Dual Anticipation Timing Mechanisms in Synchronous Tapping

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Abstract

The time perception mechanism in anticipatory timing control was investigated in synchronization tapping task. Especially negative asynchrony phenomenon that the tap onset precedes the stimulus onset was used as an example of anticipatory response. In this experiment, to clarify the effects of higher brain function such as attention and working memory, dual task method was applied and word memory task was used as a secondary task. The results revealed the presence of two types of anticipatory mechanisms from the standpoint of attentional resources involved in time perception. One is the anticipatory tapping that is influenced by attention of subject and seen in the interstimulus-onset interval (ISI) range of 2400 to 3600 ms. In this region, the magnitude of synchronization error (SE) between tap onset and stimulus onset was scaled by the ISI. The other is the automatic anticipation that is not affected by attention and is seen in the 450 to 1800 ms range. SE in this region was constant and independent of the ISI. Accordingly, this anticipatory timing mechanism in synchronous tapping is thought to be a dual process including the explicit processing of the temporal information and the implicit automatic anticipation.

Keywords Dual anticipation, Timing mechanism, Attention, Synchronous tapping

1. Introduction

When humans are engaged in a cooperative activity, an important skill is mutually coordinating the timing of actions[1,2]. An anticipatory synchronous mechanism related to development of time for an external event is thought to be indispensable to generate such coordinated movement. The importance of this anticipatory timing control becomes clear if you consider, for example, what goes into playing together in a musical ensemble. However, it has been reported that a time difference exists between awared subjective synchrony and physical synchrony (for example, the negative asynchrony phenomenon)[3-5]. Thus, analysis of coordinated activity should be done not only in physical process but also in subjective process in which higher brain function such as attention and working memory are involved.

The synchronization tapping task has been used as the simplest system for examining the mechanism behind coordination of timing. In this experiment, the subject is required to synchronize movement such as the tapping of a finger with a constant stimulus such as a sound or light that is periodically repeated. The most striking example that demonstrates the occurrence of anticipatory timing control for this synchronous tapping is the phenomenon where the onset of each tapping precedes the onset of stimulus by several 10 ms[3-5]. This pressing in advance phenomenon, which the subject himself is unaware of, demonstrates that the command to move the finger is generated, at the very least, before the auditory stimulus and that an anticipatory timing control is present. The negative time offset caused by this tapping in advance is referred to as negative asynchrony, and it is a phenomenon that is always observed with the synchronization tapping task in response to a periodic stimulus.

To examine this type of phenomenon, Mates and Pöppel *et al.* conducted an synchronous tapping experiment using a periodic auditory stimulus within a range of 300 to 4800 ms[7]. They confirmed that negative asynchrony was observed for all of the above stimulus intervals despite a difference in degree of its occurrence. In addition, they found that the upper limit for the generation of a stable negative asynchrony with small fluctuation is 2 to 3 sec for the inter stimulus-onset interval (ISI). It was also reported that if this ISI limit is exceeded, then reactive responses become mixed in together with the negative asynchrony.

It has been found that the functions of the cerebellum and the basal ganglia are important in the neural mechanisms that support perception of short time intervals of less than 1 sec by using the synchronization tapping tasks, other types of time discrimination tasks and time reproduction tasks[8-11]. Moreover, higher brain functions are said to contribute to the perception of time intervals that exceed 2 to 3 sec such as attention and working memory[12,13]. Ivry *et al.* conducted a series of experiments on time perception under 2 set of conditions, short (400 ms) and long (4 sec), in subjects with injuries to the cerebellum and prefrontal cortex. They found that subjects with injury to the prefrontal cortex exhibited a deterioration in performance only for the long-duration discrimination tasks, and they also found a deficient in the working memory function. These findings suggest the importance of the role of working memory in the perception of long time periods[14].

The possibility exists that these two types of time perception mechanisms contribute to the occurrence of negative asynchrony. However the experiments of Mates and Pöppel *et al.* did not adequately clarify whether the appearance of stable negative asynchrony reflects differences in time perception mechanisms such as described above. Study has yet to be done to clarify whether there is a relationship between the mechanism behind anticipatory timing synchrony and the time perception mechanism over such a wide range. We previously hypothesized that anticipatory timing control is based on two different time perception mechanisms and the negative asynchrony that occurs in particular during ISIs that exceed 2 to 3 sec is generated by a time perception mechanism in which higher brain functions are involved[15]. Therefore, the research presented herein was done based on this hypothesis by conducting an experiment designed to determine the effects of these higher brain functions such as attention and working memory on a synchronization tapping task.

