Two types of phase error correction mechanisms in synchronization tapping

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Abstract

Timing mechanism is being widely investigated in synchronization tapping and time cognition mechanism is studied in relation with the duration of time. Thus, in this study, we investigated the relationship between timing mechanism and time cognition mechanism. Specifically, the phase error correction system in synchronization tapping was analyzed in relation with the time duration of stimulus. Synchronization error (SE) between an auditory stimulus and a finger tap was manipulated under various conditions of inter stimulus-onset interval (ISI), and the response was measured through the temporal development of inter tap-onset interval (ITI). In the first half of each trial, ISI was fixed (FISI condition) to control the time duration, and SE was fixed (FSE condition) in the latter half to control the timing mechanism. And we analyzed the correlation between SE difference (= SE in FSE – mean SE in FISI) and ITI difference (= mean ITI in FSE – mean ITI in FISI). Our results showed that: (1) Depending on the ISI used under the FISI condition, two types of correlation were observed as shown in the following. (2) When the ISI was short (ISI < 900ms), a negative proportional relationship was observed between the SE difference and the ITI difference, and in addition, this response did not require attentional resources. (3) When the ISI was long (ISI ≥ 900ms), responses where the ITI difference is not proportional to the SE difference was observed in a positive region of SE difference, and this response disappeared in case without attentional resources. These results indicate the timing mechanism in the synchronization tapping is composed of two types of phase error correction mechanisms, the automatic one and the cognitively controlled one.

1 Introduction

Humans adapt to dynamic environment, and the ability to move in synchrony with the environment is absolutely critical. The importance of this type of timing mechanism becomes clear if one considers about what is involved in catching or hitting a ball.

1.1 Timing mechanism

Synchronization tapping task are widely used in research on the timing mechanism between external events and internal cognitive events. This is the psychological task in which the subject synchronizes his tapping to a rhythmic stimulus. This task has a long history (Dunlap 1910, Johnson 1898) and various experiments have been conducted in order to elucidate this timing mechanism (as review, Aschersleben, 2002; Repp, 2001).

Especially, negative asynchrony phenomenon is well known in synchronization tapping task (Dunlap, 1910; Johnson, 1898; Miyake, 1902). It is a phenomenon that is characterized by the subject tapping several ten milliseconds prior to the generation of an auditory stimulus without the subject being aware of it. This phenomenon has been found not only with auditory stimuli and finger tapping, but also has been observed with visual stimuli (Kolers & Brewster; 1985) and foot tapping (Bard et al., 1991). Furthermore, Mates et al. (1994) investigated the negative asynchrony over a range of ISIs (ISI: Inter Stimulus-onset Interval), and the upper limit for this phenomenon was found to be around 2 to 3 seconds. These facts suggest the presence of a timing prediction system in synchronization tapping and its dependency to time duration.

A study was also conducted where a fluctuation was added periodically to the ISI in this synchronization tapping (Thaut et al., 1998). The results indicated that the synchronization error (SE) between tap and stimulus and tap interval (ITI: Inter Tap-onset Interval) adapted to the fluctuation of the ISI. Repp (2001) conducted a similar experiment in which the stimulus interval (ISI) was changed stepwise. By controlling the width of the ISI change, the results showed that the response differed depending on whether the subject was aware of the change or not. This suggests the relationship between timing mechanism and the cognitive process.

Some models for synchronization tapping tasks have been also proposed, and the phase error correction mechanism and the period error correction mechanism were mainly studied (Hary, Moore 1987; Vos, Helsper 1992). Mates (1994) further considered the influence from the delay of nerve conduction process in relation with the hypothesis of Fraisse (Fraisse 1978, Poeppel et al. 1990). In addition, Repp (2001) proposed a similar model in which the coefficient of the phase error correction was changed depending on the cognition process of subject. However, in these models, there is no detailed mention about the relationship between the timing control mechanism and cognitive process.

1.2 Time cognition mechanism

Next, let's look at timing mechanisms from a wider viewpoint including the cognition mechanism. Research on mental time assumes the multiple mechanisms including time perception for below several seconds and time estimation for longer time. Tapping tasks is categorized into the time perception group based on this viewpoint.

In this group, we explain the paired comparison method and the reproduction method in relation with tapping task. The paired comparison method is that subjects compare the length of standard stimulus with presented stimulus. This task is often used when examining discrimination function of time (Getty 1975). The reproduction method is a technique for reproducing time so that it is subjectively the same as the duration that has been presented (Szelag et al. 2002). Thus in synchronization tapping tasks, the tapping interval is compared to the presented interval, and this time interval is reproduced in tapping. In this respect, synchronization tapping task can be regarded as a combination of the paired comparison method and the reproduction method.

Some cognitive models have also been proposed, and there are two main types. The first is a model premised on the presence of an internal clock that counts time (Creelman 1962; Treisman 1963; Geissler 1987; Kristofferson 1984). The second is a model in which the perceived duration is based on the amount of information processed in a given interval (Brown 1995; Fraisse

1963; Ornstein 1969). In addition, there is the model of Thomas and Weaver (1975), which combines these two models. These models suggest the possibility of multiple mechanisms involved in time cognition.

