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# Two types of anticipation in synchronization tapping

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**Abstract.** The time perception mechanism in anticipatory timing control was investigated in a synchronization tapping task. An especially negative asynchrony phenomenon in which the tap onset precedes the stimulus onset was used as an anticipatory response. In this experiment, to clarify the effects of higher brain functions, such as attention, a dual-task method was applied and a word memory task was used as a secondary task. The results revealed 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 and seen in the interstimulus-onset interval (ISI) range of 1 800 to 3 600 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 1 500 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 attention processing of temporal information and the embodied automatic anticipation.

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**Key words:** synchronization tapping, negative asynchrony, anticipation, timing control, attention, working memory

## INTRODUCTION

Mutual coordination of timing is required to produce synchronous cooperative behavior between humans, and an anticipation mechanism related to external events is thought to be indispensable to generate such movement. The importance of this timing control becomes clear if one considers, for example, what goes into playing together in a musical ensemble. However, it has been reported that a time difference exists between awareness of cognitive synchrony and physical synchrony, such as a negative asynchrony phenomenon (see next paragraph). Thus, an analysis of this anticipation mechanism should be done, not only for the physical process, but also for the cognitive process in which higher brain function such as attention (Kahnemann 1973) is involved.

The synchronization tapping task has been used as the simplest system for examining the timing mechanism. In this experiment, the subject is required to synchronize his finger movement with a periodic auditory or visual stimulus. The most striking example that demonstrates the occurrence of anticipatory timing control is the phenomenon whereby the onset of each tap precedes the onset of stimulus by several 10 ms (Aschersleben and Prinz 1995, Fraisse 1966, Kolers and Brewster 1985, Mates et al. 1994, Peters 1989, Stevens 1886, Woodrow 1932). This pressing-in-advance phenomenon, for which the subject himself is unaware, demonstrates that the motion command to the finger is generated before the onset of auditory stimulus, suggesting a process of anticipatory timing control. The negative time offset caused by 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 et al. (1994) conducted a synchronous tapping experiment using a periodic auditory stimulus within a range of 300 to 4 800 ms. They confirmed that negative asynchrony was observed for all of the above stimulus intervals, despite a difference in the degree of its occurrence. In addition, they found that the upper limit for the generation of stable, negative asynchrony with small fluctuation is 2 to 3 seconds for the interstimulus-onset interval (ISI). It was also reported that if the ISI limit is exceeded, then reactive responses become mixed in with the negative asynchrony.

It has been found that the function of the cerebellum is important in neural mechanisms that support perception of short time intervals of less than 1 second, by using synchronization tapping tasks, other types of time discrimination tasks and time reproduction tasks (Ivry 1996, 1997, Pascual-Leone 2001, Rao et al. 1997). Moreover, higher brain functions contribute to the perception of time intervals that exceed 2 to 3 seconds (Brown 1997, Kagerer et al. 2002). Mangles et al. (1998) conducted a series of experiments on time perception under 2 sets of conditions, short (400 ms) and long (4 seconds), in subjects with injuries to the cerebellum and prefrontal cortex. They found that subjects with an injury to the prefrontal cortex exhibited deterioration in performance, only for the long-duration discrimination tasks; they also found a deficiency in the subject's working memory function. These findings suggest a multicomponent timing mechanism (Ivry 1997) and the importance of the role of working memory in the perception of long time periods.

From these backgrounds, however, the experiments of Mates et al. (1994) did not clarify this role, and possibly these two types of timing mechanisms contribute to the occurrence of negative asynchrony. Miyake et al. (2001) proposed the hypothesis of a dual-anticipation mechanism in sensory motor coupling, and an experiment supporting it was recently reported (Zelaznik et al. 2002). Therefore, the research presented herein was based on this hypothesis, by conducting an experiment designed to determine the effects of higher brain functions, such as attention on a synchronization tapping task.

A number of cognitive models have been proposed on the relationship between perception of a time interval that exceeds 2 to 3 seconds and attention. Among these, the "attention allocation model" is based on the premise that decision-making time is determined by the extent of attentional resources allocated to the temporal information processing system, *versus* the mental activity processing system unrelated to time (nontemporal information processing) (Brown 1997, Macar and Casini 1999). Central execution of working memory has been clarified as being involved in this allocation of attention (Baddeley 1986, 1998a,b, Osaka 2000). According to the attention capacity model of Kahnemann (1973), there is a limited amount of attentional resources, and these resources determine the limits in the processing of perceptual information. Attention is a critical resource to the execution of mental activities, and it 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 difficult 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 decisions becomes disrupted, and the anticipatory timing control is thought to be affected.

