SICE Annual Conference in Fukui, August 4-6, 2003
Fukui University, Japan

Two Types of Anticipation in Sensory-Motor Coupling

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Abstract: The anticipatory timing control in sensory-motor coupling is indispensable to generate coordinative movement among humans, however its cognitive mechanism still remains obscure. In this study we used synchronization tapping task as a model system, and negative asynchrony phenomenon[1-7] where the tap onset precedes the stimulus onset was analyzed as an example of the anticipation. Especially, applying dual task method[8], the relationship between the anticipation mechanism and the higher brain function such as attention[9] and working memory[10] was investigated. The results revealed two types of anticipatory timing control. In the inter stimulus-onset interval (ISI) range of 450 to 1800ms, automatic anticipation that is not affected by attentional resources was observed and was based on feed forward dynamics. In the 2400 to 3600ms range, the anticipation showed trade-off relationship in the allocation of attentional resources. Magnitude of synchronization error (SE) between tap onset and stimulus onset in this region was scaled by the ISI and the feed back dynamics concerning ISI was suggested. Accordingly, anticipation in timing control was shown to be a dual processing between the attentional process and the embodied automatic process.

Key Words: anticipation, sensory-motor coupling, synchronization tapping, negative asynchrony, attentional resources

The synchronization tapping has been used as the simplest system for examining the mechanism behind coordination of timing in sensory-motor coupling. The most interesting phenomenon observed in this task is the negative asynchrony, which the subject himself is unaware of. This phenomenon where the onset of each tapping precedes the onset of stimulus by several 10ms has been regarded as an anticipatory timing control. On the other hand, a number of cognitive models have been proposed on the relationship between time perception and attention. The attention allocation model as an example is based on the premise that decision-making time is determined by the ratio of allocated attentional resources between temporal information processing and mental activity processing that is unrelated to time[11-12]. 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[9]. Therefore, the research presented herein was done based on this hypothesis, by conducting an experiment to determine the effects of these higher brain functions such as attention and working memory on a synchronization tapping task.

The dual task method[8] was used in the control of 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). We employed a word memory task as the secondary task to restrict the attention control to short-term memory and this type of memory has been regarded as a function of working memory. 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[13]. The obtained phonemic information 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[11].

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. If the attentional capacity 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 requested to push the button in synchrony with the onset of periodic pulse of 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 6000ms.

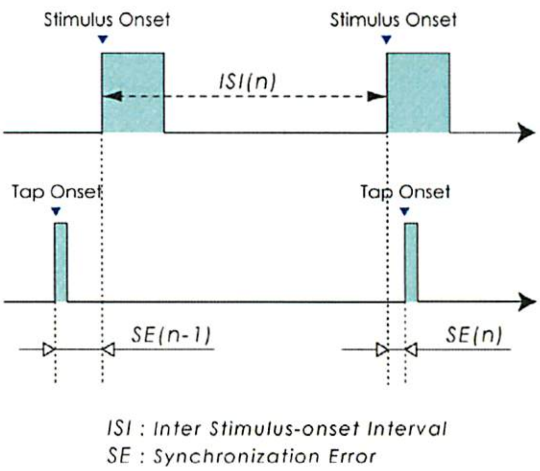

Fig.1 Temporal relationship between tapping onset and stimulus onset. The data measured during this experiment is stimulus onset and tap onset. The time difference between the stimulus onset and the tap onset was defined as the Synchronization Error (SE). Negative SE indicates that the tapping precedes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