Many studies have also been conducted using brain imaging. Juepner et al. (1995) employed tasks that compared the length of a presenting stimulus to a standard stimulus of 300 ms. Their results revealed that the cerebellum, basal ganglia and thalamus were activated in the judgment of the task. In addition, Rao et al. (2001) also performed a pair comparison task with duration of 1200 ms. Their results suggested that the premotor cortex, inferior parietal cortex, and dorsolateral prefrontal cortex (DLPFC) are important in time cognition. These two researches show the correlation between the active brain region and the time duration of stimulus.

Lewis and Miall (2003a) categorized literatures based on the relationship between the activated brain areas and the type of tasks performed. Their results showed that time cognition mechanisms can be broadly divided into two types. One is a mechanism referred to as an automatic mechanism. This mechanism exhibits a strong correlation with areas of the brain associated with movement such as the cerebellum and premotor cortex. This mechanism is mainly observed in the time perception task with shorter time interval (< 1 sec) (Rao et al, 1997). The other mechanism is referred to as the cognitive controlled mechanism. This mechanism is highly correlated with the areas that are strongly linked to higher brain function such as the prefrontal cortex. This is observed in the time perception with longer time interval (> 1 sec), which stands in contrast to the automatic mechanism.

From these neurological viewpoints, the time cognition mechanisms have been classified based on the differences in the activated brain areas that are dependent on the time duration (Gibbon et al., 1997; Hazeltine, 1997; Ivry, 1996; Lewis, Miall, 2003,a, 2003b; Rammsayer, 1999).

1.3 Research objectives

The above findings suggest that research on the time cognition mechanism and the timing mechanism involved in tapping are mutually interrelated. And to reveal this relationship is the matter of great interest.

One example is available in research that has been conducted on the classification of two types of timing mechanism based on duration in synchronization tapping tasks (Miyake et al., 2004). This study used the dual task method (Baddeley, 1986) based on the attentional capacity model of Kahrnemann (1973). The results indicate that the neural base related to the generation of a negative asynchrony phenomenon differs for long and short ISIs.

It has been suggested that attentional resources that are selectively consumed in the dual task method correspond to the working memory that has been found in the prefrontal cortex (Baddeley, 1998; Osaka, 2000). The prefrontal cortex that is related to working memory has also been regarded as an area connected with time cognition over long periods in the field of neurology (Casini, Macar, 1996). The classification conducted by Miyake et al. (2004) should correspond to the classifications made based on brain functional research.

However, the relationship has not been clarified between the time cognition mechanism and the timing mechanism in synchronization tapping. Thus, the objective of our research is to clarify timing mechanism as the phase error correction in the tapping task and determine the relationship with the time cognition mechanism.

The detailed methods that are used in this research are: (1) the regulation of the phase error (SE) between the stimulus and tapping to control the timing mechanism; and (2) the use of multiple ISIs in order to observe changes in the time cognition mechanism depending on the duration; (3) the observation of the changes using the dual task method in order to examine the influence from higher brain function.

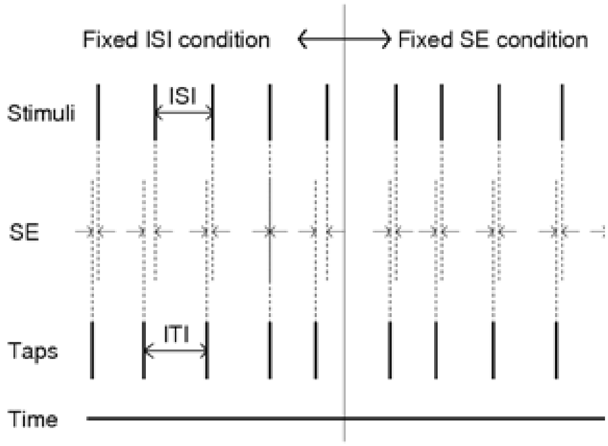


Figure 1 Detail of experimental procedure
This figure shows a detail of this experiment. The left of vertical line shows FISI condition. The right shows FSE condition.

2 Methods

2.1 Subjects

The subjects were 6 male graduate school student volunteered to participate in the experiments without payment. One of the subjects was the author himself. All of the subjects had previously participated in a pilot experiment on synchronization tapping. The age of subjects were 23 to 31 years old with a mean of 25.2 years. Everyone in the group was right-handed based on self report, and none had any motor, cognitive or sensory dysfunctions.

2.2 Experimental system

The auditory stimulus was a square wave with a frequency of 500 Hz and duration of 100 ms. The sound was generated by a PC and presented through headphone (SONY MDRZ600ST). The button was a 6 mm plastic disk with a slide down stroke of 1 mm or less, and it was connected to the PC via a parallel port. The onset time was recorded when the button was pushed. A sampling rate of 1/2048 sec was used to measure the presentation of the stimulus and response. The system was constructed using the programming language C and run on an IBM-compatible PC. The OS was IBM DOS2000 (single task OS). The data analysis was conducted using MS Office Excel.

