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Two Modes of Anticipation in Sensori-Motor Synchronization

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Abstract: We investigated the anticipation mechanism of timing control in sensori-motor synchronization. This was studied by using synchronization finger tapping between tap onset and periodic tone onset. As a result, we clarified that there were two modes of anticipatory timing control, one is anticipation with attention and the other is anticipation without attention. These facts indicate that anticipation of timing is realized by dual mechanism.

Keywords: anticipation, selective attention, timing control, sensori-motor synchronization

1. INTRODUCTION

Synchronization of finger tapping with repetitive sensory events is an experimental paradigm that has been used for studying sensori-motor behavior [1-8]. In this paradigm, one phenomenon of interest is the systematic temporal asynchrony between stimulus onsets and corresponding tap onsets. Most often a lead of tap onsets is observed without the subject being aware of it [1-4,6,9,10], and this anticipatory response is thought to be important to clarify the temporal integration process in the timing control of brain [11,12]. However it is still remained obscure, and here we investigate the relationship between this anticipation and selective attention. Reading short composition during tapping behavior was used to control the attention of subjects. As a result, we found two types of anticipation dynamics. One needed selective attention for anticipatory response and fluctuation of the process had long-range correlation. The other type response did not depend on the attention and its temporal correlation was very short. These facts indicate that timing control process is realized by dual-anticipation mechanism in sensori-motor synchronization.

It has already been established that such anticipatory response in tapping is influenced by various external factors, like the rhythmic structure, lateralization, or the sensory modality of stimuli [3-5,13]. Especially, influence of the interstimulus-onset interval duration (further shortly interstimulus interval, ISI) on the time differences between the stimulus onsets and corresponding tap onsets (further called synchronization error, SE) was widely studied [2,5,6,14,15]. While for isochronous sequences with ISIs up to 1800 msec, anticipatory responses were observed, the responses for ISIs longer than 2400 msec was a gradual transition from anticipatory toward reactive responses [15].

These observations could be understood within the general framework of a temporal integration process that is supposed to have a maximal capacity (integration interval) of approximately 3 sec [11,12]. This temporal integration is called "3 sec window," that has close relationship to the phenomenon of "subjective present" [16] and the state of being conscious [11]. Thus it is also important to clarify the mechanism of this anticipation process in relation with the emergence of consciousness. From this background, we investigated this anticipatory response in sensori-motor synchronization from the viewpoint of selective attention that corresponds to subject's conscious state.

In this investigation, the changes of subject's ability to synchronize tapping to periodic stimulus sequences were explored in dependence on the subject's attention. Subject's task was to synchronize his/her finger tap onsets to auditory stimuli onsets with fixed interstimulus intervals (ISIs) as precisely as possible. These experimental methods are based on the previous Mates' report [15]. This synchronization task was analyzed as the temporal development of synchronization errors (SEs). Subject's selective attention was controlled by reading short composition silently during the above tapping experiment (see Methods).

2. RESULTS & DISCUSSIONS

The results confirmed the influence of the selective attention on synchronization errors (SEs). Examples of temporal development of SEs are depicted in Figure 1. Negative SE means anticipatory response and positive SE corresponds to reactive response. In both cases with attention and without attention, time series of stable anticipatory response was observed when interstimulus intervals (ISIs) were between 450 and 1200 msec. When subjects tapped with attention, the alternation between anticipatory and reactive responses was typical in the sequences with ISIs between 2400 and 4800 msec, and it became stable reactive response with ISIs beyond 6000 msec. These results well coincides with Mates' report [15]. However, when subjects tapped without attention, such anticipatory responses disappeared in the sequences with ISIs beyond 2400 msec and stable reactive response became dominant.