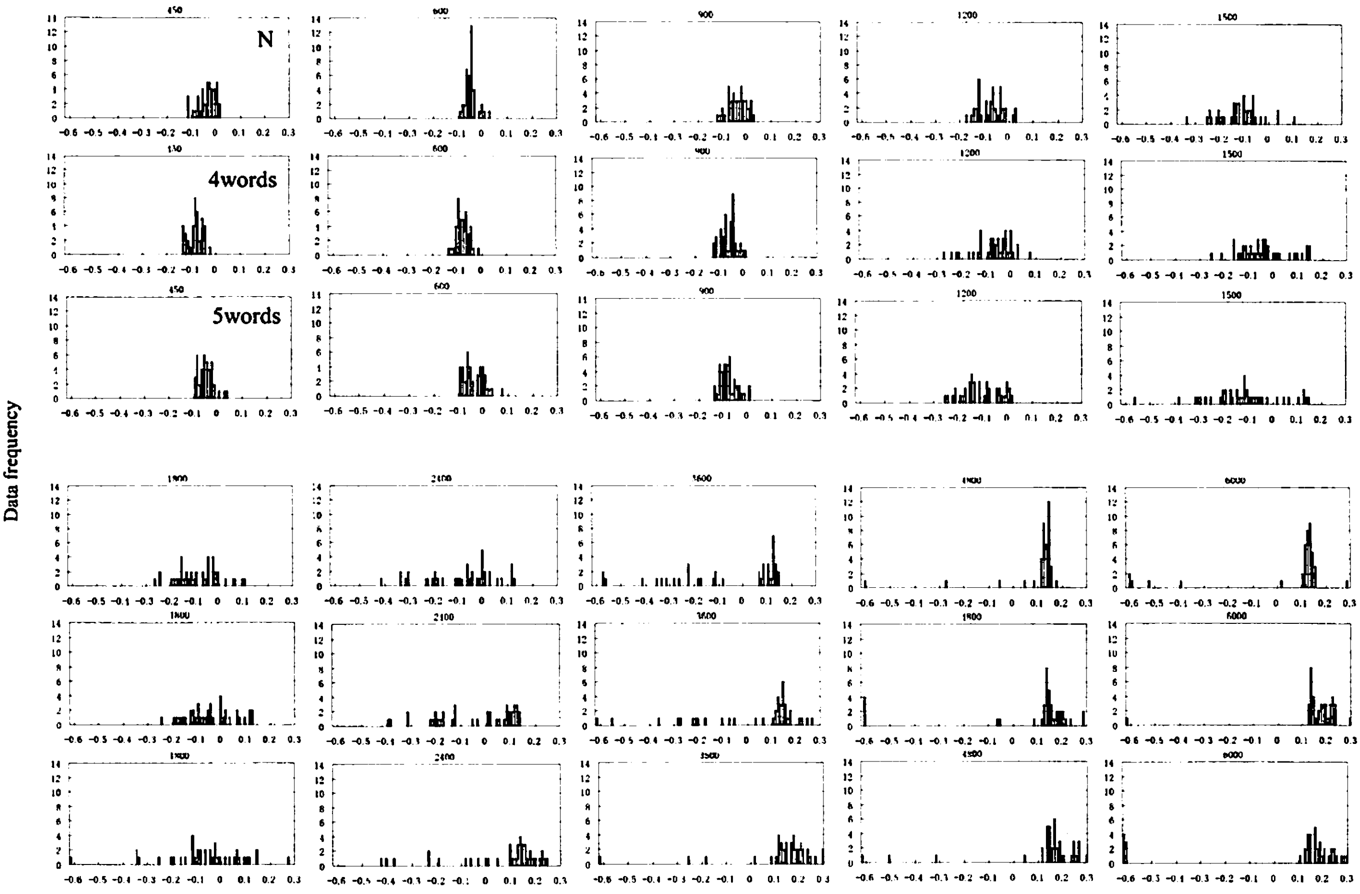

Fig.2 Example of Synchronization Error (SE) distribution. SE distribution for every Inter Stimulus-onset interval (ISI) of subject A is shown. Upper side of the figure corresponds to the normal condition, lower two figures correspond to the memory condition. Here N represents the normal synchronization tapping, and 4words or 5words represents the tapping with 4 or 5 words memory task respectively. The number at the head of each figure represents ISI [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). 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 data 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 shown in Fig.1.

The SE distribution at each ISI is shown in Fig.2. 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 corresponding 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 6000ms. 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 3600ms. Almost the same distribution is seen with the M condition, but reactive tapping begins to be seen from around 2400ms for the M condition with both 4 words and 5 words.