2.3 Definition of parameters used in tapping tasks

Three experimental parameters were used in the tapping task. They are the inter stimulus-onset interval (ISI) that indicates the interval of the stimulus onset, the inter tap-onset interval (ITI) that indicates the tapping difference between the tap onset of the subject and the stimulus onset. Especially, the SE takes a negative value when the subject's tap precedes the auditory stimulus.

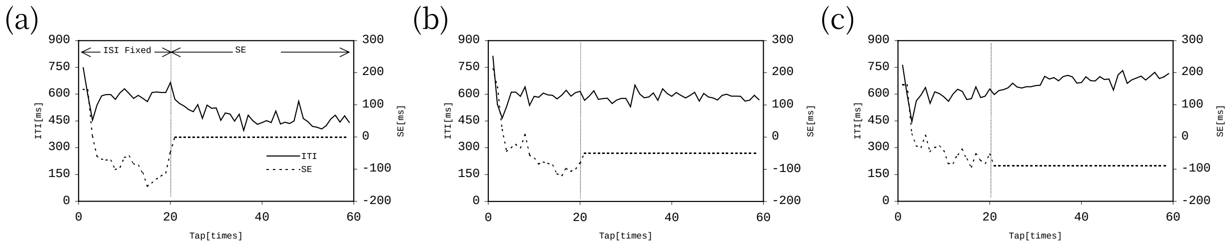


Figure 2 Temporal development of inter tap-onset interval (ITI)
(a) ISI = 600, SE = 0 (b) ISI = 600, SE = −50 (c) ISI = 600, SE = −90. In this graph the primary vertical axis is the subject's ITI, the secondary vertical axis is the tap and presenting stimulus SE and the number of taps is the horizontal axis. The dotted line at taps = 20 indicates where the stimulus presentation method changed. On the left side of the line, the stimulus (ISI) is fixed as the FISI condition. The right side is the FSE condition is where the stimulus (SE) becomes fixed.

2.4 Task and experimental procedure

The subject was instructed to synchronize their tap onset and auditory stimulus onset as precisely as possible. Then, the subject was seated in a chair in a quiet room with his eyes closed. He placed his arms on a table, held the button box with his thumb and middle finger and tapped the button with the index finger of his right hand. One trial was composed of tapping the button continuously 60 times.

The presentation method of the auditory stimulus was changed within one trial for the first 20 taps and the latter 40 taps. As shown in Fig.1, for the 20 taps in the first half, the auditory stimulus was presented at fixed intervals in the same manner as a typical synchronization tapping task (fixed ISI condition [FISI condition]). For the 40 taps in the latter half, the auditory stimulus was presented at a fixed time after the subject tapped (fixed SE condition [FSE condition]). The two conditions were switched continuously and the subjects were unaware of the changes in the conditions.

Five different ISIs (450, 600, 900, 1200 and 1800 ms) were used under the FISI condition. Seven SEs were used (0, −10, −30, −50, −70, −90, and −110 ms) under the FSE condition. The SE is negative under the FSE condition, because the auditory stimulus is presented after the tap. The ISIs and SEs were combined and then each subject underwent 35 trials. The trials were conducted in random order. The timing of the auditory stimuli onset and the timing of the taps onset were recorded for all of the trials. These data were then used to calculate the time development for SE and ITI. Data of first 5 taps and stimuli were removed from analysis.

A normal condition and a reading condition were used in the dual task method. The normal condition was the condition with tapping only. The normal condition is assumed herein unless otherwise stated. Under the reading condition, the same task was performed while reading a simple passage. The luminance on the desk during the reading condition was approximately 250 lux. The period for performance of the task under these two conditions was more than two weeks. The text used in the reading task was written in simple Japanese and taken from *The Cathedral and the Bazaar* by Eric S. Raymond. In addition, problems with two responses were prepared on the content of the passage in order to evaluate comprehension so as to confirm that the attentional resources of the subject had been allocated to the reading.

3 Results

3.1 ITI temporal development under the FSE condition

Three typical temporal developments of ITI response were observed under the FSE condition in the latter half of the trial. An example obtained under the FSE condition is shown in Fig. 2. The vertical axis is the ITI and the horizontal axis is the number of taps. The vertical dotted line where taps equal 20 is the boundary where the stimulus condition changes. The left side of the vertical dotted line represents the FISI condition while the right side of the vertical dotted line represents the FSE condition. The ISI for the FISI condition is 600 ms in these three examples.

Fig.2a is an example where the SE is fixed at 0 ms under the FSE condition. In this case, the ITI under the FSE condition decreased gradually in comparison with the ITI under the FISI condition. Fig.2b is a trial in which the SE was -50 ms, and the ITI exhibited no significant changes after the change of experimental conditions. Fig.2c is a trial in which the SE was -90 ms, and the ITI increased after the experimental conditions were changed.