To clarify these typical characteristics, time series of SEs were statistically analyzed. Figure 2a shows the averaged SE obtained under various ISIs. When subjects tapped with attention, anticipatory responses were observed in the conditions with ISIs up to 4800 msec, and reactive responses became dominant beyond ISI 6000 msec. In the tapping without attention, however, the anticipation was observed only when ISIs are up to 1200 msec. Here, there are significant differences between averaged SE with attention and without attention in ISIs between 2400 and 4800 msec, but there are no significance in ISIs of 450 and 1200 msec. These results suggest that there are two types of anticipatory responses. One observed in ISIs between 2400 and 4800 msec needed attention (type-A), but the other observed in ISIs up to 1200 msec did not need it (type-B).

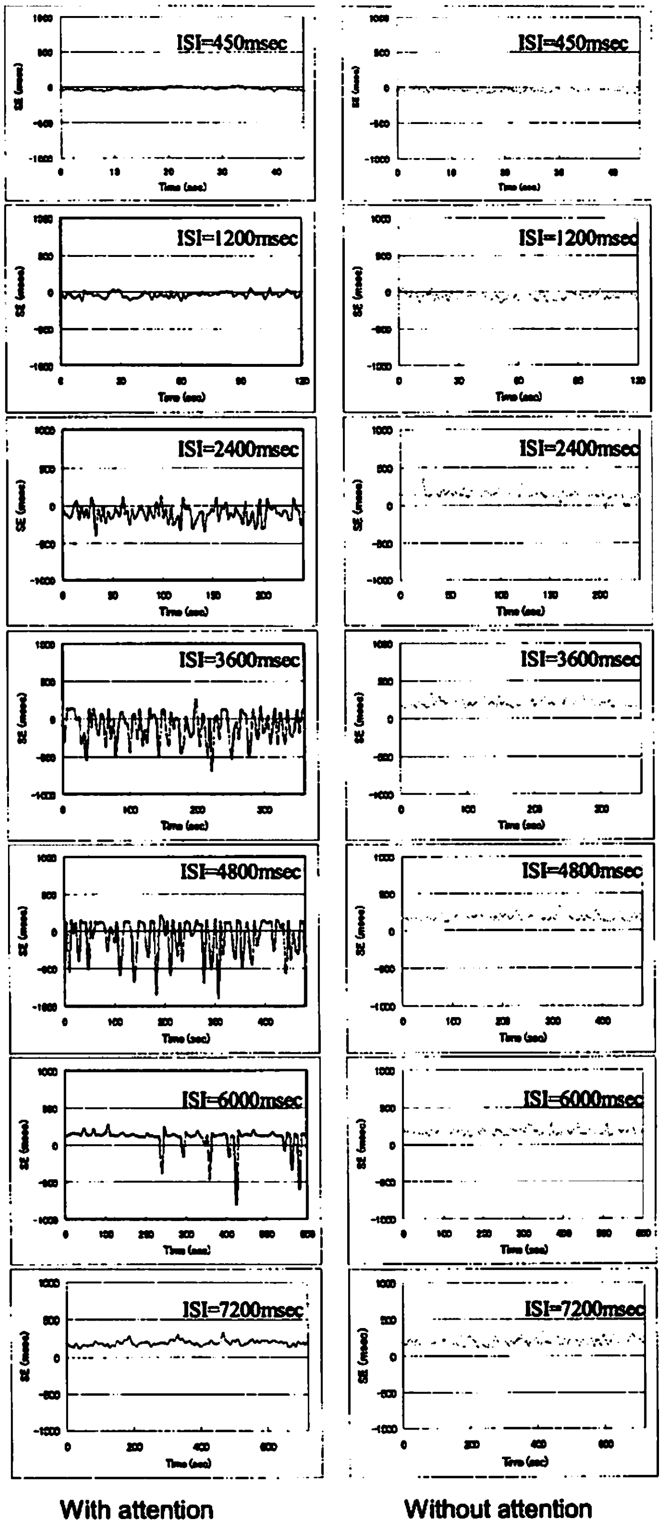


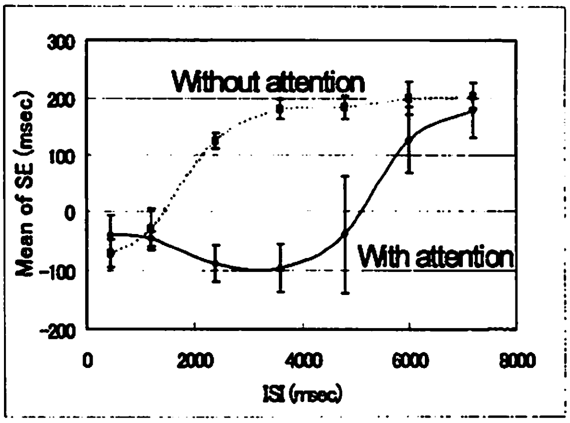
Figure 1 Temporal development of synchronization error (SE). Left and right column corresponds to tapping with attention and without attention, respectively.

As depicted in Figure 2b, large standard deviation of SEs corresponding to significant fluctuation was also observed in case of type-A anticipation. In other conditions, their standard deviations were relatively small. Furthermore, using questionnaire survey, subjective intensity of attention was measured in tapping with attention. Assigning a certain value to the answered sequence of intensity (see Methods), we clarified that the intensity of attention became significantly larger in case with ISIs between 2400 and 4800 msec as shown in Figure 3. This region of ISI is well coincided with that obtained in type-A anticipation. Therefore, it was shown that anticipatory responses emerged in sensori-motor synchronization could be categorized into two sub-dynamics. Type-A anticipation depends on attention and type-B does not.