The percentage of anticipatory tapping 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 under the N condition was found to be anticipatory in the ISI range of 450 to 1800ms and the anticipatory tapping occurrence rate tended to decrease as the ISI was increased from 2400ms and above. Mates *et al.* found that the time capacity of 2 to 3 sec corresponds to the ISI in which reactive tapping begins[6]. 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 1800ms, but the anticipatory tapping occurrence rate was smaller for 5 words at higher ISIs. Table 1 shows the results of a *t*-test on the mean value of the anticipatory tapping occurrence rate for the combinations of N-4 words, N-5 words and 4-5 words by each ISI.

The above results demonstrate that when tapping is performed with an ISI of 1800ms or less, memory tasks are not affected by the interference with attention, but are adversely affected ISI in the ISI range of 2400 to 3600ms. Furthermore with an ISI of 4800ms or higher, the effect of attention was small, and the occurrence rate for anticipatory tapping was extremely low. Thus,

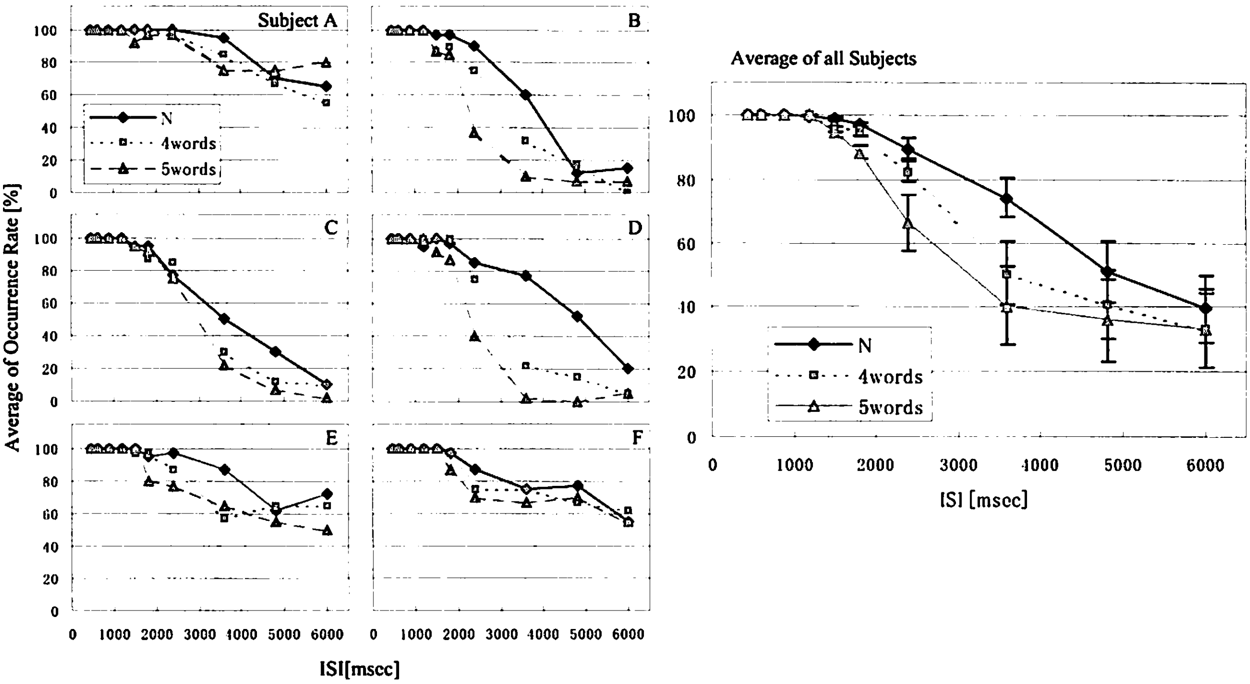

Fig.3 Occurrence rate of anticipatory tapping. The anticipatory tapping was defined as the tapping with SE less than 0.1sec. Since distinguishing between the reactive and anticipatory tapping was relatively simple in the SE distribution for ISI=6000ms, and only those taps that were thought to be reactive were selected out. Then the SE mean value was calculated and it was 0.151 sec under the N condition (standard deviation among subjects = 0.0157). Thus, SE = 0.1sec was uniformly fixed as the standard value for all subjects and ISIs, and a SE value less than this was classified as anticipatory tapping. Left figures are the data from 6 subjects and right figure is the average between 6 subjects. Abbreviations are the same to Fig.2. Error bar shows the Standard Error of all subjects.