## METHODS

A dual-task method (Baddeley 1986) is used in the control of subject attention. This is an experiment in which the processing capacity required for executing a primary task is reduced by having the subject engage in an additional (or secondary) task while still engaged in the primary task. Well-known examples of these types of test are the reading span test (Daneman and Carpenter 1980, Osaka and Osaka 1994) that measures the working memory capacity when a subject is simultaneously reading a short sentence out loud and engaged in a word memory task. Another is the articulatory suppression method, which examines the organization of coding of auditory information when a subject is engaged in a cognitive activity such as memory, while simultaneously repeating a word such as "a" or "the" (Saitoh 1997). 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, 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 attention capacity that is available in the tapping task was controlled by using the memory task with two different numbers of words as a secondary task. If the attention 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.

The subjects were asked to press a button in synchrony with the onset of a periodic pulse auditory stimulus as their primary task. A total of 10 different ISIs were used in this study, and this task was performed under the following 2 conditions: each trial comprised a fixed ISI auditory stimulus for the controlled condition (N condition) and was 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 details are explained in the following section(s).

### Tapping task

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, 1 200, 1 500, 1 800, 2 400, 3 600, 4 800 and 6 000 ms. The sequence of ISIs was randomized in each subject, and 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.

### Definition of parameters

The data that were measured during this experiment were 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 et al. (1994) tapping can be di-

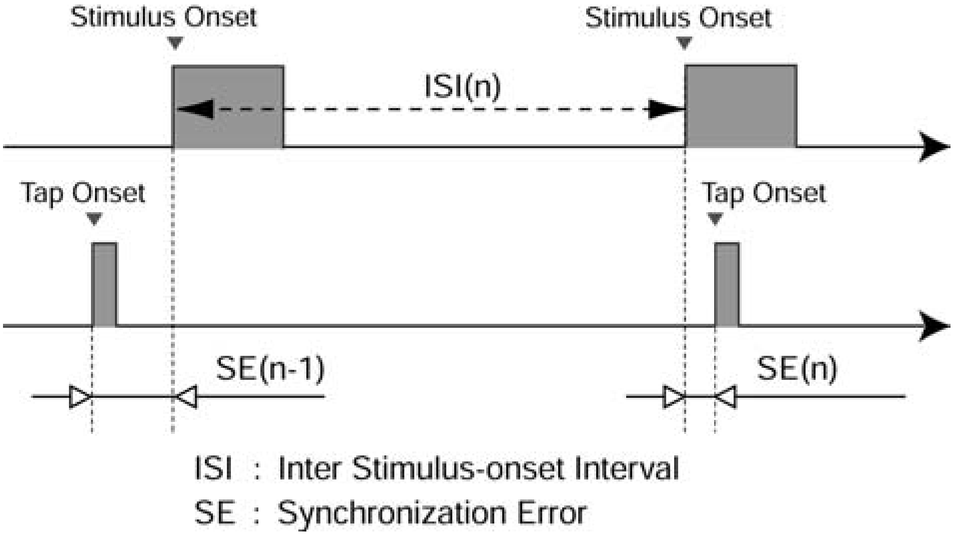

Fig. 1. Temporal relationship between tapping onset and stimulus onset. The data measured during this experiment is stimulus onset and tap onset. The time difference between the stimulus onset and the tap onset was defined as the synchronization error (SE). Negative SE indicates that the tapping precedes the stimulus onset and corresponds to anticipatory tapping. The time difference between two successive stimulus onsets was defined as the Interstimulus-onset Interval (ISI). The duration time of each stimulus is 100 ms.

vided into 2 types: 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.

### Subjects

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

### System

The system used in this experiment was loaded onto a PC (IBM ThinkPad 535) with a single task OS (IBM PC-DOS 2000). 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 of 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.

### Procedure

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

#### *N CONDITION – CONTROLLING CONDITION*

Each trial consisted of set ISI auditory stimuli, and was 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, data recording began 10 seconds after the onset of the initial tap in each trial.