In the next, to clarify the dynamics of these anticipatory responses, fluctuations of SEs were investigated by using return map, in which n-th state is plotted on horizontal axis and (n+1)-th state is plotted on vertical axis. This map indicates the temporal relationship between n-th and (n+1)-th states. Figure 4 shows return maps obtained under the conditions with ISIs of 1200, 4800, and 7200 msec.

In both cases with and without attention, maps of ISI 1200 msec correspond to type-B anticipatory response. Both n-th and (n+1)-th states of SE distributed around the negative steady state point. This means that stable anticipatory response and random fluctuation process are superimposed. Map of ISI 4800 msec that is observed with attention correspond to type-A anticipatory response. In this condition, cyclic process between anticipatory response with negative SE and reactive response with positive SE became dominant. Especially, one-to-many type divergence process was observed in the transition from reactive to anticipatory response, and many-to-one type convergence process was realized in the reversed transition. This fact suggests that fluctuation of type-A anticipation derives from long-range temporal interaction. Maps of the other conditions correspond to reactive response and SEs distributed around the positive steady state point.

Furthermore to clarify the mechanism of this long-range temporal interaction, we calculated the following value. We divided SEs into two categories. One is SE in anticipatory response SE(AR), and the other is SE in reactive response SE(RR). Here, the relationship between average of SE(AR) and ISI and the relationship between average of SE(AR)/ISI



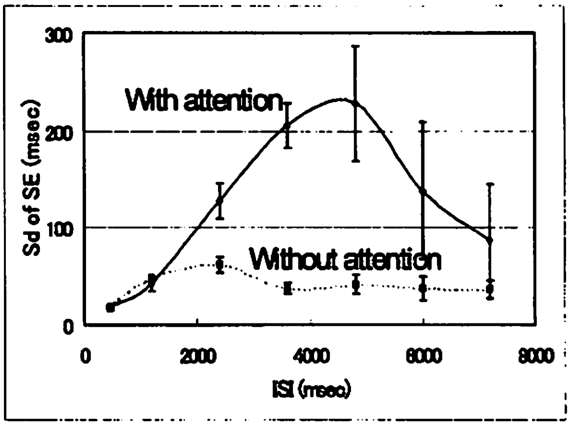


Figure 2 Statistical analysis of synchronization error (SE). Upper and lower figure corresponds to mean value and standard deviation of SE, respectively. In each graph, tapping with attention and without attention is superimposed.

