Chapter 4

Influence of Auditory Pacing on the Control of Rhythmic Movement in Physical Therapy

Masanori Ito, Yuki Takahashi, Satoshi Fujiwara and Naoki Kado

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/67428

Abstract

The electromyographic reaction time data responses to various rhythm shifts are discussed in Section 2 of this chapter. The following four experimental designs were introduced: (1) subliminal rhythm shift with shortened interval, (2) subliminal rhythm shift with lengthened interval, (3) subliminal rhythm shift with random interval, and (4) differences in the rate of rhythm shift. We found that the periodic rhythmic stimulation is predicted to comprise some time duration. Furthermore, the reactive movements can be performed without delay under conditions with an interstimulus-onset interval shift of 7% of 1500 ms. When the physical therapist facilitates rhythmical reactive periodic movement using an external event such as a handclap, it will be desirable to keep the rhythm shift within 7% of the interstimulus-onset interval. The variabilities of the intertap interval in the continuation paradigm of sensorimotor synchronization are discussed in Section 3. The participants performed self-paced, synchronization-continuation, and syncopation-continuation tapping tasks. We found that the accuracy of the periodic movement with an interstimulus-onset interval of 1000 ms can be improved by using auditory pacing. However, the consistency of periodic movement is mainly dependent on innate skill; thus, improvement in consistency from pacing alone is unlikely.

Keywords: auditory, external pacing, rhythmic movement, reaction time, sensorimotor synchronization

1. Introduction

Producing rhythmic and periodic movement is one of the important aspects of movement control. In physical therapy, external events such as auditory stimuli and visual stimuli might be used as triggers for the facilitation of periodic movement. Rhythmic coordinated movement is impaired in patients with motor diseases such as Parkinson's or those who have experienced a stroke. It is possible that an auditory pacing event could be useful as physical therapy in treating movement disorders. In a physical therapy study, during a target-hitting task using flexion and extension of the elbow, variability of electromyogram patterns of the biceps brachii decreased with pacing using a regular auditory rhythm, compared with that during the no-pacing and irregular auditory rhythm conditions [1]. In clinical studies, it has been reported that an intervention using rhythmic auditory stimulation improved gait velocity, cadence, and stride length in patients with Parkinson's disease [2] and gait velocity, stride length, and electromyographic activity of the medial gastrocnemius in patients with hemiparetic stroke [3].

When performing a rhythmic movement using periodic auditory stimuli as a trigger, the subjects can select a variety of movement patterns (such as reaction, synchronization, and syncopation). In this chapter, the electromyographic reaction time (EMG-RT) data responses to various rhythm shifts [4–7] are discussed in Section 2, and the variabilities of intertap interval (ITI) in the continuation paradigm of sensorimotor synchronization [8] are discussed in Section 3. Furthermore, each section includes an explanation of the clinical consideration in physical therapy.

2. Influence of various rhythm shifts on reactive periodic movement

The EMG-RT is defined as the interval between the stimulation signal and the onset of voluntary electromyographic activity of a response, and reflects the time of the central process. The presentation of periodic stimuli creates predictions and expectations. During the reaction-time task, the EMG-RTs are shortened in the first three stimuli when applying the periodic stimuli. On the other hand, the different intervals inserted in periodic stimuli sequences causes a delay in EMG-RT [9]. Regarding the facilitation of reactive periodic movement during physical therapy, if the physical therapists provide periodic rhythm by handclap, it will be impossible to replicate the exact time interval without deviation in the absence of a metronome. The studies described in this section show the EMG-RT data responses to various rhythm shifts. Additionally, we clarify the relationship between the degree of stimulus interval deviation and the delay of EMG-RT in the reactive periodic movement.

2.1. Apparatus for recording the EMG-RT

The same apparatus was used for EMG-RT measurements in experiments 1–4, which are discussed in this section. The telemetry EMG measuring system (MQ8; KISSEICOMTEC, Matsumoto City, Japan) was loaded onto a PC (VersaPro VY20F/AG-W; NEC). The auditory stimulus system was set up using SoundTrigger2Plus (KISSEICOMTEC). Auditory stimuli were delivered via headphones. The presented auditory stimulus and EMG signals were recorded with a data acquisition system (VitalRecorder2; KISSEICOMTEC), and recorded signals were analyzed by an EMG signal analysis program (BIMUTAS-Video; KISSEICOMTEC). The surface electrodes (LecTrode NP; ADVANCE, Tokyo, Japan) were placed over the right tibialis anterior muscle.