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 unaffected by the subject's attention, anticipatory tapping affected by the subject's attention and reactive tapping.

The reduction in the attentional resources by the execution of a secondary task did not have an effect on the negative asynchrony occurrence rate in the 450 to 1800ms 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. 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 2). This result suggests that the attentional resources required to memorize 5 words exceeds or is close to the capacity limit. Therefore, this result suggests that an independent timing control mechanism of attentional resources functions exists in this ISI range. Movements that can be executed independent of mental processing are referred to as "automaticity"[14] and regulation of movement through the cerebellum and the basal ganglia is known to be involved in these movements[15-19].

The synchronization tapping task in the ISI range of 2400 to 3600ms was substantially affected by the lowered attentional 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, not all tapping became 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

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

Table 1 Result of t-test about the occurrence proportion of anticipatory tapping. This shows the results of t-test on the mean value of the occurrence proportion of anticipatory tapping among all subjects for the combinations of N-4 words, N-5 words and 4-5 words by each ISI. "*" and "#" shows significant difference by p<0.05 and 0.05d"pd"0.10 respectively. Blank column shows other results. We tested except the ISIs of 450, 600, 900ms(all condition), and 1200ms(4-5words), because occurrence proportions in these conditions were almost all 100% in these range. A significant difference was observed only at 2400 and 3600ms for the N-4-words condition while a significant difference was observed from 1500 to 3600ms for N-5-words condition. In addition, the occurrence rate was significantly lower for 5 words in comparison with 4 words at 1800 and 2400ms.