The subjects were instructed to synchronize their taps to the auditory stimuli as precisely as possible. It was thus thought that the observed behavioral response would reflect the internal cognitive state of the subjects. Specifically, the ITI would increase or decrease depending on the temporal order of the tap onset and stimulus onset perceived by the subject. However, the auditory stimulus was presented after the tap onset in all cases under the FSE condition. Thus it was shown that the SE between the tap and auditory stimulus in physical time should be distinguished from the SE perceived by the subject (perceived SE, PSE). And we analyzed the relationship between the ITI difference versus the PSE.

3.2 Relationship between the SE difference and the ITI difference

The following methods were used to evaluate the PSE. The time difference perceived by the subject (PSE) is thought to be 0 ms for the SE that was observed under the FISI conditions, because the task was to synchronize the auditory stimuli and taps. Accordingly, the PSE can be estimated by subtracting the SE which was fixed in the FSE condition from the mean SE under the FISI condition. This is also the SE change from the first half to the latter half of the trial, and it shall be referred to hereafter as the SE difference. At this time, the SE difference corresponds to the PSE

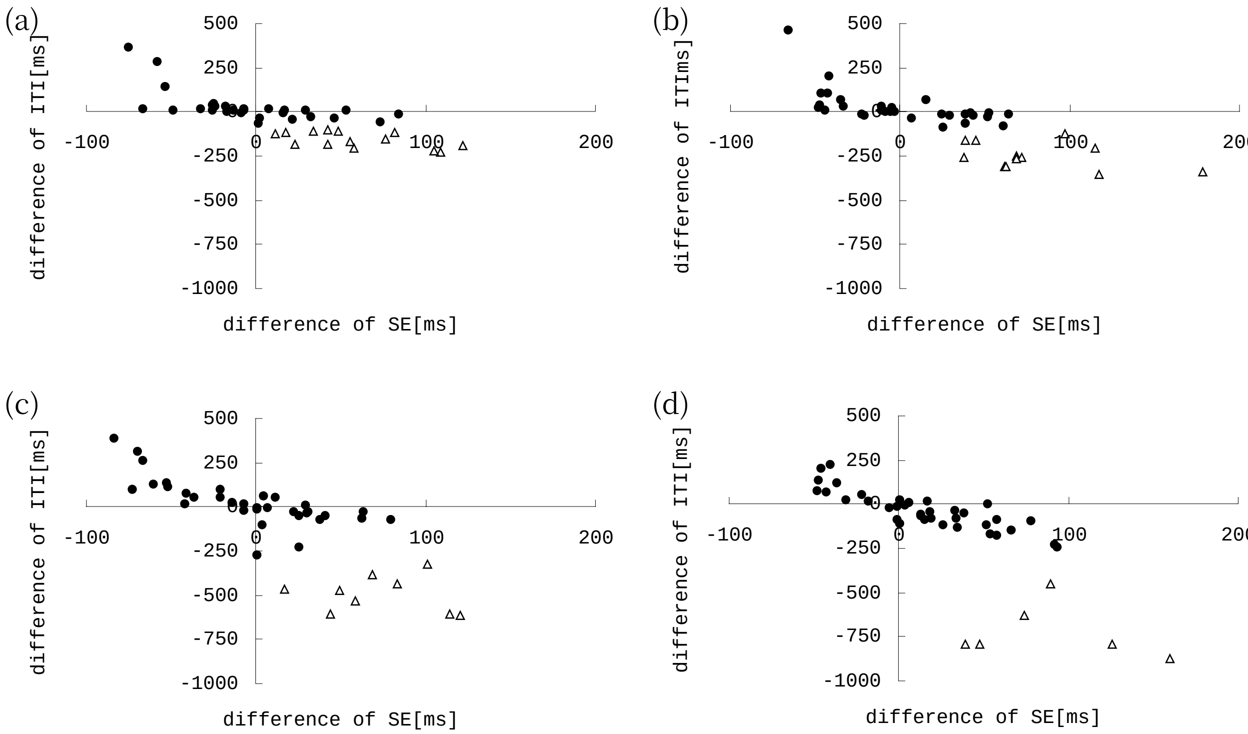
The horizontal axis in Fig.3 represents the SE difference under the FSE condition, which was calculated using the equation: SE difference = (SE under the FSE condition) – (mean SE under the FISI condition). A positive SE difference corresponds to the order where perceived stimulus onset precedes the perceived tap onset, and a negative SE difference corresponds to the opposite order. The vertical axis represents the ITI difference between the FISI condition and the FSE condition, which was calculated based on the following equation: ITI difference = (ITI mean under the FSE condition) – (ITI mean under the FISI condition).

Fig.3a-e shows a plot of the data collected from all subjects, and each figure corresponds to the data obtained in each ISI used under the FISI condition. These results show a negative proportional relationship between the SE difference and the ITI difference, however this relationship weakens as the ISI increases.

The Ward method (Ward 1963) was then used here in order to perform a detailed analysis of the relationship between the SE difference and the ISI difference and classify the data into two clusters. A standardized squared Euclidean distance was used to create parameters of the SE difference and the ITI difference. Cluster 1 represented in black corresponds to the negative side of SE difference, and cluster 2 represented in white corresponds to positive side of SE difference. The correlation coefficients between the SE difference and the ITI difference in each cluster are shown in Table 1.