2. Results

A number of cognitive models have been proposed on the relationship between perception of a time interval that exceeds 2 to 3 sec and attention. Among these, the "attention allocation model" is based on the premise that decision making time is determined by to what extent attentional resources are allocated to the temporal information processing system versus mental activity processing system (non-temporal information processing) that is unrelated to time[13,16]. The central executive of working memory has been pinpointed as being involved in this allocation of attention[17]. According to the attention capacity model of Kahnemann, there is a limited amount of attentional resources, and these resources determine the limits in the processing of perceptual information[18]. Attention is a critical resource to the execution of mental activities, and attentional resources can be appropriately allocated to each separate task based on the tendencies and intent of each individual during the simultaneous execution of multiple tasks. In this condition, it becomes possible to quantify the amount of the attentional resources that have been allocated based on the magnitude of the mental processing involved.

We examined the range of ISI that the attention affected in a synchronization tapping task based on the above models. If the attention of subjects is directed toward the processing of information other than tapping during a synchronization tapping task, it becomes impossible for the subjects to use the amount of attention required in the processing for the execution of the tapping task, which are part of limited capacity of the attentional resources. If the amount of attention required in the tapping task exceeds the remaining resources, then sufficient processing resources cannot be allocated to the temporal information processing system, and the ability to make temporal decision becomes disrupted and the anticipatory timing control is thought to be affected.

A dual task method is used in the control of subject attention. This is an experiment in which the processing capacity required for executing a task (primary task) is reduced by having the subject engage in an additional task (secondary task) while still engaged in the primary task. Well-known examples of these types of test are the reading span test[19] that measures the working memory capacity when a subject is simultaneously reading a short sentence out loud and engaged in word memory task or the articulatory suppression method that examines the organization of coding of auditory information when a subject is engaged in a cognitive activity such as memory and simultaneously repeating a word such as "a" or "the"[20]. We employed a word memory task as the secondary task in order to control the attention of the subject.

The word memory task was used to restrict the target of attention control to short-term memory and to determine the correlation between attention and negative asynchrony in the synchronization tapping task. This type of transient memory has been regarded as a function of working memory, and employed as a secondary task to divert the attentional resources of the subject. In this study, the difference in memorized words is regarded as the difference in the amount of attentional resources, and attentional capacity that is available in the tapping task was controlled using the memory task with two different numbers of words as a secondary task. If the attentional capacity that is required by the memory task corresponds to the processing resources that are used in the synchronization tapping task, some type of interference effect appears between them, and the difference in the number of memorized words is thought to reflect the occurrence rate of negative asynchrony.

2.1 Correct response rate for word memory task

The subjects were asked to press a button in synchrony with the onset of periodic pulse auditory stimulus as their primary task. A total of 10 different ISIs were used in this study: 450, 600, 900, 1200, 1500, 1800, 2400, 3600, 4800 and 6000 ms. This task was performed under the following 2 conditions.

Each trial was composed of a fixed ISI auditory stimulus for the controlled condition (N condition) and was

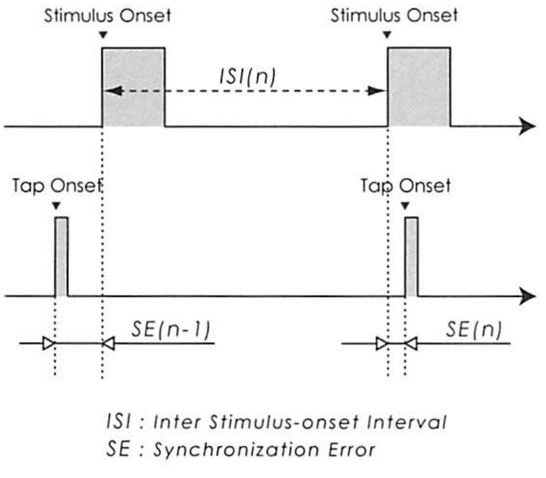

Fig.1 Illustration of temporal relationship between tapping and auditory stimulus. Gray area expresses the duration of each auditory stimulus(100ms).

Table 1 Percentage of correct answers in memory test. The value of each subject is the average value of all trials.