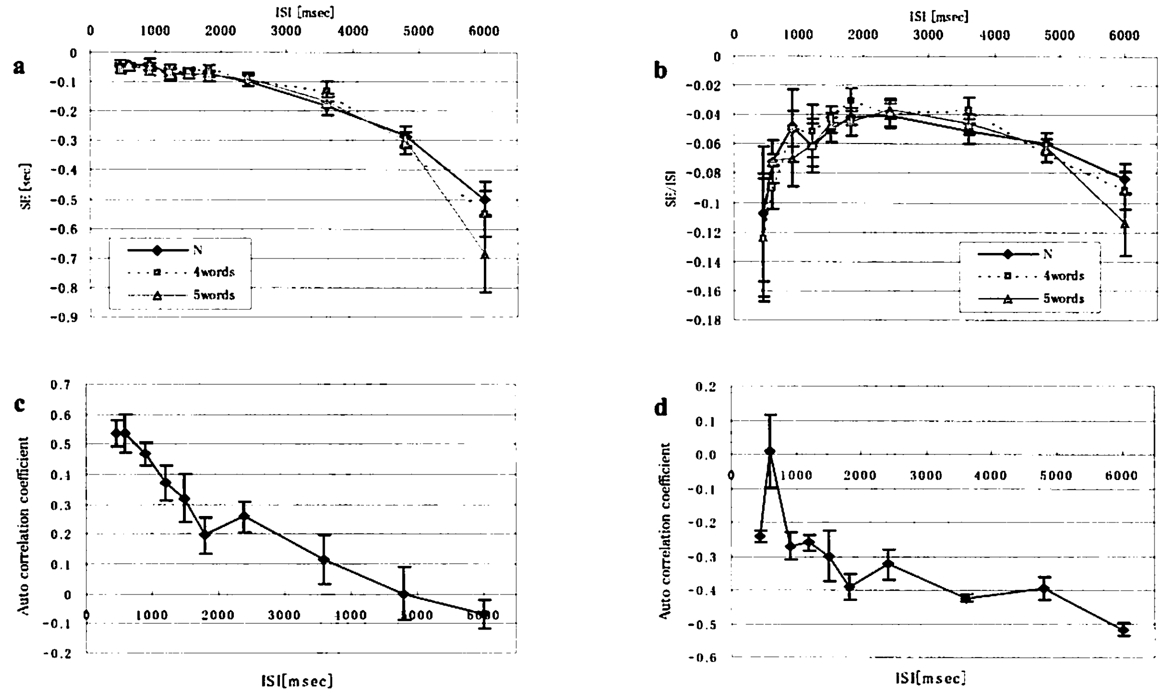

Fig.4 Effects of ISI to the anticipation mechanism. a, Relationship between average of SE and ISIs in anticipatory tapping. By using the definition used in Fig.3 the anticipatory tapping was extracted from all tapping, and the average of SE was calculated for each subject. b, Relationship between average of SE/ISI and ISIs in anticipatory tapping. Details are the same to a. c, Auto correlation coefficient (Lag=1) of the time series of SE (not divided in two modes). d, Auto correlation coefficient (Lag=1) of the time series of ITI (not divided in two modes). These four figures show the average value of 6 subjects. Error bar shows the Standard Error of all subjects.

processing efficiency. 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. The obtained phonemic information 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[11,20,21]. In this way, the tapping task and word memory task may compete in the allocation of phonemic storage capacity. 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 1800ms or less contradicts this line of thinking. Therefore 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.

It became also clear that there are differences in the anticipatory timing mechanism with a specific ISI set when the SE and SE/ISI 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 as shown in Figs. 4a and 4b. From these figures, if the data of SE is limited only to the anticipatory tapping, the SE and SE/ISI were almost constant in the range from 450 to 1800ms and 2400 to 3600ms respectively. These results suggest that the anticipation mechanism is different at the border around 1800ms. This was also supported by the analysis of auto-correlation coefficient as shown in Figs.4c and 4d. In the range from 450 to 1800ms, auto-correlation coefficient of SE is positive more than 0.3, suggesting temporal development of SE is a process with feed

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

Table 2 Percentage of correct answers in memory test. The value of each subject is the average value of all trials. The values for each subject are the mean values for each trial. The correct response rate among all 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.

forward manner. Moreover, auto-correlation coefficient of Inter Tap-onset Interval (ITI) is negative less than -0.3 in the range from 2400 to 3600ms. This suggests that tapping in this region is a process with feedback dynamics. Thus, it can be said that anticipation mechanism in the ISI range from 450 to 1800ms is automatic process. However, the anticipation in the range of 2400 to 3600ms is characterized by the fact that the magnitude of negative asynchrony (SE) is scaled by ISI, suggesting the retention and memory mechanism of information related to stimulus period and the presence of a feedback processing mechanism based on it.

Our research was aimed at furthering psychological analysis related to the mechanism in the anticipatory timing control that is indispensable in cooperative activity among humans. The results revealed for the first time the presence of two types of anticipatory mechanisms in synchronization tapping from the standpoint of attention involved in time perception. Accordingly, this anticipation in sensory-motor coupling can be regarded as a dual process between the implicit automatic anticipation and the explicit anticipation of temporal information.

Methods

Tasks

Subjects were instructed to adjust their tap onsets to stimulus onsets as precisely as possible and the reproduction of tone duration was not explicitly required. 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 6000ms. The intervals between tone onsets (ISIs) in a sequence were constant in each trial. The duration of each auditory stimulus was 100ms in a rectangular envelope and the frequency was 500Hz. 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.

Subjects

Subjects were six healthy graduate school students (male, ages 22-27). They all had former experience in synchronization tapping tasks having participated in similar experiments and none of the subjects exhibited any hearing abnormalities. All of the subjects were volunteers, right-handed and neurologically normal.

System

The system used in this experiment was loaded onto a PC (IBM ThinkPad 535) with a single task OS (IBM PC-DOS2000). The program used in the study was originally 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. 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 response key was similar to those used on computer keyboards. A possible multiple event detection, which might result from mechanical switch bouncing, was eliminated. The key produced no additional sound when pressed. All factors possibly influencing synchronization performance were kept constant over trials.