The results when the ISI under FISI condition was small (ISI < 900) are shown in Fig.3a and b. A strong negative correlation coefficient (< –0.4) was observed in cluster 1 and cluster 2 as shown in Table 1. The difference in the correlation coefficient between these two clusters was small (< 0.25). Based on this result, it was shown that there was a negative strong correlation between the SE difference and the ITI difference in a short ISI.

The results when the ISI under FISI condition was large (ISI ≥ 900) are shown in Fig. 3c, d and e. A strong negative correlation coefficient (< –0.7) was observed between ITI difference versus the SE difference in cluster 1 as shown in Table 1. However the correlation coefficient was low (> –0.25) in cluster 2, and the



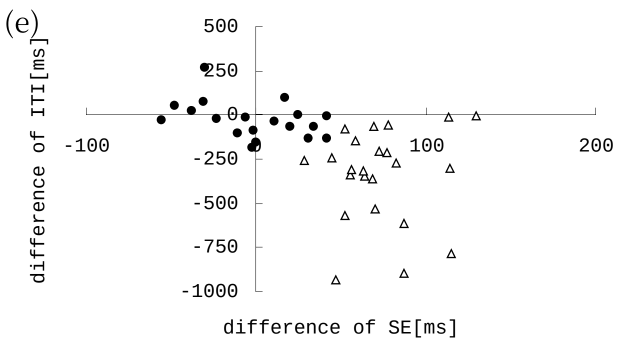


Table 1 Correlation coefficients for the SE difference and the ITI difference under the normal condition

ISI	Cluster1	Cluster2
450	-.619	-.598
600	-.619	-.406
900	-.732	-.127
1200	-.862	-.237
1800	-.392	.069

Figure 3 Relationship between the SE difference and ITI difference under normal condition
(a) ISI = 450 (b) ISI = 600 (c) ISI = 900 (d) ISI = 1200 (e) ISI = 1800. The horizontal axis is the SE difference and the vertical axis is the ITI difference. The dividing of the clusters is performed based on these values. The negative side of the SE difference is cluster 1 and the positive is cluster 2.

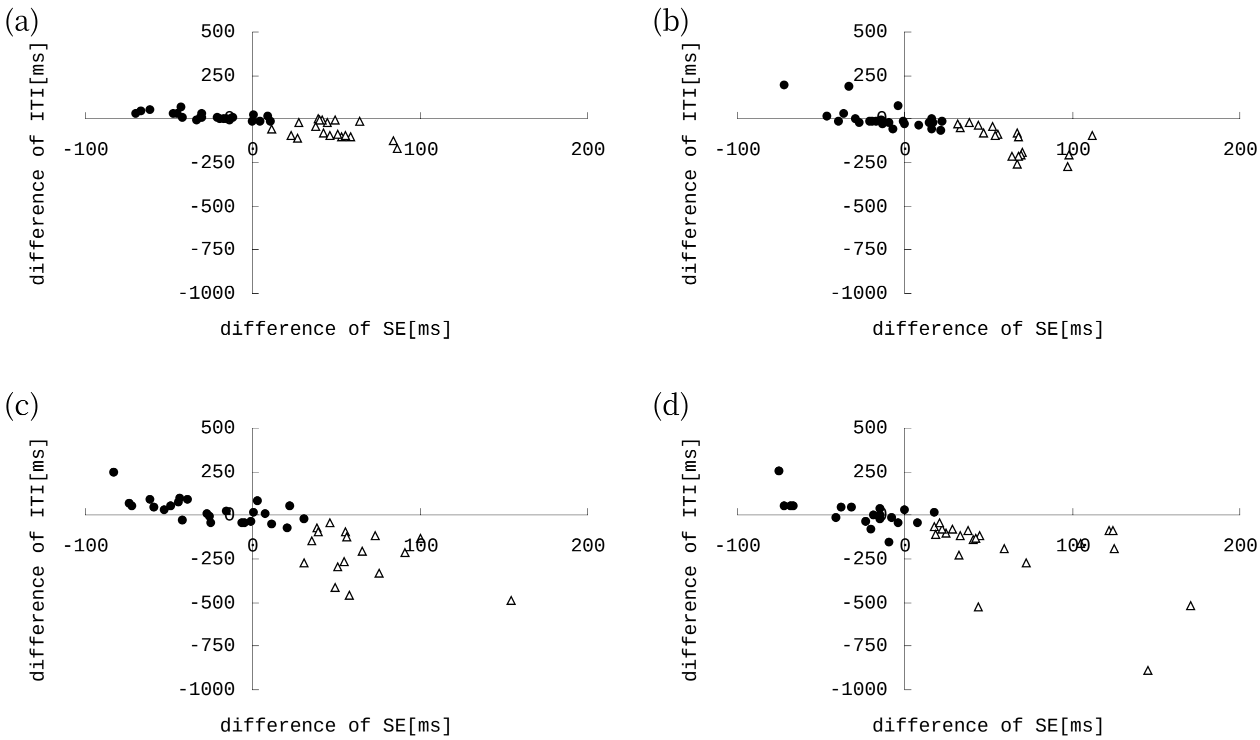
difference in the correlation coefficients between clusters was large (> 0.4). In particular, the correlation coefficient was close to 0 when ISI = 1800. It was thus clarified that the proportional relationship between the SE difference and the ITI difference was weak in cluster 2 in the presence of a long ISI. In addition, this non-proportional response was observed only when the SE difference was in the positive region.