#### *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 a Japanese phonetic character, which consisted of 3 to 5 morae. A "morae" is a syllable characteristic to Japanese. 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 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-word condition and 3.68 for the 5-word condition. The trials were started simultaneously, by the subject pressing the space bar on the computer keyboard. Once the space bar was hit, the word set was displayed in the center of the monitor screen (IBM ThinkPad 535) for 3 seconds; the monitor was then blacked out, and an auditory stimulus was immediately presented and the subject 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-word condition and 5-word condition, whereas subjects D, E and F went through the experiment in the order of N condition, 5-word condition and 4-word condition.

The subjects were also prohibited from timing the tapping by counting to themselves while tapping or by making rhythmical physical movements. Each trial was conducted after a suitable interval. This was done to ensure that the concentration of the subject was not adversely affected by fatigue as a result of the preceding trials.

## RESULTS

### Correct response rate for word memory task

The correct response rates for the word memory tasks for each subject are shown in Table I. 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 occurred between the mean values for the 2 groups at $P<0.05$ when a Wilcoxon sign rank sum test was performed. There was an exceptionally large drop in performance observed for subject B. Memorization of 4 words was at a level of difficulty that could be executed almost perfectly by each of the subjects, whereas there was a difference for the 5-words memorization task that could, however, be characterized as difficult. This result suggests that the attentional resources required to memorize 5 words exceeded or was close to the capacity limit.

Table I

Correct response rate for memory task

| Subject | 4 words (%) | 5 words (%) |
|---|---|---|
| A | 100.0 | 96.4 |
| B | 92.0 | 77.3 |
| C | 98.9 | 90.9 |
| D | 100.0 | 94.6 |
| E | 98.9 | 92.8 |
| F | 100.0 | 98.2 |
| Average | 98.3 | 91.7 |

The value for each subject is the subject's average value of all trials.

### Distribution of synchronization errors (SE)

The data that were obtained through this experiment were stimulus onset and tap onset. Synchronization error (SE), which expresses the time difference between the stimulus onset and the tap onset, was mainly analyzed as an index reflecting the temporal relationship between stimulus and response. A positive SE value indicated that the tap onset lagged behind the stimulus onset. As can be seen in the experiments of Mates et al. (1994), 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 a stimulus. For this reason, the former is referred to as anticipatory tapping and the latter as reactive tapping.

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 1 500 ms is focused around a shift in the negative direction, with a small spread. This is a distri-