http://dx.doi.org/10.5772/67428

2.2. EMG-RT measurements

2.2.1. Subliminal rhythm shift with shortened interval

The purpose of experiment 1 was to investigate the influence of a subliminal rhythm shift with a shortened interval on the control of reactive movement. Fourteen healthy subjects (10 men, 4 women; mean age, 25.4 years) participated in this experiment. The subjects were right-foot dominant and kicked the balled with their right foot. Subjects had no motor function abnormalities of the right ankle and no hearing abnormalities. The experiment was conducted in a quiet room. The subjects were seated with 90° of knee flexion. All subjects performed the reaction-time tasks, raising their right ankles in response to the auditory stimuli. Their eyes were closed to exclude the influence of vision during the tasks. The following three test conditions were applied: (1) periodic auditory stimuli with an interstimulus-onset interval (ISI) of 1500 ms and a shift in the last stimulus interval only to (2) 1425 ms (the interval shortened 5% of 1500 ms), and (3) 1200 ms (the interval shortened 20% of 1500 ms), respectively, in successive stimulus sequences with an ISI of 1500 ms. Each condition was composed of 6–10 stimuli. There were 15 trials performed during each condition for a total of 45 trials. EMG-RT values for the last stimulus were compared among the three conditions. One-way repeated measures analysis of variance (ANOVA) revealed a significant difference between the EMG-RT values under different conditions (see **Figure 1**). Tukey's posthoc test showed that the EMG-RT was

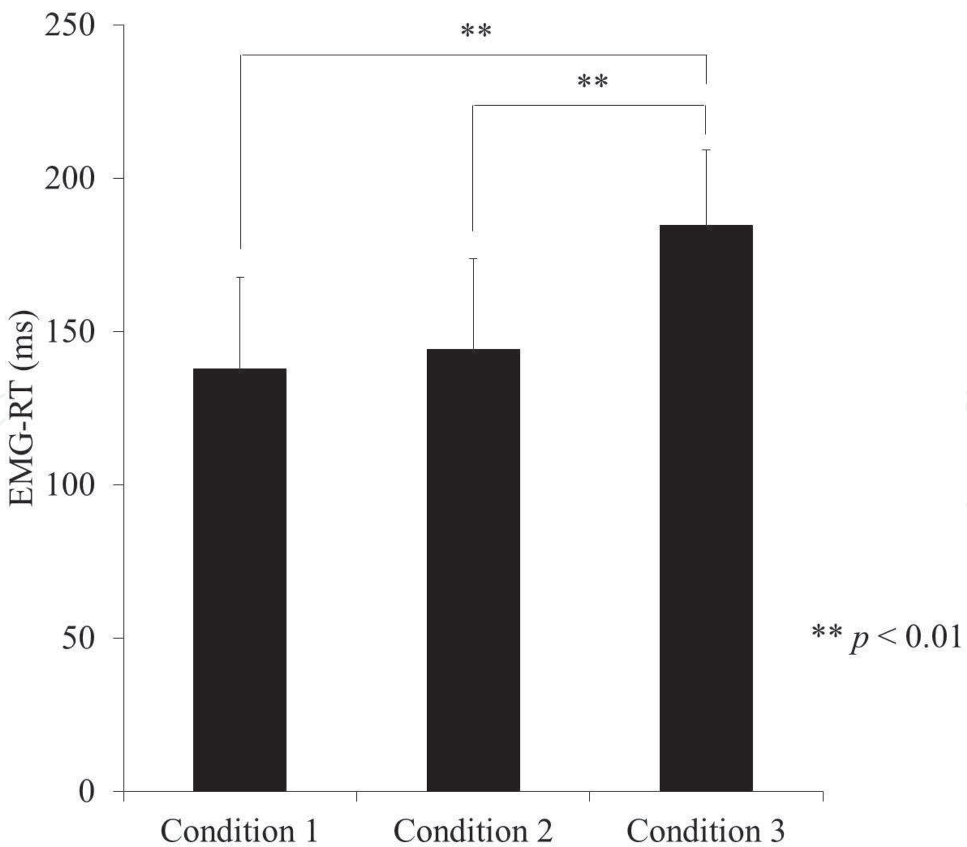

Figure 1. EMG-RT values of conditions 1–3.

significantly delayed under condition 3 (184.7 ± 24.6 ms, $p < 0.01$) compared with that under conditions 1 (138.0 ± 29.7 ms) and 2 (144.3 ± 29.4 ms). A comparison of conditions 1 and 2 revealed no significant differences.

2.2.2. Subliminal rhythm shift with lengthened interval

Experiment 2 aimed to investigate the influence of a subliminal rhythm shift with a lengthened interval on the control of reactive movement. Thirteen healthy individuals (10 men, 3 women; mean age, 27.4 years) were included in this study. All subjects were right-footed according to the Chapman's foot-preference inventory (mean score, 14.8) [10]. The subjects had no motor function abnormalities of the right ankle and no hearing abnormalities. All subjects performed the same reaction-time tasks as those in experiment 1. The following three test conditions were applied: (1) periodic auditory stimuli with an ISI of 1500 ms, and a shift in the last stimulus interval only to (2) 1575 ms (the interval lengthened 5% of 1500 ms), and (3) 1800 ms (the interval lengthened 20% of the 1500 ms), respectively, in successive stimuli sequences at an ISI of 1500 ms. Each condition was composed of 6–10 stimuli. There were 15 trials performed during each condition for a total of 45 trials. EMG-RT values for the last stimulus were compared among the three conditions. One-way repeated measures ANOVA revealed a significant difference between the EMG-RT values under different conditions (see **Figure 2**). Tukey's posthoc test showed that the EMG-RT was significantly delayed under