These results can be summarized as follows. At a short ISI (< 900), the difference in the correlation coefficient was small (< 0.25) between the two clusters, and the points for both clusters are almost entirely linear as shown in Fig.3a and b. These findings suggest that the two clusters have the same mechanism. In contrast, the differences in correlation coefficients were large (> 0.4) between the clusters with a long ISI (≥ 900). The points for both clusters do not line up as shown in Fig.3c, d and e, and these findings suggest that different mechanisms exist in the two clusters. Specifically, responses where the SE difference and the ITI difference are not proportional were only observed where the SE difference is in the positive range.

3.3 Relationship between SE difference and ITI difference under the reading condition

The dual task method was used to examine the effect of higher brain function. The same task described above was used as the primary task, and a reading task was used as the secondary task. This condition is referred to as the reading condition. Furthermore, the condition without reading task is referred to as the normal condition. After the completion of the reading task, the subjects were asked to answer questions with two choices to determine the degree of understanding. The resulting percentage of correct answers for all subjects was a mean of 85.2% (range of 76.9% to 94.7%). This result indicates that the attentional resources of the subjects are sufficiently used during the reading task.

Fig. 4 shows the relationship between the ITI difference and the SE difference under the reading condition. Specifically, the horizontal axis is the SE difference and the vertical axis is the ITI difference. Clusters were also created in the same manner as described above. Table 2 shows the correlation coefficients



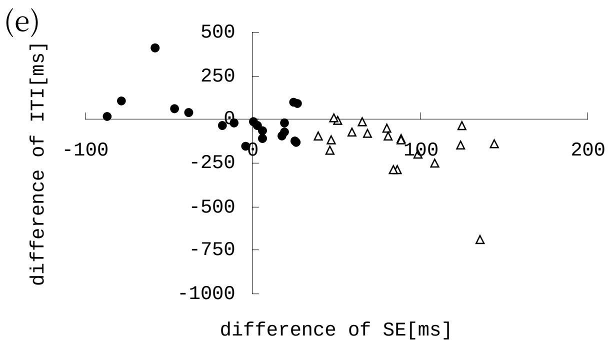


Table 2 Correlation coefficients for the SE difference and the ITI difference under the reading condition

ISI	Cluster1	Cluster2
450	-.682	-.42
600	-.622	-.626
900	-.634	-.417
1200	-.607	-.552
1800	-.528	-.488

Figure 4 Relationship between the SE difference and the ITI difference under the reading condition
(a) ISI = 450 (b) ISI = 600 (c) ISI = 900 (d) ISI = 1200 (e) ISI = 1800. The axes and clusters are in conformity with Fig. 3.