Subject	4 words	5 words
A	100 [%]	96.4 [%]
B	92.0	77.3
C	98.9	90.9
D	100	94.6
E	98.9	92.8
F	100	98.2
Average	98.3	91.7

performed for each of the 10 types of ISI. During the trials, the subjects were required to manually press a button at the same time as the onset of the stimulus as precisely as possible. For the memory task condition (M condition), the word memory task was conducted parallel to the same type of tapping as with the N condition. The words that the subjects were asked to remember were composed of only Japanese phonetic *hiragana* or *katakana*, and the word set was displayed in the middle of a screen for only 3 seconds when the subject hit the space bar. The screen was blacked out after 3 seconds, the auditory stimulus was given immediately and the subject was required to perform the tapping task while retaining the words that had been displayed. Immediately after completing the tapping for a fixed period of time, the subject was asked to verbally repeat the retained words.

The correct response rates for the word memory tasks for each subject are shown in Table 1. The values for each subject are the mean values for each trial. The correct response rate among the subjects was 98.3% for 4 words and was 91.7% for 5 words. A significant difference was observed between the mean values for the 2 groups at $p < 0.05$ when a Wilcoxon sign rank sum test was performed. A large drop in performance observed for subject B was exceptional. Memorization of 4 words was at a level of difficulty that could be executed almost perfectly by each of the subjects while there was a difference for the 5-words memorization task that can, however, be characterized as difficult.

2.2 Distribution of synchronization errors (SE)

The data that was obtained through this experiment was stimulus onset and tap onset. Synchronization error (SE) that expresses the time difference between the stimulus onset and the tap onset was mainly analyzed as an index for reflecting the temporal relationship between stimulus and action. A positive SE value indicated that the tap onset lagged behind the stimulus onset. As can be seen in

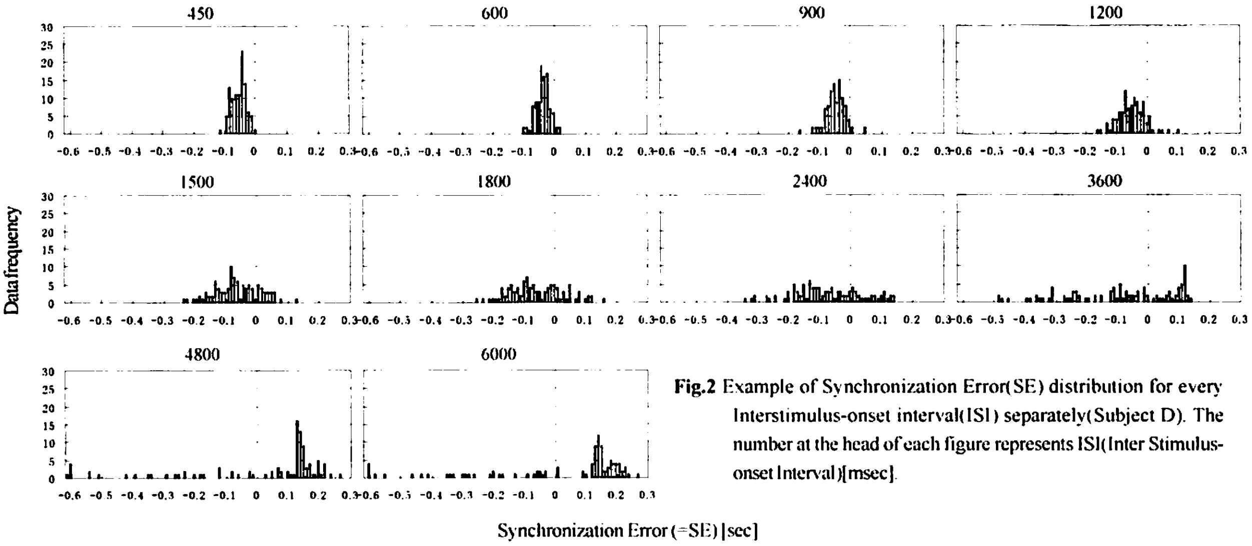

Fig.2 Example of Synchronization Error(SE) distribution for every Interstimulus-onset interval(ISI) separately(Subject D). The number at the head of each figure represents ISI(Inter Stimulus-onset Interval)[msec].

