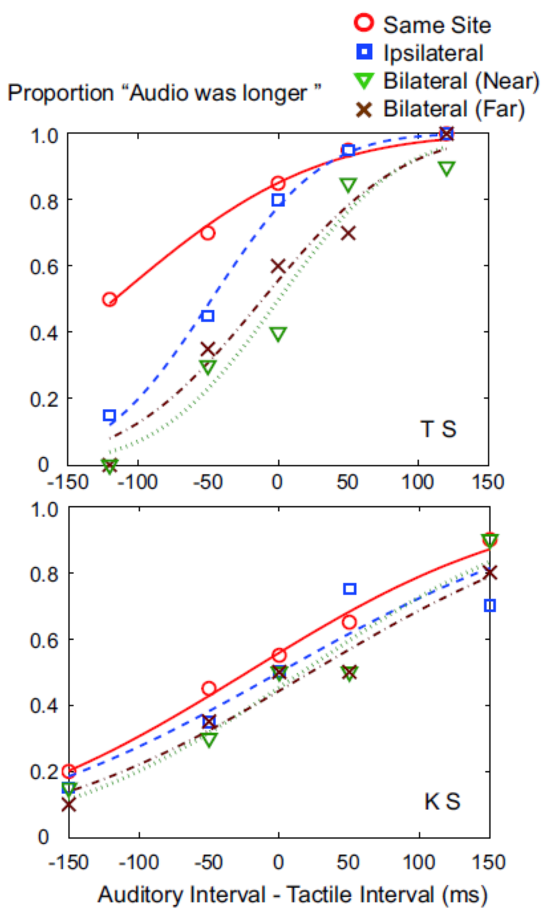
Experiment 2. We assumed that tactile interval perception is not so stable, and therefore used auditory comparison stimuli.

Two beeps were sequentially provided in the same way as tactile stimuli. Actually, we set the interval difference for the auditory stimuli and subjects to compare them with tactile stimuli, which had exactly a 1 second interval. In each trial, the auditory stimuli always preceded tactile stimuli and presented with an interval chosen from 5 values between 850 and 1150 ms. The subject's task was to compare the two stimuli groups and to choose which interval was longer than the other. The other experimental conditions were the same as Experiment 1. The same four experienced psychophysical observers as participated in the previous experiment, as well as two more subjects, volunteered for this study.

3.1 Results and Discussion

Figure. 6. shows the rates of the "Sound was longer" responses obtained. The horizontal and vertical axes represent the interval difference between the auditory interval and the tactile interval, and the rate of a subject's response of "Sound was longer."

When the auditory stimuli interval was 850 ms, the rate of an answer of "Sound was longer" was around 0 in almost all conditions. On the other hand, when an interval of 1150 ms was presented, the rate increased to 1. These tendencies were observed for all subjects. To a greater or lesser extent in each subject, first red and blue lines then green and brown lines increased asymptotically to 1.