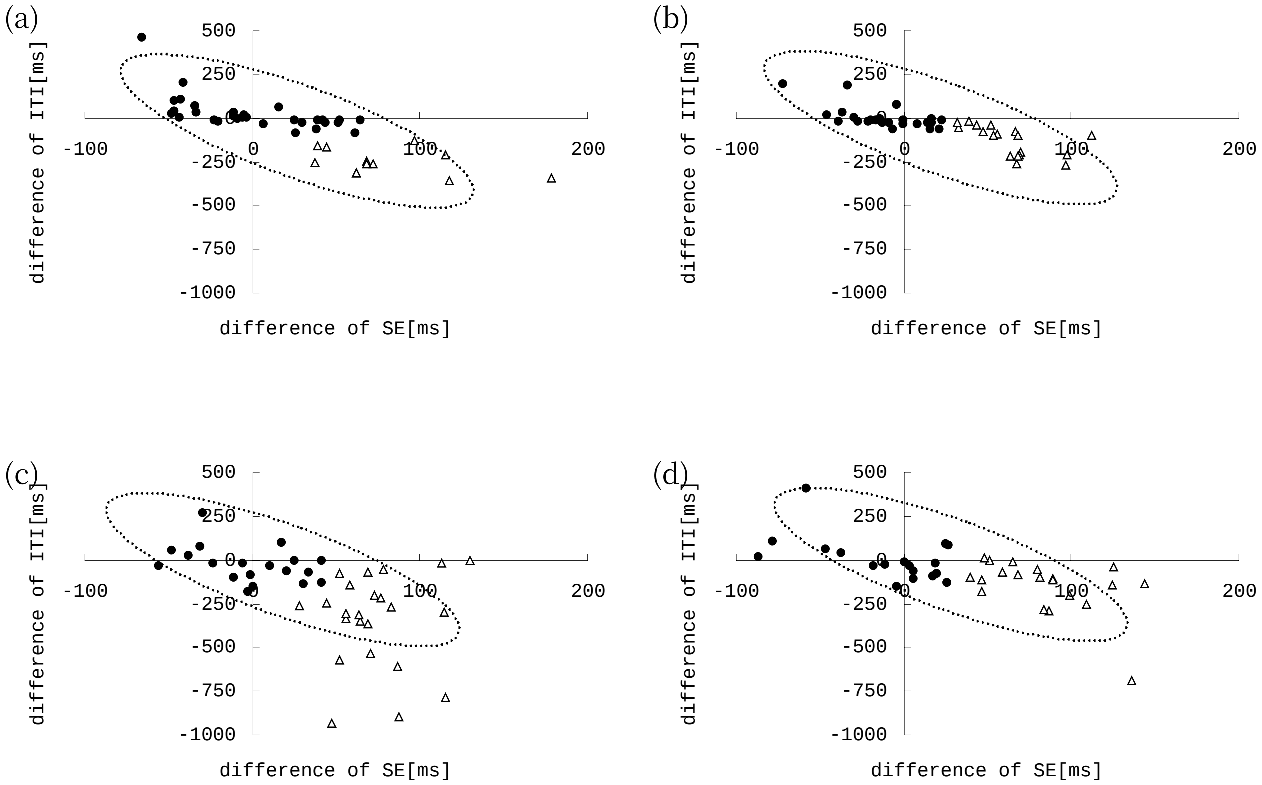


Figure 5 A comparison of the relationship between SE difference and ITI difference in the normal condition and reading condition
(a) normal condition, ISI = 600 (b) reading condition, ISI = 600 (c) normal condition, ISI = 1800 (d) reading condition, ISI = 1800. The axes and clusters are in conformity with Fig. 3.

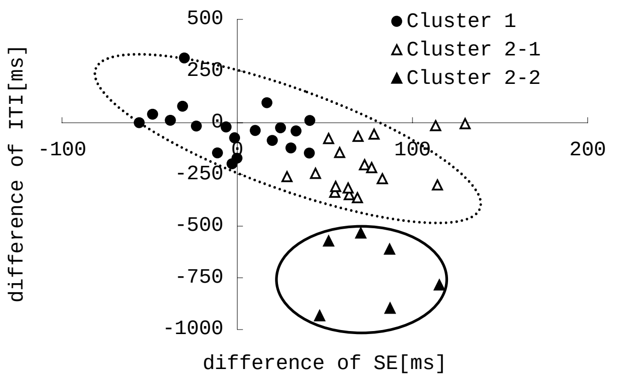


Figure 6 Two types of relationships between the SE difference and the ITI difference
The analysis has been conducted on the cluster 2 structure with an ISI = 1800 under normal condition. The axes are in conformity with Fig. 3. Here cluster 1 is the same as cluster 1 in Fig. 3. Cluster 2 in Fig. 3 has been divided into two clusters. The cluster 2-1 includes the extrapolation of cluster 1 and the cluster 2-2 does not include it.

between the SE differences and the ITI differences for each cluster.

As shown in Fig.4, it was clarified that there is a negative proportional relationship between the SE difference and the ITI difference regardless of the ISI used under the FISI condition. These results revealed that both clusters were almost linear for all ISIs. Furthermore, the ITI difference had a strong negative correlation (< –0.4) to the SE difference, and the difference of the correlation coefficients between clusters was small (< 0.3).

These results show that the proportional relationship exists between the SE difference and ITI difference regardless of the ISI under the reading condition. And responses where the SE difference and ITI difference are not proportional were not observed under this condition, suggesting that this non-proportional response is related to the higher brain function that is used under the reading task.

Next a detailed analysis of the responses that showed differences between normal condition and reading condition is conducted. Fig.5 shows the relationship between ITI differences and the SE differences. Fig.5a and b correspond to normal condition and reading condition at ISI = 600, and Fig.5c and d represent normal condition and reading condition at ISI = 1800. In these figures, those areas that show a proportional relationship between the SE difference and the ITI difference are enclosed by a broken line.

As shown in Fig.5, the points lined up almost linearly with the exception of ISI = 1800 under the normal condition. This finding suggests that even among the points classified in cluster 2, responses based on the original cluster 1 and the same mechanism are contained. Based on this idea, cluster 2 obtained in the normal condition with ISI = 1800 was divided into two clusters as shown in Fig.6. The result is a cluster (cluster 2-1) that has the same proportional relationship to cluster 1 and a cluster (cluster 2-2) that does not.

Cluster 2-1 is thought to be included in a mechanism that generates proportionality between the SE difference and ITI difference. On the other hand, the ITI difference shows a large shift in the negative direction in cluster 2-2. Furthermore, this response where the SE difference and the ITI difference are not proportional was only observed where the SE difference is in the positive region. These facts clearly show that this mechanism is different from the mechanism that makes the SE and ITI difference proportional.