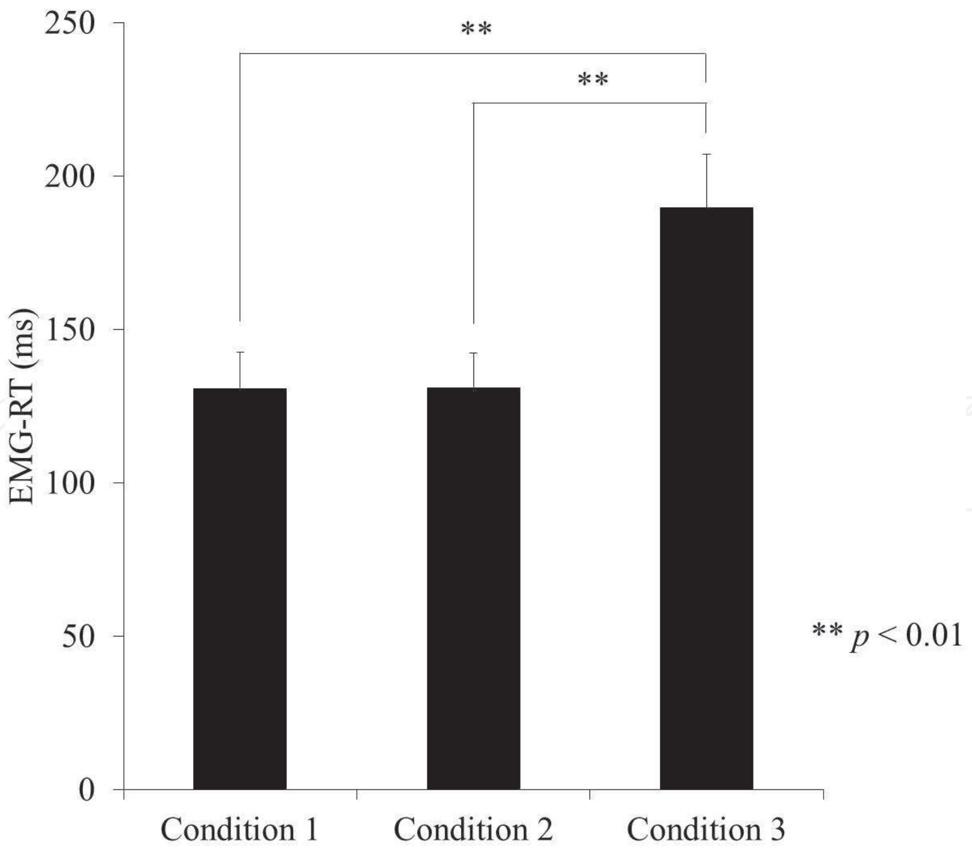

Figure 2. EMG-RT values of conditions 1–3.

condition 3 (189.8 ± 17.3 ms, $p < 0.01$) compared with that under conditions 1 (130.9 ± 11.8 ms) and 2 (131.1 ± 11.2 ms). A comparison of conditions 1 and 2 revealed no significant differences.

2.2.3. Subliminal rhythm shift with random interval

Experiment 3 included 14 healthy subjects (11 men, 3 women; mean age, 28.5 years) who performed the same reaction-time tasks as those in experiments 1 and 2. All subjects were right-footed according to the Chapman's foot-preference inventory (mean score, 14.6) [10]. EMG-RT was measured under the following three test conditions: (1) periodic auditory stimuli with an ISI of 1500 ms, (2) a random ISI shift in the range of 1463–1537 ms (range of ±5% of the 1500 ms), and (3) a random ISI shift in the range of 1350–1650 ms (range of ±20% of 1500 ms). In condition 3, the time differences between consecutive ISIs were set longer than 75 ms and 10 auditory stimuli were provided per trial. There were 10 trials performed during each condition for a total of 30 trials. EMG-RT values corresponding to the 1st–10th stimuli were compared within each condition using one-way repeated measures ANOVA. When a significant difference was recognized, paired comparisons were performed using Tukey's posthoc test. The EMG-RT values for conditions 1–3 are shown in **Table 1**. In conditions 1 and 2, EMG-RT value responses to the 2nd–10th stimuli were significantly shortened compared with the response to the 1st stimulus ($p < 0.01$), and the responses to the 3rd–10th stimuli were significantly shortened compared with the response to the 2nd stimulus ($p < 0.01$). In condition 3, EMG-RT value responses to the 2nd–10th stimuli were significantly shortened compared with the response to the 1st stimulus ($p < 0.01$), and the responses to the 3rd stimulus was significantly shortened compared with the response to the 2nd stimulus ($p < 0.01$). On the other hand, EMG-RT value responses to the 7th–10th stimuli were significantly delayed compared with the response to the 3rd stimulus ($p < 0.01$).