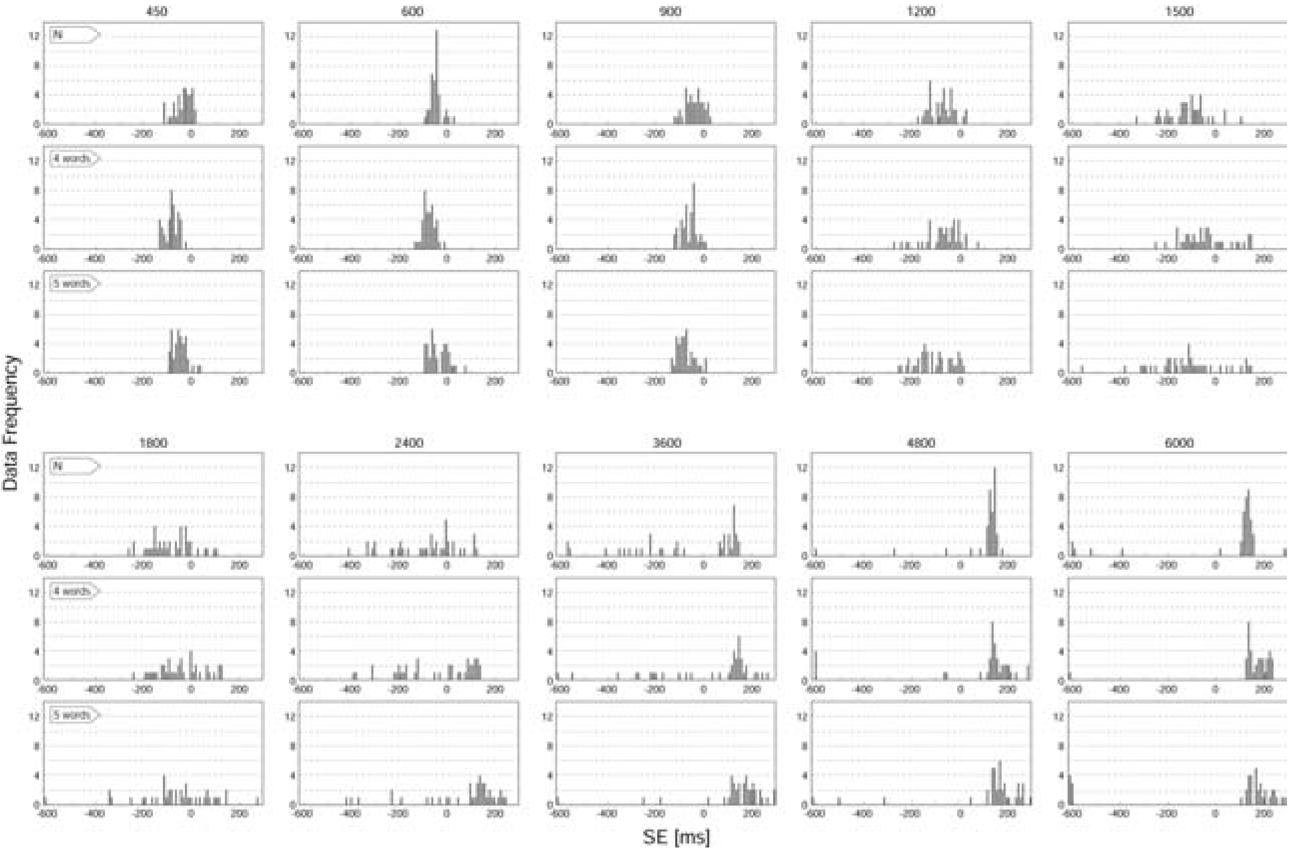

Fig. 2. Example of synchronization error (SE) distribution. SE distribution for every interstimulus-onset interval (ISI) of subject A is shown. The upper side of the graph corresponds to the normal condition, the lower two graphs correspond to the memory condition. Here N represents the normal synchronization tapping, and 4 words or 5 words represent the tapping with 4 or 5 word memory tasks, respectively. The number at the head of each graph represents ISI (ms).

bution 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 4 800 to 6 000 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 1 800 to 3 600 ms. Almost the same distribution is seen with the M condition, but reactive tapping is seen from around 1 800 ms for the M condition, with both 4 words and 5 words, while reactive tapping is noticeable in the area around an ISI of 3 600 ms for the N condition.

### 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 therefore necessary to distinguish between the two types of tapping modes. An examination of the SE distribution for ISI = 6 000 ms as shown in Fig. 2, reveals that 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 have been reactive were selected out in tapping at an ISI of 6 000 ms, and the SE mean value among the subjects was calculated on the basis of the SE mean for each subject. It was 151 ms under the N condition (standard deviation among subjects = 15.7). Thus, the border between the two types of tapping was defined as a value which subtracted 3 times of standard deviation from the mean value, and SE = 100 ms was uniformly fixed as the boundary value for all subjects and ISIs. A SE values larger than this were classified as reactive tapping, and all other tapping were classified as anticipatory tapping.