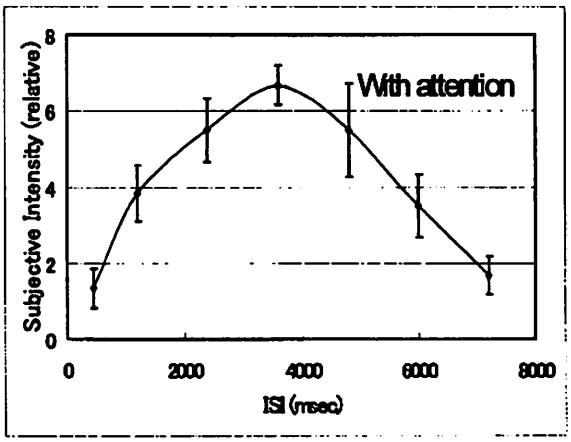


Figure 3 Subjective intensity of selective attention. The data were obtained under tapping with attention.

and ISI were shown in Figure 5a and 5b, respectively.

From Figure 5a, it is shown that SE(AR) is constant in case with ISIs between 450 and 1800 msec. This means SE in anticipatory response is independent of ISI. From Figure 5b, it is shown that SE(AR)/ISI is constant with ISIs between 2400 and 4800msec. This indicates that SE(AR) is normalized by ISI, in other words, the anticipation mechanism has long-range interaction with ISI. This anticipation is thought to correspond to Type-A anticipation. From these results, two anticipation mechanisms, Type-A and Type-B, can be characterized by the length of temporal correlation.

3. CONCLUSION

From these experimental results, we can conclude that anticipation mechanism of timing control in sensori-motor synchronization is composed of two different sub-dynamics. Type-A anticipation necessitates selective attention and it has long-range temporal interaction. Type-B does not depend on the attention and its interaction range is short. Therefore, it is suggested that the dynamics of type-A anticipation is derived from some short-term memory related process that has close relationship to the state of being conscious. However, type-B anticipatory response is supposes to be generated from body- related sub-conscious dynamics, because it needs no attention and its interaction range is very short.

In this study, we showed that anticipatory response in sensori-motor synchronization is composed of two different dynamics. One is suggested to be body related process and the other is consciousness related process. This dual- anticipation mechanism indicates that temporal integration process in 3 sec window is also realized as a dual-dynamics.

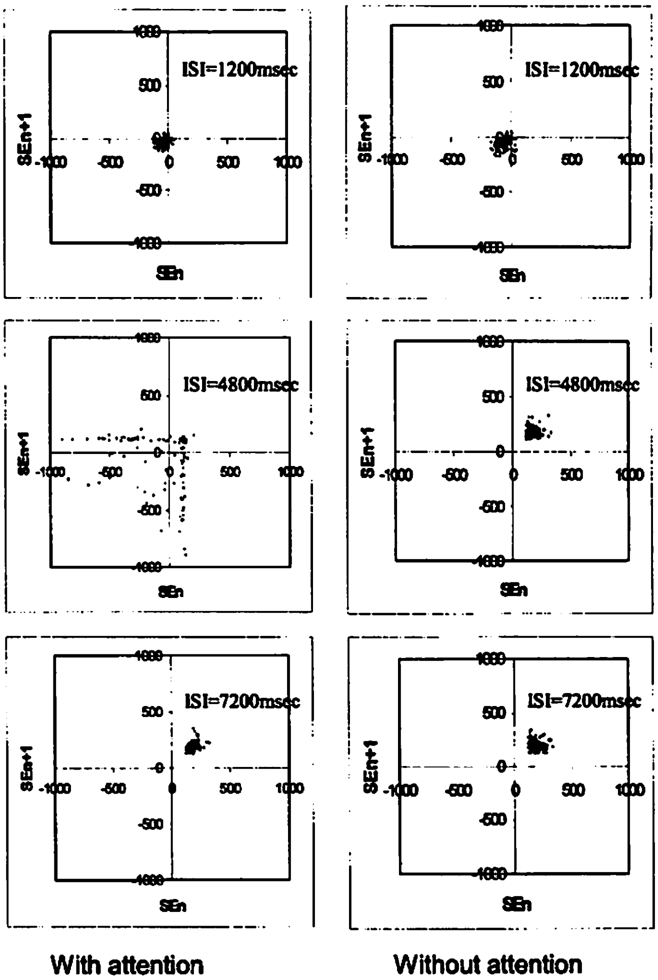
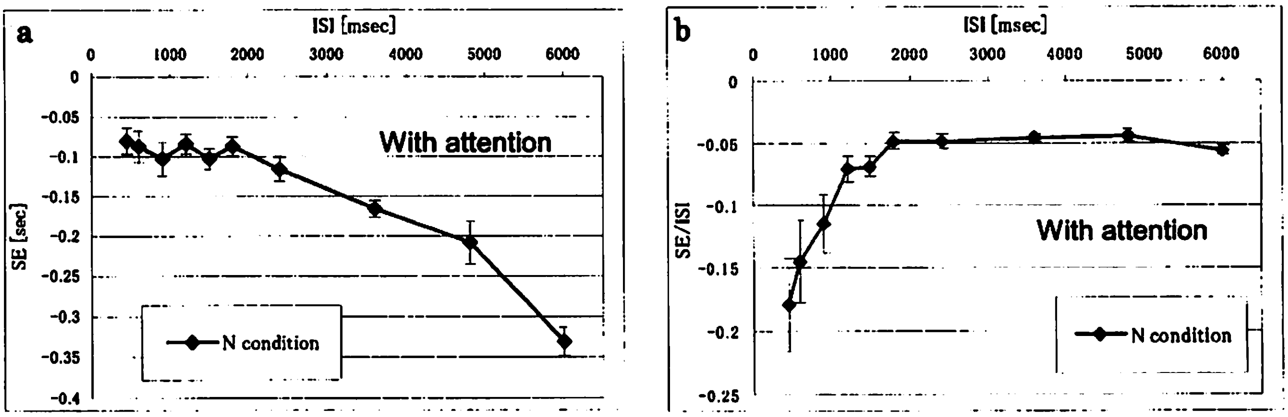