2.2.4. Differences in rate of rhythm shift

Experiment 4 aimed to investigate the influence of differences in the rate of rhythm shift on the control of reactive movement. Ten healthy individuals (8 men, 2 women; mean age, 25.5 years) performed the same reaction-time tasks as those in the previous EMG-RT measurements. All subjects were right-footed according to the Chapman's foot-preference inventory (mean score,

	Stimulus number									
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**
Condition 1	196.7 (19.4)	158.3 (17.5)	134.2 (15.5)	132.4 (14.2)	132.7 (13.0)	133.8 (14.6)	134.9 (13.7)	134.5 (13.2)	136.7 (15.8)	136.2 (14.0)
Condition 2	198.6 (19.6)	159.9 (21.0)	133.7 (12.9)	133.4 (13.1)	134.3 (13.5)	134.8 (13.3)	136.6 (12.8)	137.1 (13.7)	137.6 (13.6)	138.7 (11.9)
Condition 3	199.5 (15.0)	159.3 (15.3)	138.8 (15.3)	149.1 (19.0)	152.1 (14.4)	153.8 (14.5)	159.6 (12.7)	160.0 (13.0)	161.0 (10.8)	165.0 (11.5)

Note. Values are mean (SD, standard deviation).

Table 1. EMG-RT values for conditions 1–3 (unit: ms).

13.8) [10]. The following 21 test conditions were applied: periodic auditory stimuli with an ISI of 1500 ms, and only the last stimulus interval shifted to 1485, 1470, 1455, 1440, 1425, 1410, 1395, 1380, 1365, 1350, 1335, 1320, 1305, 1290, 1275, 1260, 1245, 1230, 1215, and 1200 ms (intervals shortened from 1 to 20% of 1500 ms), in successive stimuli sequences at an ISI of 1500 ms. Each condition was composed of 6–10 stimuli. There were 10 trials performed during each condition for a total of 210 trials; each subject performed the 210 trials over a period of 5 days (42 trials per day). EMG-RT values for the last stimulus were compared among the 21 conditions. EMG-RT value responses to stimuli with an ISI of 1500 ms (no rhythm shift) were 142.4 ± 8.9 ms. The EMG-RT values for 20 test conditions with rhythm shift are shown in **Table 2**. The EMG-RT values of shifts in ISI from 8 to 20% of the 1500 ms were significantly delayed compared with those during the periodic auditory stimuli with an ISI of 1500 ms with shifts in ISI from 1 to 7% of 1500 ms ($p < 0.01$). The EMG-RT values of shifts in ISI from 15 to 20% of 1500 ms were significantly delayed compared with shifts in ISI from 8 to 11% of 1500 ms ($p < 0.01$).

2.3. Practical considerations for the use of reactive periodic movement in physical therapy

Small changes below 5% of the base interval are considered to be below the threshold of conscious recognition [11]. For a base interval of 1500 ms, our three experiments revealed that the reactive movements can be performed without delay under conditions with an ISI shift below the threshold of conscious recognition. The periodic rhythmic stimulation is predicted to comprise some time duration. The prediction system for stimuli plays the same role as in the case of constant rhythm in such an ISI shift, and the readiness for movement will be maintained in the central nervous system. On the other hand, changes of 20% of the base interval are considered to be above the threshold of conscious recognition [11]. Our data showed that EMG-RTs were delayed during the 20% ISI shift. The prediction system for the stimulus loses its ability, and the central nervous system will need to provide new motor commands. Furthermore, experiment 4 revealed that the periodic rhythmic stimulation with the 1500-ms interval is predicted to comprise an approximately 100 ms duration. The reactive movements can be performed without delay with an ISI shift of 7% of 1500 ms. Finger tapping produces a series of intervals with substantial variability, even when they are intended to be regular; the typical SD is 3–6% of an ISI within a range of 200–2000 ms [12]. When the physical therapist facilitates rhythmical reactive periodic movement using a handclap, it will be desirable to keep the rhythm shift in a range within 7% of the ISI.

Rate of rhythm shift									
1%	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
141.6 (8.6)	141.9 (8.6)	143.3 (5.7)	146.9 (8.9)	145.4 (8.6)	142.9 (7.2)	147.3 (8.0)	164.2 (10.0)	166.5 (7.5)	165.0 (4.8)
11%	**12%**	**13%**	**14%**	**15%**	**16%**	**17%**	**18%**	**19%**	**20%**
164.7 (9.6)	174.0 (12.0)	175.2 (10.7)	174.8 (11.8)	181.3 (8.5)	182.7 (12.5)	186.9 (7.3)	187.0 (9.7)	186.8 (8.3)	189.3 (14.4)

Note. Values are mean (SD).

Table 2. EMG-RT values for 20 test conditions with rhythm shift (unit: ms).

http://dx.doi.org/10.5772/67428

3. External pacing on the control of periodic movement

3.1. Influence of pacing with auditory stimuli on movement continuation

The purpose of this study was to determine if the pacing of external events could be used to control rhythmic movement by comparing the variability of periodic tapping using the self-paced, synchronization-continuation, and syncopation-continuation paradigms.

Eighteen healthy subjects (8 men, 10 women; mean age, 23.9 years) participated in this study. All subjects were strongly right-handed according to the Edinburgh Handedness Inventory (mean laterality quotient, 91.2) [13]. The subjects had no motor function abnormalities of the right index finger and no hearing abnormalities. Regarding the apparatus, the MQ8, VitalRecorder2, and BIMUTAS-Video introduced in the previous section were also used in this study. The auditory stimulus system was set up using Viking Quest (Nicolet Biomedical, Wisconsin, USA).