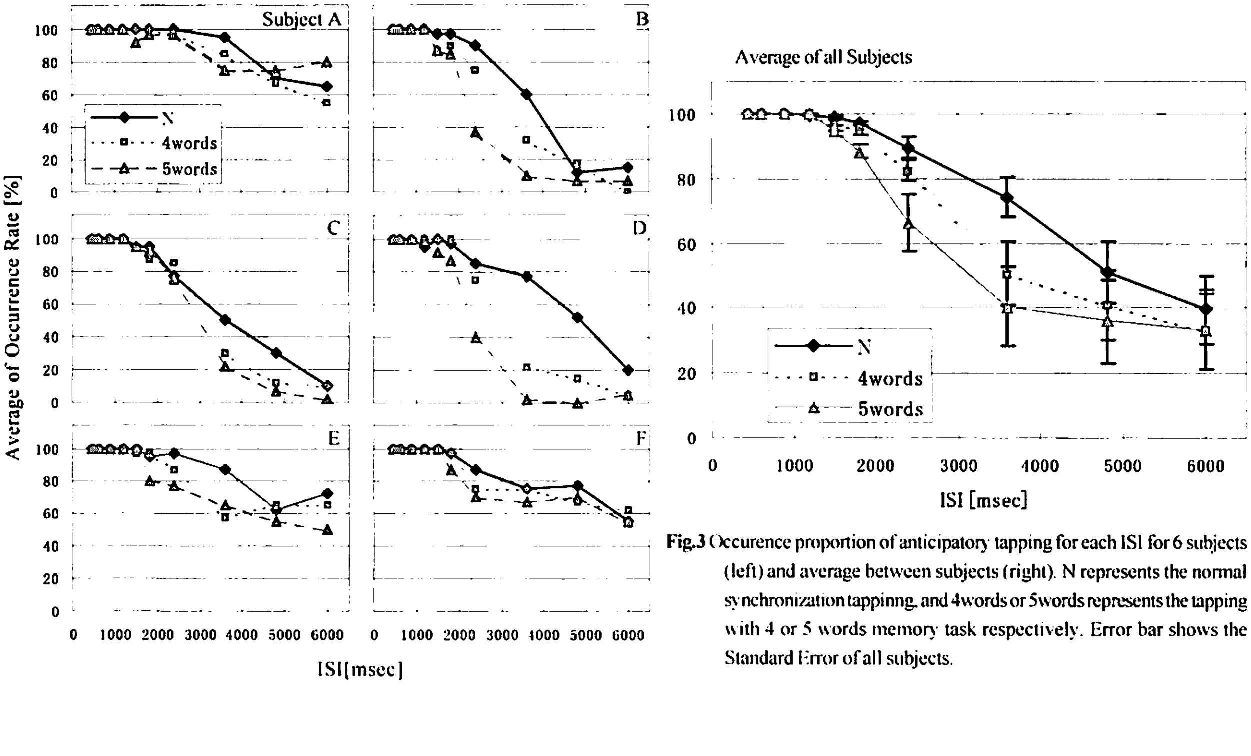

Fig.3 Occurence proportion of anticipatory tapping for each ISI for 6 subjects (left) and average between subjects (right). N represents the normal synchronization tappinng, and 4words or 5words represents the tapping with 4 or 5 words memory task respectively. Error bar shows the Standard Error of all subjects.

the experiments of Mates and Pöppel *et al.*[7], tapping can be divided into two types. One is the tapping in which the negative asynchrony phenomenon is observed and the other is reactive tapping to stimulus. For this reason, the former is referred to as anticipatory tapping and the latter as reactive tapping, and the relationship between these parameters is as shown in the Fig. 1.

The SE distribution at each ISI is shown in Fig. 2 for Subject D. The negative SE indicates that the tap precedes the auditory stimulus. If you look at the shape of the SE distribution for the N condition, it can be divided into 3 types. First the SE distribution for the small ISIs from 450 to 1800 is focused around a shift in the negative direction with a small spread. This is a distribution that corresponds to anticipatory tapping, specifically tapping that generates a stable negative asynchrony. As the ISI increases, the dispersion of the distribution grows, and a sharp peak on the positive side is seen in the distribution from 4800 to 6000 ms. This positive peak reflects reactive tapping, or specifically, tapping that occurs reflexively after hearing the stimulus. Anticipatory tapping with a large negative SE and reactive tapping are mixed in the intermediate ISIs from 2400 to 3600 ms. Almost the same distribution is seen with the M condition, but reactive tapping begins to be seen from around 2400 ms for the M condition with both 4 words and 5 words, while reactive tapping is noticeable in the area around an ISI of 3600 ms for the N condition.