Figure 4 Return map of synchronization error (SE). Left and right column corresponds to tapping with attention and without attention, respectively.

Figure 5 **a.** Relationship between average of SE(AR) and ISI. **b.** Relationship between average of SE(AR)/ISI and ISI. Here SE(AR) means SE in anticipatory response.



4. METHODS

Subjects

Subjects were four neurologically normal, right-handed volunteers (two female and two male, ages 25-41). They all had former experience in tapping tasks, having participated previously in similar experiments. But all subjects have no background of professional music player.

Stimuli

Sequences consisting of 110 tonal stimuli were used. The interval between tone onsets (interstimulus interval, ISIs) in a sequence were constant (isochronous sequence). Seven different duration of ISI were used in different trials: 450, 1200, 2400, 3600, 4800, 6000, and 7200 msec. Tones had a frequency of 500 Hz and a duration of 100 msec in a rectangular envelope.

Control of attention

Selective attention was controlled by silently reading short composition during tapping experiment and subjects were requested to report the contents after finishing each trial. The short composition that was selected from newspaper's articles written by subject's mother language was used. Subjective intensity of attention during each trial was also measured by questionnaire survey. Subjects were instructed to estimate the sequence of intensity after finishing one set of trials. We assigned 1 to the lowest intensity and 7 to the highest intensity.

Apparatus

The auditory stimuli were controlled and subject's responses were recorded on an IBM compatible computer operated by MS-DOS. The temporal resolution was 1 msec. Tones were generated by triggering a rectangular signal of the internal sound generator of the computer. They were presented through headphones, and the loudness of tone was adjusted to a comfortable level for each subject. 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

Subjects were instructed to adjust tap onsets to stimulus onsets as precisely as possible and the reproduction of tone duration was not explicitly required. Subjects were also instructed not to make any mental counting for estimating the timing of tap onsets. They used their right hand to respond to the tones and pressed a button beneath their index finger. In experiment, short rest period were introduced between trials. The presentation order of the different ISIs was randomized and two orders of experiment were done in each subject. To avoid the influence of transient process at the beginning of the trials, the first 5 taps in a sequence was discarded from the analysis.

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