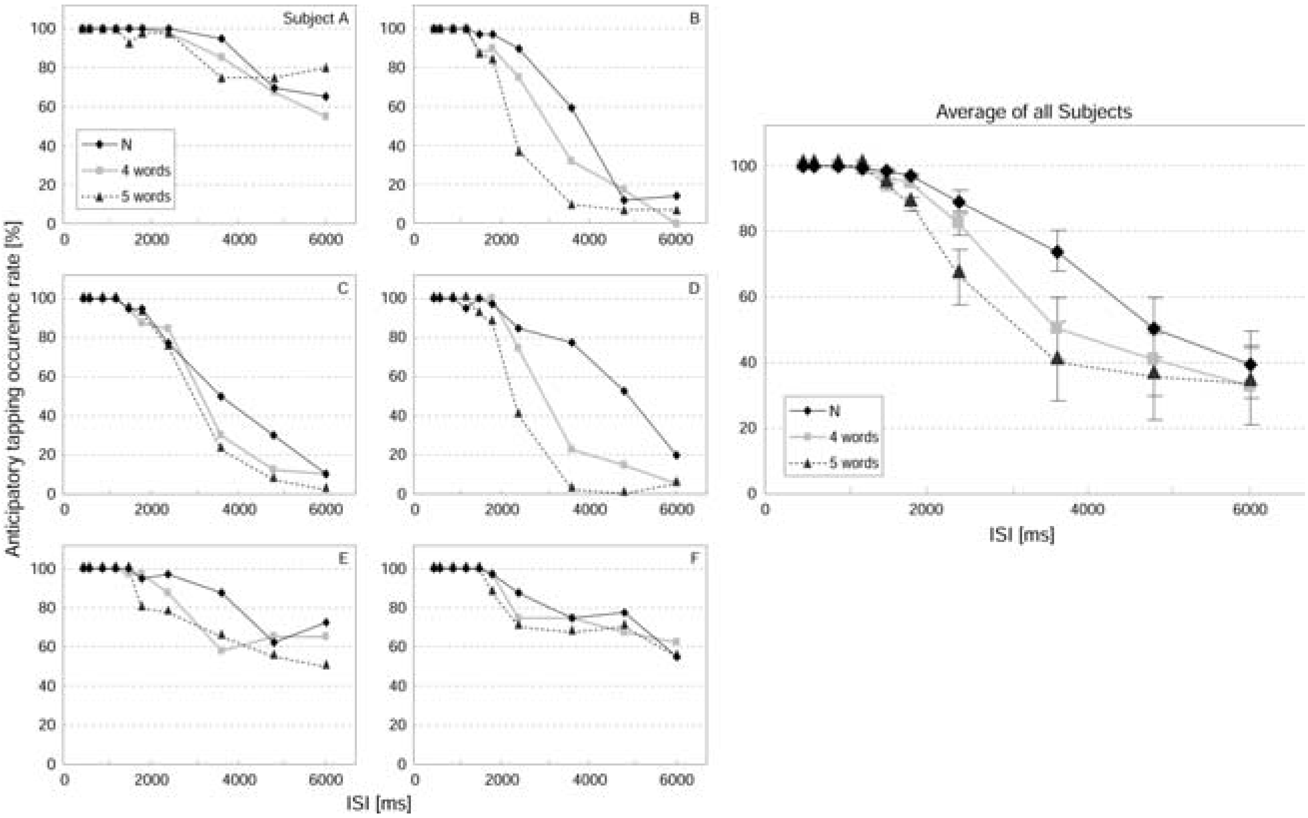

Fig. 3. Occurrence rate of anticipatory tapping. The anticipatory tapping was defined as the tapping with SE less than 0.1 second. Left graphs are the data from 6 subjects, and the right graph is the average among 6 subjects. Abbreviations are the same as those in Fig. 2. The error bar shows the standard error of all subjects.

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-word condition and 5-word condition (Fig. 3). This percentage is called the anticipatory tapping occurrence rate. Almost 100% of tapping at an ISI of not more than 1 500 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 1 800 ms. Mates et al. (1994) found that the time capacity of 2 to 3 seconds corresponds to the ISI in which reactive tapping begins. It was also found that at an ISI of not more than 1 500 ms, 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, compared with that under the N condition. In addition, if 4 word and 5 word conditions are compared, almost no difference is observed at a short ISI up to 1 500 ms, but the anticipatory tapping occurrence rate was smaller for 5 words, at higher ISIs in comparison with 4 words.

Table II 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 3 600 ms for the N-4 word condition, whereas a significant difference was observed from 1 800 to 3 600 ms for the N-5 word condition. In addition, the occurrence rate was significantly lower for 5 words at 1 800, compared with 4 words. However, considering the fact that the correct response rate under the 5 word condition for the word memory task was significantly lower compared with the 4 word condition, the N-5 word condition should be used as a dual-task condition to measure the influence from attentional resources.