2.3 Separation of reactive tapping and its occurrence rate

Our objective was to obtain information on anticipatory timing control and we did not analyze reactive tapping that is simply a reflexive movement. For this reason, it was thus necessary to distinguish between the two types of tapping modes. If you look at the SE distribution for ISI = 6000 ms as shown in Fig. 2, almost all the taps were reactive. Since the SE that preceded the auditory stimulus exhibited a large shift in the negative direction, distinguishing between the two types of tapping was relatively simple. Only those taps that were thought to be reactive were selected out in the tapping at an ISI of 6000 ms, and the SE mean value among the subjects was calculated based on the SE mean for each subject. It was 0.151 sec under the N condition (standard deviation among subjects = 0.0157). Thus, SE = 0.1 sec was uniformly fixed as the standard value for all subjects and ISIs, and a SE value larger than this was classified as reactive tapping. All other tappings were classified as anticipatory tapping.

The percentage of anticipatory tapping that was observed at each ISI for each subject and the mean among subjects were calculated under the N condition, 4-words condition and 5-words condition (Fig. 3). This percentage is called the anticipatory tapping occurrence rate. Almost 100% of tapping at an ISI of not more than 1800 ms under the N condition was found to be anticipatory, and it was further found that the anticipatory tapping occurrence rate tended to decrease as the ISI was increased from 2400 ms and above. Mates and Pöppel *et al.* found that the time capacity of 2 to 3 sec corresponds to the ISI in which reactive tapping begins. It was also found that at an ISI of not more than 1800, almost 100% of tapping was anticipatory under the M condition at both 4 words and 5 words. The anticipatory tapping occurrence rate for a higher ISI was smaller when compared to that under the N condition. In addition, if 4 words and 5 words are compared, almost no difference is observed at a short ISI up to 1800 ms, but the anticipatory tapping occurrence rate was smaller for 5 words at higher ISIs in comparison with 4 words.

Table 2 shows the results of a *t* test on the mean value of the anticipatory tapping occurrence rate among all subjects for the combinations of N-4 words, N-5 words and 4-5 words by each ISI. A significant difference in the occurrence rate for anticipatory tapping was observed only at 2400 and 3600 ms for the N-4-words condition while a significant

Table 2 Result of t-test about average value of predictive tapping occurrene proportion of all subjects. We tested possible three combinations. "*" and "#" shows significant difference by $p<0.05$ and $0.05<=p<0.10$ respectively. Blank column shows other results. We tested except the ISI of 450, 600, 900ms(all condition), and 1200ms(4-5words), because occurrence proportions in these conditions were almost all 100% in these range.

ISI	N-4words	N-5words	4-5words
450			
600			
900			
1200			
1500		#	
1800		*	*
2400	#	*	#
3600	*	*	
4800			
6000			

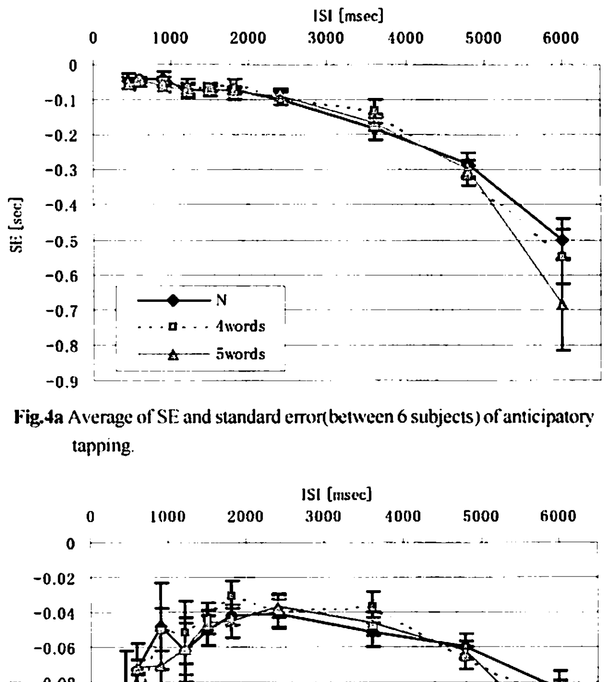

Fig.4a Average of SE and standard error(between 6 subjects) of anticipatory tapping.