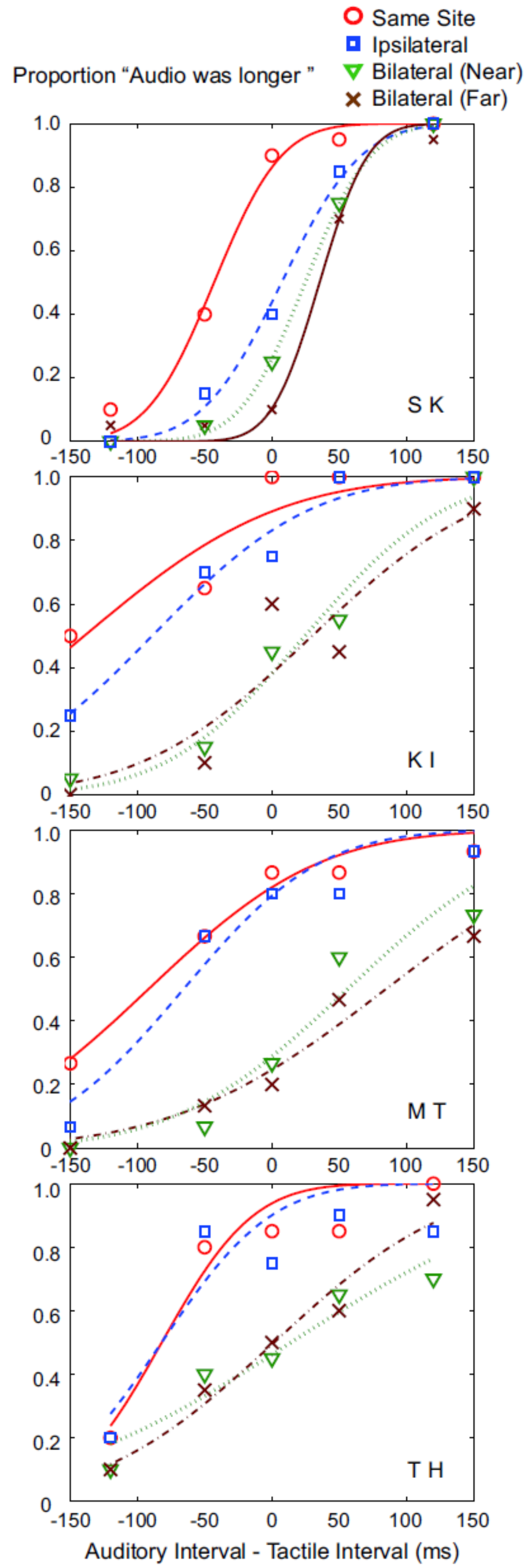


Figure 6. Experiment 2 (Time Interval)

The Point of Subjective Equality was calculated for all place conditions. 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. The shifts of PSEs in three place conditions from same site condition are shown in Figure. 7. The symbols indicate individual data, and the bars indicate the average (n = 6).

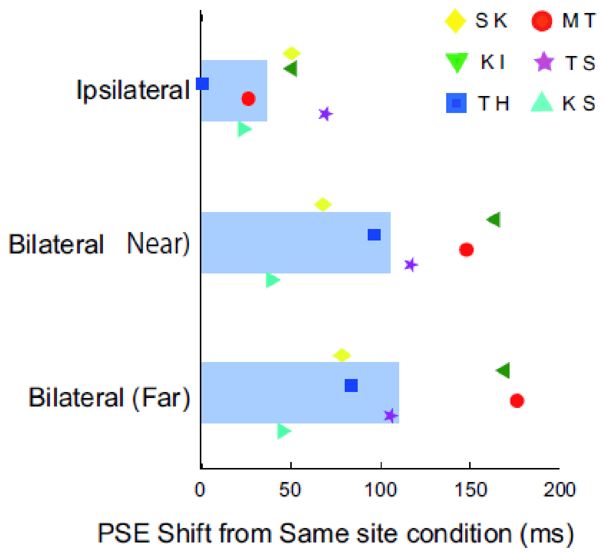


Figure 7. The PSE Shift of Subjective Temporal Interval from Same site Condition

Surprisingly, this result shows that time sensation was altered by the finger position. Note that we used multi modal comparison in this experiment, and exact PSE time does not have any meaning. Thus, the focus of this study is to compare results between conditions. Based on the same-site condition's PSE which showed the most negative value, the ipsilateral condition showed a more positive value, and bilateral conditions showed a much more positive value. There are no significant differences between the two bilateral conditions. What is interesting here is that although time sensation seems at a glance to be a higher order process, it showed the same tendency as the simultaneous results. Is this possible?

With the long history of research into the relation between spatial and temporal dimensions, it has been established that the perception of brief temporal intervals is influenced by the context in which they are presented. Using three light flashes indicating two distances and two time intervals, it was demonstrated that judgments of these two intervals varied according to the two distances. Furthermore, distances varied by intervals. The former phenomenon has been called "kappa effect," and the latter is the "tau effect" [7, 8]. These have been shown by many researchers in many modalities, including tactile perception, and are indisputable results. Although these appear to be contradictory arguments at a glance, here we advocate that a simple temporal judgment is not directly affected by spatial information. As a matter of fact, there is one old study about the tactile kappa effect, which carefully and cleverly tested this effect by using postural illusion [9]. As a conclusion, the researchers said that the definition of distance, which takes account of temporal judgment, is not spatiotopic, and not even somatotopic, but rather perceptual distance. This conclusion is really interesting and impressive and, from another standpoint, this result shows that the kappa effect emerges in the high-order function of tactile information flow. When one tries to produce the kappa effect, one needs a context of stimulus. Two stimuli cannot make any context, more than three stimuli need to be used. We guess that both the tau effect and the kappa effect work in relation to context. It looks like a kind of fitting function, which fits the middle signals to ideal temporal position into context of stimuli group. Now, therefore, we insist that simple temporal interval judging is made at the primitive order of tactile information processing, not at the same order as the kappa effect.