The experiment was conducted in a quiet room. The subjects were seated with eyes closed and the right forearm was placed in a pronated position on a desk in front of them. They were required to tap with the right index finger during the following three tasks: task 1, self-paced tapping with no auditory stimuli with the subjects performing 15 successive taps for the directed interval; task 2, synchronization-continuation tapping, which incorporated the subjects tapping in synchrony with 15 periodic auditory stimuli (pacing phase), and then continuing to perform 15 taps at the same rate without the auditory stimuli (continuation phase); task 3, syncopation-continuation tapping, which involved the subjects tapping in synchrony with the midpoint of each stimulus of 15 periodic auditory stimuli (pacing phase), and then continuing to perform 15 taps at the same rate without the auditory stimuli (continuation phase). The time difference between the onset of two successive stimuli was defined as the ISI, and a total of three different ISIs were used in the pacing phase of tasks 2 and 3: 1000, 2000, and 5000 ms. These were also the directed intervals used in task 1. Each task was repeated three times and a total of nine trials were performed at random by each subject. The execution of each task in each subject was carried out over 3 days. Task 1 was performed on day 1, and then tasks 2 and 3 were performed at random. The parameters evaluating the tapping were the mean and coefficient of variation (CV) of the ITI. Synchronization error (SE) in the pacing phase of task 2 was defined as the time difference between the taps and stimulus onset. SE in the pacing phase of task 3 was defined as the time difference between the taps and midpoint of successive stimuli. In all tasks, the latter 10 ITIs in each sequence were used for analysis. The paired *t*-test was used to compare the pacing phases of tasks 2 and 3. One-way repeated measures ANOVA was used to compare task 1 and the continuation phases of tasks 2 and 3. When a significant difference was recognized, paired comparisons were performed using Tukey's posthoc test. In the pacing phases of tasks 2 and 3, the distribution of SE was also considered within these comparisons.

The mean and CV values of the ITI for the pacing phases of tasks 2 and 3 are shown in **Table 3**. There were no significant differences according to the paired *t*-test. Distributions of SEs for the pacing phases of tasks 2 and 3 are shown in **Figures 3** and **4**. A positive asynchrony for any ISI was observed in task 3 compared with that during task 2. In addition, as the duration of ISI increased, the distribution became less peaked. The mean and CV values

	Task 2	Task 3
Mean (ms)		
1000 ms	996.3 ± 3.7	997.3 ± 4.4
2000 ms	1999.2 ± 10.9	1994.1 ± 15.6
5000 ms	5003.4 ± 19.9	5004.1 ± 49.0
CV (%)		
1000 ms	3.1 ± 0.9	3.0 ± 1.3
2000 ms	3.8 ± 1.4	4.2 ± 2.5
5000 ms	4.4 ± 2.0	4.4 ± 2.4

Note. Values are mean ± SD.

Table 3. Mean and CV values in the pacing phases of tasks 2 and 3.

of the ITI for task 1 and the continuation phases of tasks 2 and 3 are shown in **Table 4**. For the ISI of 1000 ms, one-way ANOVA revealed a significant difference between the mean ITIs for different tasks. Posthoc analyses showed that the mean ITI was significantly smaller in tasks 2 and 3 when compared to that in task 1. For the ISI of 2000 ms, the CV was significantly larger for task 3 than for task 1. For the ISI of 5000 ms, the mean ITI was significantly larger for tasks 2 and 3 than for task 1, and the CV was significantly larger for tasks 2 and 3 than for task 1. There were no significant differences among other comparisons.

In the pacing phase, there was no difference in the accuracy or consistency of tapping between the synchronization and syncopation patterns. On the other hand, the distribution of SE showed different characteristics between the two paradigms. The SE distribution of the synchronization paradigm for the ISIs 1000 and 2000 ms displayed similar tendencies to a previous study in which SE almost always indicated negative asynchrony with a small spread in SE distribution for ISIs from 450 to 1500 ms, and anticipatory tapping with a large negative SE and reactive tapping were mixed in SE distribution for ISIs from 1800 to 3600 ms [14]. In both paradigms, positive asynchrony representing reactive tapping was seen. In the synchronization tapping task, anticipatory tapping and reactive tapping were identified when the standard value of SE was set at 100 ms [14]. When we adopted this criterion, the SE data for task 2 identified reactive tapping (0, 13, and 52 of 180 trials for ISIs 1000, 2000 and 5000 ms, respectively). The distribution of SE in syncopation tapping using isochronous auditory stimuli has not been reported in previous studies. Although the SE distributions of the pacing phase of synchronization and syncopation were different, there was no difference in the accuracy and consistency of tapping between these patterns. Rhythmic synchronization tasks require two timing demands: rhythm production at the same frequency as an external stimulus and motor responses that coincide in time with the stimulus. In the pacing phase of this study, the rhythmicity of periodic movement might have been mainly controlled by temporal information from the auditory stimulus rather than the error between auditory stimuli and tapping.