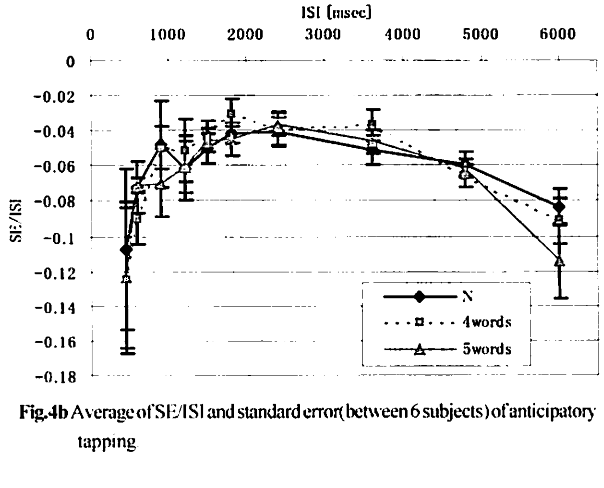

Fig.4b Average of SE/ISI and standard error(between 6 subjects) of anticipatory tapping.

difference was observed from 1500 to 3600 ms for N-5-words condition. In addition, the occurrence rate was significantly lower for 5 words in comparison with 4 words at 1800 and 2400 ms.

The above results demonstrate that when tapping is performed with an ISI of 1800 ms or less, memory tasks are not affected by the interference with attention, but are adversely affected with an ISI in the range of 2400 to 3600 ms. Furthermore with an ISI of 4800 ms or higher, the effect of attention was small, and the occurrence rate for anticipatory tapping was extremely low. It seems that this region should be considered as under the domain of reactive tapping as shown in Fig. 2. Thus, it was determined that the synchronization tapping in the stimulus period of 6 sec or less can be divided into the 3 regions of anticipatory tapping that is unaffected by the subject's attention, anticipatory tapping that is affected by the subject's attention and reactive tapping.

However in the region of 2400 to 3600 ms, which is affected by attention, despite an increase in the occurrence rate for reactive tapping under the influence of the memory task that functions as a secondary task, not all tapping is reactive. In this ISI region, it has been found that there is competition for the use of attention resources between the tapping task and the memory task that determines the processing efficacy, or in other words, a "trade-off relationship" exists. This result corresponds to the "attention capacity hypothesis," which was initially explained.

2.4 SE mean values and SE/ISI mean values

It became also clear that there are differences in the timing control mechanism with a specific ISI set when the SE values are compared between ISIs. Particularly, the anticipatory tapping was extracted from all tapping, and the SE and the SE divided by each ISI were calculated for each subject. The obtained mean values for 6 subjects are shown in Figs. 4a and 4b. From these figures, if the data of SE is limited only to the anticipatory tapping, there were ISI regions that the SE mean values and the SE/ISI mean values were fixed. The SE mean values were almost constant in the range from 450 to 1800 ms, and it was found that the magnitude of negative value increased above these levels. In contrast, the SE/ISI mean value was almost constant in the range from 2400 to 3600 ms.

These results suggest that the mechanism for anticipatory timing control is different at the border around 1800 ms. It can be said that the magnitude of ISI in the timing synchronization process is not important for tapping with a comparatively short ISI in the range from 450 to 1800 ms. However, the magnitude of negative asynchrony in the range of 2400 to 3600 ms can be characterized as the scaling by ISI. This suggests that a systematic memory mechanism for anticipatory tapping exists in the synchronization process for time intervals longer than 1800 ms. In addition, it was also observed that when the ISI is 4800 or 6000 ms, the SE/ISI value moves in the negative direction. Although the reason is unclear, it must be remembered that the anticipatory tapping occurrence rate was extremely low in this region.

3. Discussion

The objective of this research was to examine the interference effect of a secondary task that places a psychological load on a synchronization tapping task in order to determine the ISI range that affects attention in the anticipatory timing control mechanism. The results of this research yielded the following information.

- The negative asynchrony occurrence rate was not affected by a secondary task in the ISI range of 450 to 1800 ms.
- In the ISI range of 2400 to 3600 ms, the negative asynchrony occurrence rate was significantly reduced by the simultaneous execution of a secondary task.
- The negative asynchrony occurrence rate was extremely low in the ISI range of 4800 to 6000 ms.

The N condition used in the present study was essentially the same as that used in the experiment of Mates and Pöppel *et al.*[7] The properties of the SE distribution that were observed in Fig. 2 also agreed well with their results. They reported that reactive tapping began to appear with an ISI of 2 to 3 sec and that the properties of the negative asynchrony changed in the same region. However they did not determine the mechanism of this phenomenon. The results obtained in this study based on an experiment that took into consideration the attention indicated that changes in the negative asynchrony properties depended on two timing mechanisms that qualitatively differ exist in the ISI regions of 450 to 1800 ms and 2400 to 3600 ms.