There is a clear PSE disjunction between ipsilateral tasks and bilateral tasks in Fig. 7. Surprisingly, this result suggests that this kind of temporal interval might be judged in each hemisphere, at an earlier stage. We consider that there are some different levels in temporal interval tasks, and the temporal interval task used in our experiment exists between the two kinds of tasks. The shorter (hundreds of milliseconds) task is coded at a low-level neuron nerve circuit at a primitive stage. The longer (a few seconds) task needs help from memory. To investigate what happens between these two task levels, we designed our experimental conditions in such a way that our subjects cannot answer automatically but do not have to think carefully. It is easy to assume that time sensation is created under the influence of many factors in many different layers of perception processing. Considering PSE in each place condition, we can conclude that a prototype of time sensation is built in the early stage of the brain (even at the hemisphere level), where the coordinate frame remapping of somatotopic to spatiotopic is not complete. Earlier than the kappa effect, the tau effect, and even TOJ, the temporal interval is judged once in the primitive stage as the same as simultaneity. Interestingly, 1 second is enough to judge with certainty which of two stimuli came previously, although, a judgment of the time interval of this 1 second is made at an earlier process than a temporal order judgment task. Again, temporal interval judgment -a prototype of time sensation- is affected by somatotopic distance, not by spatiotopic distance. Since this temporal interval is judged at early stage, it is slightly changed with how we touch the stimulus.

4 Conclusion

Perception information processing in a short time (around 1 second) is important for humans' sensation and movement mechanisms. Especially in tactile sensation, it is essential when judging the simultaneity of events and getting a movement of encounter objects. 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 simultaneity judgments and temporal interval judgments.

When the time interval of two stimuli is short, it is thought that the information is processed by a low mechanism such as a spatio-temporal filter. Actually, there is a clear threshold difference between ipsilateral and bilateral tasks; this fact suggests that the simultaneity filter exists at an early level mechanism. We can conclude that, in case of judgement of simultaneity, the main factor was somatotopic. On the other hand, if the stimulus presentation time is long and becomes a stage of judgment of temporal order, it has been established that the spatiotopic factor is influencial. Then, consider the longer time process which cannot process with a filter in nerve; the question then becomes which factor is the main one: the somatotopic or the spatiotopic? Results showed different processing times between within hemispheres task and across hemisphere tasks, and this suggests the priority of the somatotopic. The judgment mechanism of about a 1 second interval temporal sensation might exist in each hemisphere, though in a location where coordinate frame remapping of somatotopic to spatiotopic is not completed. This mechanism differs structurally from time processing, which straddles the hemispheres.

These simultaneity and time interval tasks showed the same tendency, although they look totally different in quality; they were affected by somatotopic distance, not by spatiotopic distance. To ensure consistency with previous works, we carefully sorted each task into stages of tactile information processing. Finally, our results suggest that when a subject received two stimuli, he or she judged the simultaneity, and the interval immediately. Although there must be many disturbance inputs in the higher stages, these prototypes of time sensation are first judged at an earlier stage. Following the addition of other tasks, further careful studies investigating the efficiency limit of somatotopic distance are required. After through 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.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Hirsh I. and Sherrick C.E.: Perceived order in different sense modalities, Journal of experimental psychology, Vol.6, No.5, pp423-432, 1961.

[2] Sherrick C.E.: Temporal ordering of events in haptic space, IEEE transactions on man-machine systems, Vol.11, No.1, pp.25-28, 1970.

[3] Martin J.H. and Jessell T.M.: Anatomy of the somatic sensory system, Principles of neural science, pp.353-364, 1991.

[4] G. Geffen, V. Rosa and M. Luciano: Effect of preferred hand and sex, Journal of Clinical And Experimental Neuropsychology, Vol.22, No.2, pp.219-231, 2000.

[5] S. Yamamoto and S. Kitazawa: Recersal of subjective temporal order due to arm crossing, nature neuroscience, Vol.4, No.7, 2001.

[6] J. Craig and X. Baihua: Temporal oeder and tactile patterns, perception & psychophysics, Vol.47, No.1, pp.22-34, 1990.

[7] Cohen J, Hansel C. E. M, and Sylvester J. D.: New phenomenon in time judgement, Nature, Vol.172, pp.901, 1953.

[8] Helson, H.: The tau effect: An example of psychological relativity, Science, Vol.71, pp.536-537, 1930.

[9] Y. Sudo : The effect of space on time estimation (S-effect) in tactual space (I) , Japanese journal of Psychology, Vol.22, pp.189-201, 1952