http://dx.doi.org/10.5772/67428

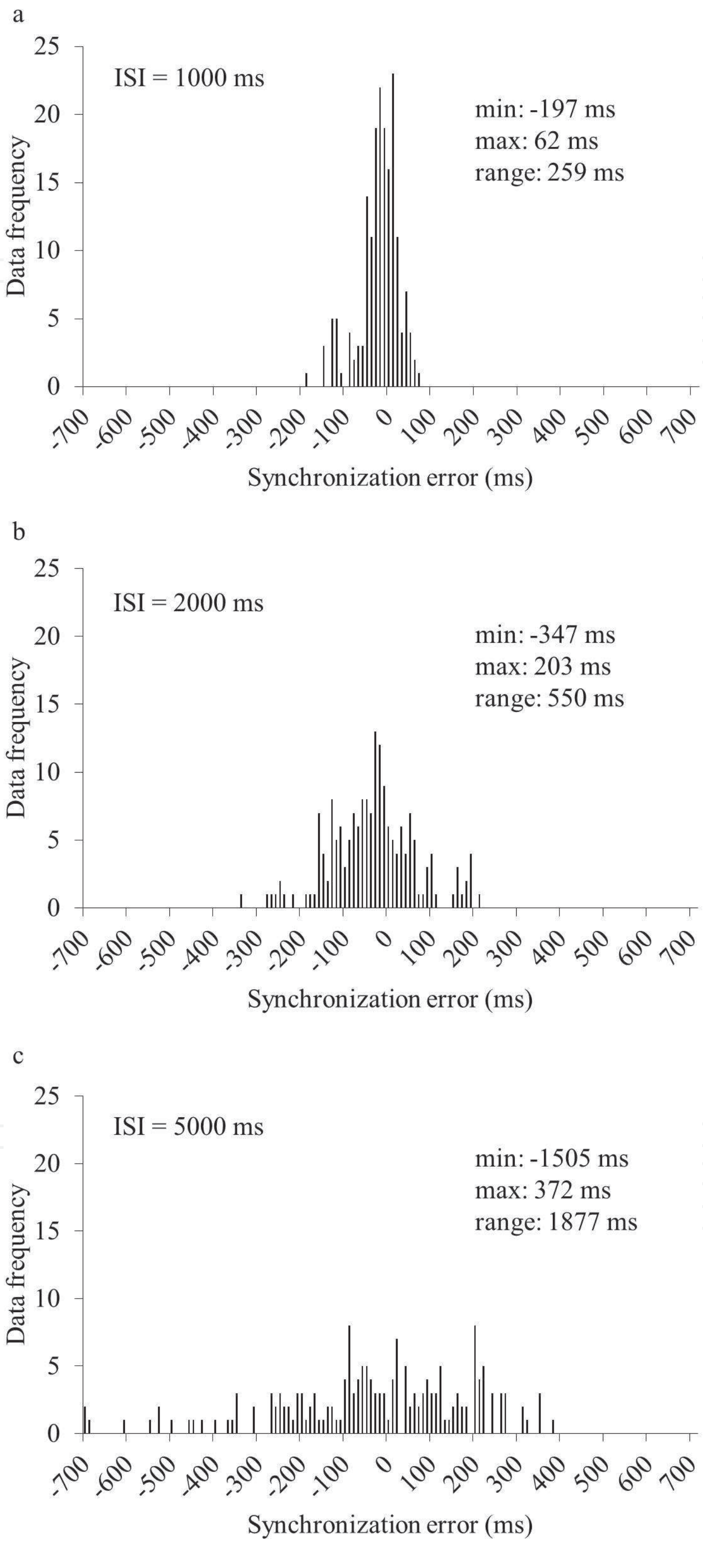

Figure 3. Distribution of SE for the ISI of (a) 1000, (b) 2000, and (c) 5000 ms in the pacing phase of task 2.