Procedure

(1) N condition: controlling condition. Each trial was made up of a set ISI auditory stimulus, and conducted for 10 different ISIs. The presentation order of the sequences with different ISIs was randomized. During each trial, the subject was instructed 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. To avoid the influence of transient process at the beginning of each trial, the data was recorded from 10 seconds after the onset of the initial tap in each trial. Short rest period were also introduced between trials.

(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 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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1. Stevens, L.T. On the time sense, Mind **11**, 393-404 (1886).
2. Woodrow, H. The effect of rate of sequence upon the accuracy of synchronization, Journal of Experimental Psychology **15**, 357-379 (1932).
3. Fraisse, P. The sensorimotor synchronization of rhythms, In J. Requin(Ed.), Anticipation et comportement (pp.233-257), Centre National, Paris (1966)
4. Kolers, P.A. & Brewster, J.M. Rhythms and responses, Journal of Experimental Psychology: Human Perception and Performance **11**, 150-167 (1985).
5. Peters, M. The relationship between variability of intertap intervals and interval duration, Psychological Research **51**, 38-42 (1989).
6. Mates, J., Radil, T., Mueler, U. & Poeppel, E. Temporal Integration in Sensorimotor Synchronization, Journal of Cognitive NeuroScience **6**, 332-340 (1994).
7. Aschersleben, G. & Prinz, W. Synchronizing actions with events: The role of sensory information, Perception & Psychophysics, 57-3, 305/317 (1995)
8. Baddeley, A. Working memory (Oxford University Press, Oxford, 1986).
9. Kahnemann, D. Attention and efforts (Prentice-Hall, Engelwood Cliffs, 1973)
10. Osaka N. Brain and working memory (In Japanese) (Kyoto University Press, Kyoto, 2000)
11. Brown, S.W. Attentional resources in timing: interference effects in concurrent temporal and nontemporal working memory tasks, Perception & Psychophysics **59**, 1118-1140 (1997).
12. Macar, R. & Casini, L. Multiple approaches to investigate the existence of an internal clock using attentional resources, Behavioral Processes **45**, 73-85 (1999).
13. Baddeley A. Working memory, Comptes Rendus de

l'Academie des Sciences —Series III— Science de la Vie, **321**, 167-173 (1998).
14. LaBerge D. Automatic information processing (Long, J. & Baddeley, A eds., Attention and performance, vol.9, 1981)
15. Ivry, R. The representation of temporal information in perception and motor control, Current Opinion in Neurobiology **6**, 851-853 (1996).
16. Ivry, R. Neural mechanisms of timing, Trends in Cognitive Science **1**, 163-169 (1997).
17. Pascual-Leone, A. Increased variability of paced finger tapping accuracy following repetitive magnetic stimulation of the cerebellum in humans, Neuroscience Letters **306**, 29-32 (2001).
18. Rao, S.M., Harrington, D.L., Haaland, K.Y., Bobholz, J.A., Cox, R.W. & Binder, J.R. Distributed Neural Systems Underlying the Timing of Movements, The Journal of Neuroscience **17**, 5528-5535 (1997).
19. Kawato, M. Computational Theory of Brain (In Japanese) (Sangyo Tosho Publisher, Tokyo, 1996)
20. Kagerer, A. Cortical involvement in temporal reproduction: evidence for differential roles of the hemispheres, Neuropsychologia **40**, 357-366 (2002).
21. Mangles, A., Ivry, B. & Shimizu, N. Dissociable contributions of the prefrontal and neocerebellar cortex to time perception, Cognitive Brain Research **7**, 15-39 (1998).
22. Pöppel, E. Mind Works: Time and Conscious Experience (Harcourt Brace Jovanovich, Boston, 1988).
23. Pöppel, E. & Schwender, D. Temporal mechanism of consciousness, International Anesthesiology Clinics **31**, 27-38 (1993).
24. Pöppel, E. Oscillation as possible basis for time perception, Studium Generale **24**, 85-107 (1971).

Acknowledgments

We thank Dr. M. Wittmann for discussions; J. Heiss, C. Adamczyk, T. Muto, T. Yamamoto and J. Tanaka for their experimental and technical supports.

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