The reduction in the attention resources by the execution of a secondary task did not have an effect on the negative asynchrony occurrence rate in the 450 to 1800 ms ISI range. The simultaneous execution of a synchronization tapping task and a secondary task could be within the range of the capacity limit of attention resources required by both tasks based on the attention capacity model that was initially proposed. The correct response rate under the 5-words condition for the word memory task was significantly lower in comparison with the 4-words condition where the correct response rate was close to 100% (Table 1). This result suggests that the attention resources required to memorize 5 words exceeds or is close to the capacity limit. Therefore, the result that the tapping task were unaffected despite this suggests that an independent timing control mechanism of attention resources functions exists in this ISI range.

Movements that can be executed independent of mental processing are referred to as "automatic" and regulation of movement through the spinal system is known to be involved in these movements. For example, there are rhythm generators in the brain stem and the spinal column such as the central pattern generator (CPG) that produce the necessary rhythmic muscle activity such as walking. These generators are thought to correspond to a timer function that sends periodic pulses in time perception and production pacemaker models[8]. The possibility has been suggested that tapping is controlled in a feed forward manner in this ISI range based on the analysis of SE's autocorrelation coefficient[21]. In particular, it was previously reported that feedback is not received directly from the periphery in the lateral cerebellum, which is in charge of timing control of movement, and an extremely simply forward control exists[22]. These mechanisms may be involved in automatic anticipatory tapping that has been observed in this research.

The synchronization tapping task in the ISI range of 2400 to 3600 ms was substantially affected by the lowered attention resources as a result of the execution of the secondary task. However, despite the fact that the occurrence rate of reactive tapping was increased under the influence of the memory tasks, all tapping did not become reactive. In addition, a difference was observed in the extent of the decrease in the occurrence rate based on the number of words. These findings indicated the presence of a trade-off relationship. Specifically, the tapping task and the memory task in this ISI range compete with each other in the consumption of attentional resources and determine the processing efficiency. Consequently, it is necessary to consider what type of processing is being used in the attention resources that have been diverted from the subject by the secondary task in order to determine the anticipatory tapping generation mechanism in this ISI range.

The processing that is required in word memory tasks can be limited to word retention activities that accompanies maintenance rehearsal. This type of maintenance rehearsal is thought to be performed by the phonemic loop function, which is a subsystem of working memory[23]. The obtained phonemic information (of a word) is automatically input into the phonemic storage that is one of the lower level system in the phonemic loop and possesses a 1 to 2 sec memory buffer. This phonemic storage has been known to be related to maintenance of information related to rhythm and time intervals[4,11]. In addition, the phonemic similarity effect in memory tasks, which is said to be based on the phonemic loop function, has been reported to be lost in the presence of the tapping task[11].

In this way, the tapping task and word memory task may compete in the allocation of phonemic storage capacity. The fact that stable tapping control is possible in the ISI range of 2 to 3 sec for the normal tapping task can be explained based on this hypothesis. However if a secondary task results in an overflow in the phonemic storage capacity, it can be thought that time anticipation will become difficult no matter what the ISI. The results of this research in which memory task had no effect at ISIs of 1800 ms or less contradicts this line of thinking. It is conceivable that anticipatory timing control is achieved through the interaction between the time perception based on phonemic storage and automatic movement mechanisms in the actual timing control.

Moreover, it has been suggested that tapping can be controlled based on feedback processing for ISIs in this 2400 to 3600 ms range[21]. Accordingly, the fact that the magnitude of SE/ISI values in this ISI range are almost constant (Fig. 4b) suggests the retention and memory mechanism of information related to this type of stimulus period and the presence of a feedback processing mechanism based on it.

Our research was aimed at furthering psychological analysis related to the time perception mechanism in the anticipatory timing synchronization, which is thought to be indispensable in cooperative activity among humans. The results revealed for the first time the presence of two types of anticipatory mechanisms in synchronization tapping task from the standpoint of attention involved in time perception. One is the anticipatory tapping that is influenced by attention and seen in the ISI range of 2400 to 3600 and the other is the automatic tapping mechanism that is not affected by attention and is seen in the 450 to 1800 ms range. Accordingly, this anticipatory timing mechanism can be thought to be a dual process that the anticipatory mechanisms works together based on the processing of the implicit automatic anticipation and the explicit processing of temporal information.

Finally, exactly how this type of perception and movement integrative process is involved in higher level brain functions such as attention and awareness is an extremely complex problem. Pöppel *et al.* have already tackled the problem of integrating information in the temporal region through the framework of a "time window"[24,25]. Humans integrate information in this 3-second time window and generate a state of awareness that corresponds to a "subjective present." The timing anticipatory mechanism is closely related to this type of temporal integration, and the results of this study suggest that this time window is formed from a dual process. If the physiological foundation for this temporal perception mechanism can be clarified through imaging techniques such as f-MRI, it can be expected to be possible to construct a model for this 2-fold mechanism, which has been uncovered in this study. Furthermore, it can be expected that this will also be connected with the techniques that underline the process of cooperation among humans from the region of subjective time.