These results demonstrate that when tapping is performed with an ISI of 1 500 ms or less, memory tasks are not affected by interference with attention, but are adversely affected with an ISI in the range of 1 800 to 3 600 ms. Furthermore, with an ISI of 4 800 ms or higher, the effect of attention was small, and the occur-

Table II

*t*-test of anticipatory tapping occurrence rate

| ISI | N - 4 words | N - 5 words | 4 - 5 words |
|---|---|---|---|
| 450 | - | - | - |
| 600 | - | - | - |
| 900 | - | - | - |
| 1 200 | | | - |
| 1 500 | | # | |
| 1 800 | | * | * |
| 2 400 | # | * | # |
| 3 600 | * | * | |
| 4 800 | | | |
| 6 000 | | | |

This shows the results of a *t*-test on the mean value of the occurrence rate of anticipatory tapping among all subjects, for the combinations of N-4 words, N-5 words and 4-5 words by each ISI. (*) Significant difference at $P<0.05$; (#) significant difference at $0.05<P<0.10$. The blank column shows other results. We tested all but ISIs of 450, 600, 900 ms (all condition), and 1 200 ms (4-5 words), because occurrence proportions in these conditions were almost all 100% in this range.

rence rate for anticipatory tapping was extremely low. It seems that this region should be considered as the domain of reactive tapping, as shown in Fig. 2. Thus, it was determined that the synchronization tapping in the stimulus period of 6 seconds or less can be divided into the 3 regions: (i) anticipatory tapping that is unaffected by the subject's attention; (ii) anticipatory tapping that is affected by the subject's attention; (iii) reactive tapping.

However, in the region of 1 800 to 3 600 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 attentional 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.

### SE mean values and SE/ISI mean values

It also became 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 Fig. 4A,B. In these figures, if the data of SE was limited to only the anticipatory tapping, there were ISI regions where the SE mean values and the SE/ISI mean values were fixed. The SE mean values were almost constant between 450 and 1 800 ms, and it was found that the magnitude of negative values increased above these levels. In contrast, the SE/ISI mean value was almost constant between 1 800 and 3 600 ms.

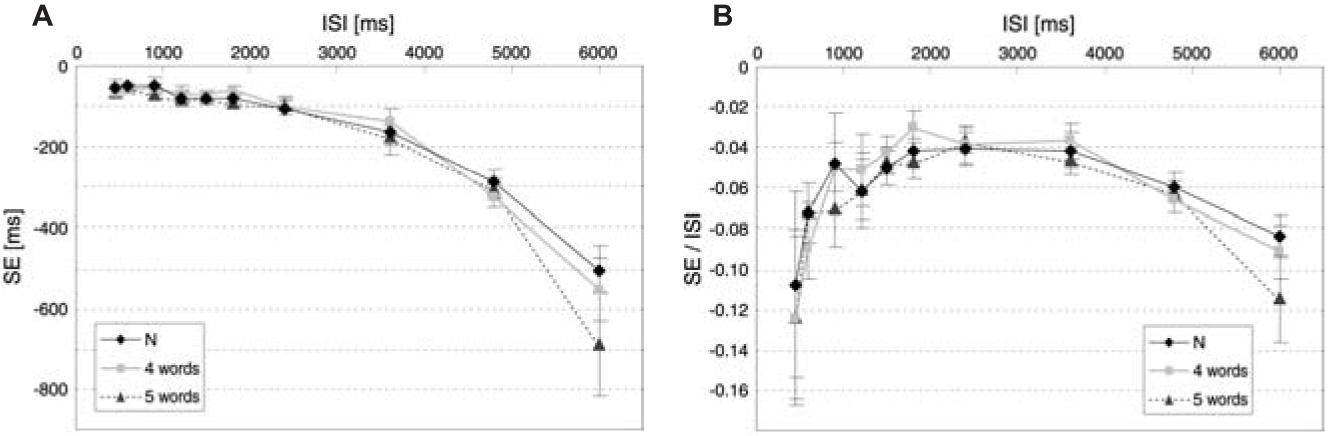

Fig. 4. Effects of ISI on the anticipation mechanism. (A) Relationship between average of SE and ISIs in anticipatory tapping. By using the definition used in Fig. 3 the anticipatory tapping was extracted from all tapping, and the average SE was calculated for each subject. (B) Relationship between average SE/ISI and ISIs, in anticipatory tapping. Abbreviations are the same as those in Fig. 2. Error bar shows the standard error of all subjects.

These results suggest that the mechanism for anticipatory timing control is different below and above 1 800 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 between 450 and 1 800 ms. However, the magnitude of negative asynchrony between 1 800 and 3 600 ms can be characterized as scaling by ISI. This suggests that a systematic memory mechanism for anticipatory tapping exists in the synchronization process for time intervals longer than 1 800 ms. In addition, it was also observed that when the ISI is 4 800 or 6 000 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.