4 Discussion

The results are summarized as follows.

(1) Depending on the SE under the FSE condition, three types of responses were found where the ITI increased, did not change or decreased. And two types of ITI response were observed depending on ISI used under the FISI condition.

(2) When the ISI was short (ISI < 900), a negative proportional relationship was observed between the SE difference and the ITI difference, and in addition, this response was unaffected in the reading task.

(3) When the ISI was long (ISI ≥ 900), response where the ITI difference is not proportional to the SE difference was observed in a positive region of SE difference, and this response disappeared in the reading task.

The experimental task was to synchronize the tap onset and auditory stimulus onset as precisely as possible. Thus, as shown in result 1, when the ITI increased under the FSE condition, it is thought that the tap was perceived by the subject as preceding the auditory stimulus. Furthermore, when the ITI decreased, it is also thought that the subject perceived that the auditory stimulus preceded the tap, and when there was no change, the tap and auditory stimulus were synchronized. However, the stimulus was presented after the tap onset in all cases under the FSE condition. Thus it was shown that the SE between the tap and stimulus in physical time should be distinguished from the perceived SE (PSE). And we analyzed the relationship between the change of ITI and the change of SE to clarify the mechanism of phase error correction.

In result 2, a negative proportional relationship was observed between the SE difference and ITI difference. This finding strongly suggests the feedback mechanism between the change of ITI and the change of SE to realize the synchronization between tap and stimulus, and the similar mechanism have also been presented as the phase error correction model by Mates (1994a, 1994b). However, he assumed that there was no awareness of the order of the auditory stimulus and the tap, and the error was ignored at SE=20 ms or less. We found, in contrast, that the relationship between the SE difference and the ITI difference as shown in Figs.3 and 4.

Furthermore, this mechanism was not influenced by the reading task and also it was mainly observed in the short ISI (< 900) region. Thus, the automatic mechanism that is independent of cognition process (LaBerge, 1975) is suggested. As the neural base of this phenomenon, a pace maker model could be considered. A pacemaker in the cerebellum (Ivry, 1997) has already been reported, and it is known that the cerebellum has high resolution of time (Bellin et al., 2002; Coull, Nobre, 1998). Moreover, since the task that was used in our research was a rhythmic tapping, the CPG, which functions as a rhythm pattern generation mechanism, is also considered as an automatic mechanism (Arshavsky et al., 1997). Based on this, the relationship between the cerebellum and CPG is suggested to be important as a neural base of this timing mechanism.

In contrast to the above case, there was another response where the SE difference was not in proportional to the ITI difference as in result 3. Especially, the cluster of non-proportional response (cluster 2) was classified into a cluster with a proportional response (cluster 2-1) and a cluster that demonstrates a large shift in ITI difference (cluster 2-2). Here, the latter case means that the time difference between the tap and auditory stimulus has been recognized as the longer duration than that of proportional response.

Since this response is not observed in reading tasks that selectively consume attention, it is thought that the recognized time difference is extended depending on the amount of attention that has been allocated to the tapping. This agrees with a report that describes the acceleration of visual information process speed (Hikosaka et al., 1993), and it suggests a mechanism that accelerates information processing based on attention. In addition, it has been further suggested that attention resources that are selectively consumed in the dual task method are also dependent on working memory that is in the prefrontal cortex (Baddeley, 1998; Osaka, 2000). It is also suggested that the reading task is related with working memory (Brebilon, 2003). These findings support the relationship between this response and the prefrontal cortex. It has already found that the prefrontal cortex is important in the cognition of durations with 1 second or longer (Lewis & Miall 2003a; Rao et al, 1997).

Furthermore, this has only been observed in a positive SE difference, and it may be related to the response that is specific to temporal order between auditory stimulus and tap was observed in the S1 area (Muller et al., 2000). If we assume that the amount of distributed attention increases before the tap and then decreases after the tap, the increase in the ITI difference on the SE difference positive side can be explained.

These changes of phase error correction mechanism which depends on the ISI are thought to correspond to the switching of time cognition mechanism that has been reported by previous researches. Furthermore, since the boundary of this switching is around at ISI of 1 second, a linkage is suggested with the switching mechanism as proposed by Lewis & Miall (2003). In addition, the proportional relationship between SE difference and the ITI difference under the reading condition was not dependent on the ISI. This finding suggests that the two types of mechanisms based on the ISI duration do not switch independently, but both mechanisms operate together.

5 Conclusion

We investigated the phase error correction mechanism in synchronized tapping. The results revealed two mechanisms that are dependent on the duration of the interval of stimuli. At a short ISI (< 900), relationship between SE difference and the ITI difference was proportional and did not require working memory, suggesting the automatic feedback control mechanism. Furthermore, non proportional response was observed with a long ISI (≥ 900), and working memory such as attention resources are required in this response. Specifically the acceleration of information processing with attention is suggested to extend (from) the SE, and as a result, the ITI difference increases. However, these two phase error correction mechanisms are not exclusive, and it is thought that they are in the mutual interaction. This dynamic relationship should be studied in the future.

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