4. Methods

4.1 Tasks

The subjects were required to press a button in synchrony with the onset of a periodic pulse auditory stimulus. They pressed the button using their right index finger. A total of 10 different ISIs were used in this study: 450, 600, 900, 1200, 1500, 1800, 2400, 3600, 4800 and 6000 ms. The duration of each auditory stimulus was 100 ms and the frequency was 500 Hz. The acoustic pressure was set at an appropriate magnitude that allowed the subjects to clearly hear the auditory stimulus, and it was the same for each subject throughout all trials.

4.2 Definition of parameters

The data that was measured during this experiment was stimulus onset and tap onset. The time difference between the stimulus onset and the tap onset was defined as the synchronization error (SE) and was the main target of analysis as an index that reflects the temporal relationship between stimulus and action. When the sign of the SE is positive, it indicates that the tapping onset lagged behind the stimulus onset. As could be seen in the experiments of Mates and Pöppel *et al.*[7] tapping can be divided into 2 broad types, the tapping in which the negative asynchrony phenomenon is observed and reactive tapping to stimulus. For this reason, the former is referred to as anticipatory tapping and the latter as reactive tapping, and the relationship between the parameters is as shown in the Fig. 1.

4.3 Subjects

Six healthy male university graduate school students in 20s volunteered to participate in this study. They all had experience in synchronization tapping tasks having participated in similar experiments and none of the subjects exhibited any hearing abnormalities. All of the subjects were right-handed.

4.4 System

The system used in this experiment was loaded onto a PC (IBM ThinkPad 535) with a single task OS (IBM PC-DOS2000). The stimulus sound was transmitted to the subject via headphones from an external sound source connected to the PC through a parallel port. In addition, the button that the subject pressed was connected to the PC via a parallel port. The program used in the study was developed using the programming language C. The measurement of the time for pressing the button and the stimulus sound presentation was done using a built-in real time clock (RTC), and the time resolution was 1 ms.

4.5 Procedure

The task that was given to the subjects was to press a button in coordination with a periodic pulse auditory stimulus. This task was conducted under the following 2 conditions.

(1) N condition: controlling condition. Each trial was made up of a set ISI auditory stimulus, and conducted for 10 different ISIs. During each trial, the subject was asked to press a button manually in synchrony with the onset of an auditory stimulus as precisely as possible. However the length of each trial was set at 1 minute in order to use a memory task as a secondary task. Thus, by changing the number of trials corresponding to the ISIs, data covering a total of 40 taps was collected for each ISI. Since the

objective was to observe a steady reaction in the subjects, the data was recorded from 10 seconds after the onset of the initial tap in each trial.

(2) M condition: memory task condition. Tapping was performed in the same manner as under the N condition in parallel with the word memory task. The subjects were asked to remember a word using the Japanese phonetic *hiragana* or *katakana*, which consisted of 3 to 5 morae. All of the words were meaningful but the combinations used in each trial were selected with the objective of making it difficult to create meaningful associations between the words. In addition, the subjects were strongly admonished not to memorize the words by using the storytelling method (a method of memorization in which a story is created using the displayed words to shift the words into long-term memory). The number of words that were displayed in each trial was either 4 or 5. The mean number of morae was 3.69 for the 4-words condition and 3.68 for the 5-words condition. The trials were started simultaneously with the pressing of the space bar on the computer keyboard by the subject. Once the space bar was hit, the word set was displayed in the center of the monitor for 3 seconds, the monitor was then blacked out, and an auditory stimulus was immediately presented and the subject was required to perform tapping for a 1-minute period while retaining the words. Immediately after completion of the tapping, the subject was asked to orally recite the retained words. The order of the words was not considered relevant. Subjects A, B and C went through the experiment in the order of N condition, 4-words condition and 5-words condition, while subjects D, E and F went through the experiment in the order of N condition, 5-words condition and 4-words condition.

The subjects were also forbidden from timing the tapping by counting to themselves while tapping or physically moving rhythmically. Each trial was conducted after a suitable interval. This was taken to ensure that the concentration of the subject was not adversely affected by fatigue as a result of effect of the preceding trial on later trials.

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