## 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: (i) the negative asynchrony occurrence rate was not affected by a secondary task in the ISI range of 450 to 1 500 ms; (ii) in the ISI range of 1 800 to 3 600 ms, the negative asynchrony occurrence rate was significantly reduced by the simultaneous execution of a secondary task; (iii) the negative asynchrony occurrence rate was extremely low in the ISI range of 4 800 to 6 000 ms.

The N condition used in this study was essentially the same as that used in the experiment of Mates et al. (1994). The properties of the SE distribution that are shown in Fig. 2 also agreed well with their results. They reported that reactive tapping began to appear with an ISI of 2 to 3 seconds, 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 attention into consideration, indicated that changes in the negative asynchrony properties depended on two timing mechanisms that qualitatively differ and exist in the ISI regions of 450 to 1 500 ms and 1 800 to 3 600 ms.

The reduction in attentional resources by the execution of a secondary task did not have a significant effect on the negative asynchrony occurrence rate in the 450 to 1 500 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 attentional resources required by both tasks, based on the attention capacity model that was initially proposed. The correct response rate under the 5-word condition for the word memory task was significantly lower, compared with the 4-word condition, where the correct response rate was close to 100% (Table I). This result suggests that the attentional resources required to memorize 5 words exceeds or is close to the capacity limit. Therefore, the result that the tapping task was unaffected, despite this, suggests that an independent timing control mechanism of attentional resources exists in this ISI range.

Movements that can be executed independently of mental processing are referred to as "automatic" (LaBerge 1975, LaBerge and Samuels 1974), 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 produces the necessary rhythmic muscle activity such as walking (Pearson 1976). These generators are thought to correspond to a timer function that sends periodic pulses in time perception and production pacemaker models (Ivry 1996). 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 (Miyake et al. 2002). 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 (Kawato 1996). These mechanisms may be involved in the automatic anticipatory tapping that has been observed in this research.

The synchronization tapping task in the ISI range of 1 800 to 3 600 ms was substantially affected by the lowered attentional resources, as a result of the execution of the secondary task. However, despite the increase in the occurrence rate of reactive tapping 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 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 attentional 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 activity that accompanies maintenance rehearsal. This type of maintenance rehearsal is suggested to be performed by the phonemic loop function, which is a subsystem of working memory (Baddeley 1998a,b). The obtained phonemic information (of a word) is automatically entered in the phonemic storage that is one of the lower level systems in the phonemic loop and possesses a 1 to 2 second memory buffer. This phonemic storage has been known to be related to maintenance of information related to rhythm and time intervals (Brown 1997, Saitoh 1997), and 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 (Saitoh 1993). In addition, the premotor area and supplementary motor area are shown to be involved in the phonemic loop (Osaka 2000), suggesting a relationship between the phonemic loop and motion control.

In this way, the tapping task and word memory task may compete in the allocation of phonemic storage capacity. This is just a hypothesis, but the fact that stable tapping control is possible in the ISI range of 2 to 3 seconds, for the normal tapping task can be explained on the basis of 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 1 500 ms or less, contradict this line of thinking. It is suggested 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 on the basis of feedback processing for ISIs in this 1 800 to 3 600 ms range (Miyake et al. 2002). Accordingly, the fact that the magnitude of SE/ISI values in this ISI range are almost constant (Fig. 4B) suggests a 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 analyses 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 the 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 1 800 to 3 600 ms and the other is the automatic tapping mechanism that is not affected by attention and is seen in the 450 to 1 500 ms range. Accordingly, this anticipatory timing mechanism can be thought to be a dual process, in which the anticipatory mechanisms work 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" (Kanabus et al. 2004, Pöppel 1971, 1978, 1988, 1997, 2004, Szelag et al. 2002, 2004). 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 of anticipation. If the physiologic foundation for this temporal perception mechanism can be clarified through imaging techniques such as fMRI, it may be possible to construct a model for the neuronal mechanism that has been uncovered in this study. Furthermore, we can also expect that this will be connected with the technology that supports the cooperative process among humans from the region of cognitive time.

## CONCLUSION

The mechanism of anticipatory timing control was investigated in a synchronization tapping task, by using a dual-task method. The results revealed the presence of two types of anticipation mechanisms from the standpoint of attentional resources involved in time perception.

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