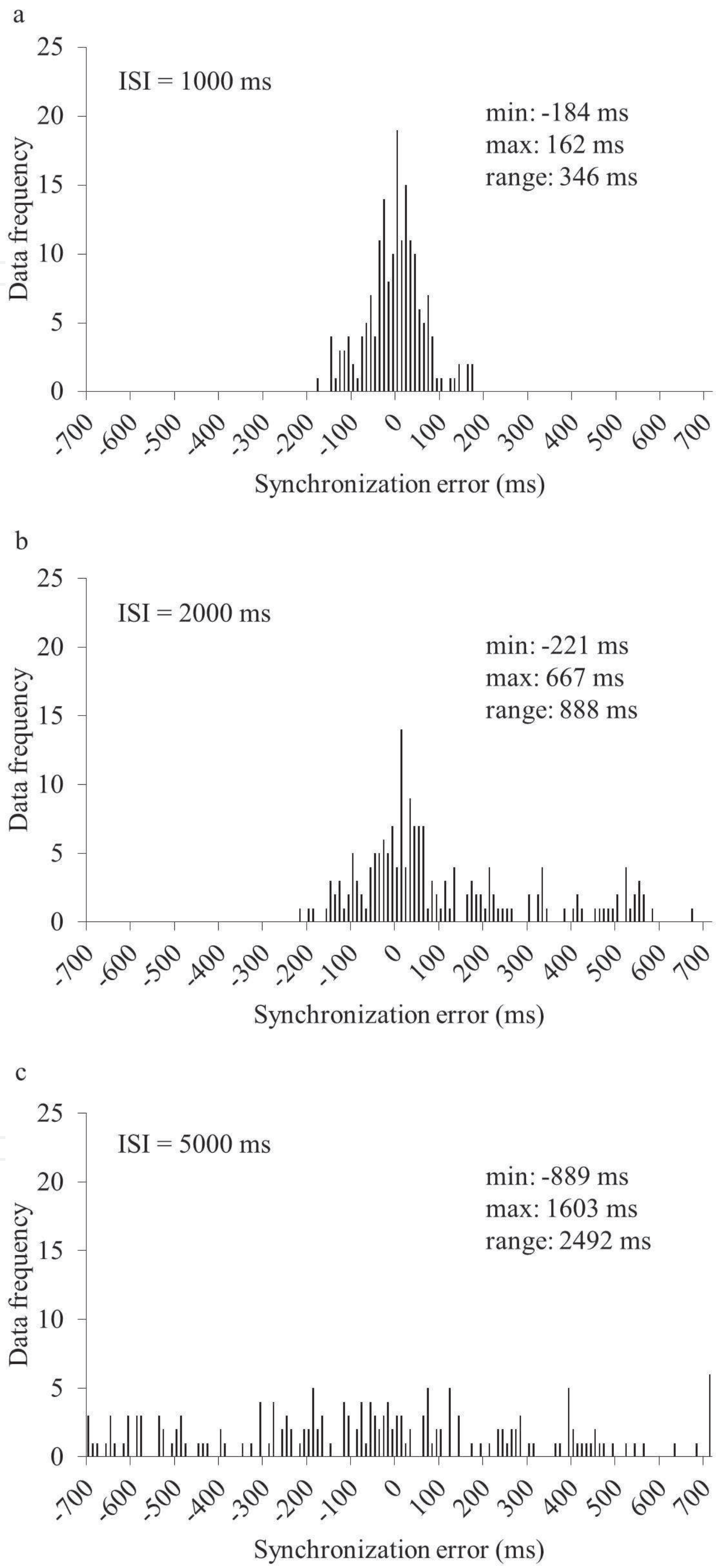

Figure 4. Distribution of SE for the ISI of (a) 1000, (b) 2000, and (c) 5000 ms in the pacing phase of task 3.

http://dx.doi.org/10.5772/67428

	Task 1	Task 2	Task 3
Mean (ms)			
1000 ms	1137.0 ± 202.9	1000.7 ± 51.7**	1022.8 ± 77.8*
2000 ms	1847.9 ± 368.8	1982.5 ± 187.2	2077.6 ± 325.5
5000 ms	4177.8 ± 1050.8	5202.6 ± 381.8**	5342.8 ± 511.4**
CV (%)			
1000 ms	4.0 ± 1.2	3.4 ± 0.9	4.0 ± 1.7
2000 ms	3.6 ± 1.1	4.1 ± 1.9	4.9 ± 1.5*
5000 ms	3.5 ± 2.0	5.4 ± 1.7*	5.9 ± 2.7**

Note: Values are mean ± SD.
*$p < 0.05$ compared with task 1.
** $p < 0.01$ compared with task 1.

Table 4. Mean and CV values in task 1 and the continuation phases of tasks 2 and 3.

For the ISI of 1000 ms, a comparison of task 1 with the continuation phase of tasks 2 and 3 showed that accuracy improved following a pacing phase, which suggests a close relationship between the length of the stimulus interval and attentional resources. A study using synchronization tapping in parallel with word-memory task demonstrated that a reduction in attentional resources caused by the execution of a secondary task did not have a significant effect on automatic anticipation in the 450–1500 ms ISI range [14]. However, in the ISI range of 1800–3600 ms, anticipatory tapping was substantially affected by tasks that decreased attentional resources. These results suggest that a timing control mechanism independent of attentional resources, the so-called "automatic movement," exists in the case of an ISI below 1800 ms, and that tapping was controlled in a feed-forward rather than feed-back manner. The results of previous studies suggest that the mechanism for anticipatory timing control is different and has an ISI threshold of 1800 ms. In addition, it was shown that prediction of the next stimulus becomes more difficult with longer ISIs. The accuracy of tapping in the continuation phase was improved by pacing at an ISI of 1000 ms. This is most likely because the interval was shorter than 1800 ms.

For the ISI of 2000 ms, a comparison of task 1 with the continuation phase of tasks 2 and 3 showed that the CV was significantly high under self-paced conditions, but only for the syncopation component. The ITI series of task 3 for an ISI of 2000 ms indicates that several subjects drift away from the 2000-ms interval during the continuation phase, although the mean ITI for the 18 subjects was 2077.6 ms. During additional analysis, the autocorrelation functions (ACF) were used for analysis of the ITI time series data. Regarding the ACF for the time series data (10 pacing phase ITIs and 10 continuation phase ITIs), the criteria for data selection of ITI drift were set as lag 1 > 0.4. Based on results of the ACF, the 18 subjects were divided evenly into two groups (the ITI drift group and ITI nondrift group). The mean ACF for the ITI series of both groups are shown in **Figure 5**. For the ITI drift group, a positive peak appears in the lag 1 autocorrelation and a negative peak appears in the lag 10 autocorrelation.

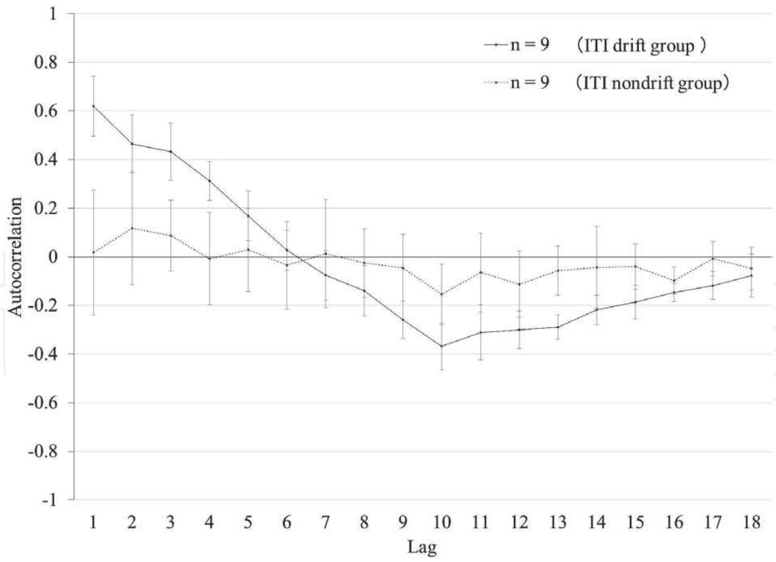

Figure 5. Mean autocorrelation functions for the ITI series in ITI drift and nondrift groups.

In a comparison of both groups, an unpaired *t*-test revealed no significant differences in the pacing (syncopation) phase. In the continuation phase, the CV of the ITI drift group (5.8 ± 1.1%) was significantly higher than that of the ITI nondrift group (3.9 ± 1.4%) (**Figure 6**).

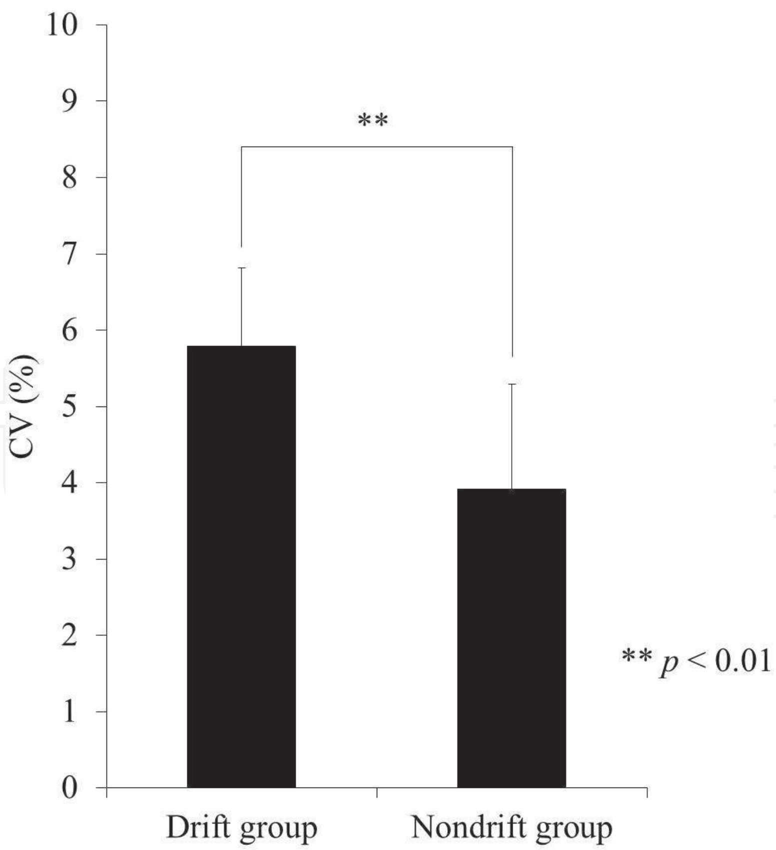

Figure 6. CV values for continuation phase of task 3 in ITI drift and nondrift groups.

http://dx.doi.org/10.5772/67428

We observed a large variation in the ITI during the continuation phase in subjects with ITI drift. The interval of 2000 ms was similar to the 1800-ms interval reported in a previous study [14], and the difficulty of the periodic movement with the 2000-ms interval was different for each individual.

A strategy used to perform syncopation tapping with a 2000-ms interval involves a stimulus and tap repeated at intervals of 1000 ms. The accurate estimation of the 1000 ms interval is required to execute this strategy. In comparing the self-paced tapping (1000 ms) in both groups, an unpaired *t*-test revealed that the CV of the ITI drift group (4.5 ± 0.9%) was significantly higher than that of the ITI nondrift group (3.3 ± 1.1%) (**Figure 7**).

Additional analysis demonstrated that the correlation coefficient was 0.42 for the mean ITI between task 1 (target duration: 1000 ms) and the continuation phase of task 3 (target duration: 2000 ms) (**Figure 8**). The area surrounded by gray in **Figure 8** shows that the ITIs for the continuation phase of task 3 are about twice the value of the ITIs for task 1.

In the continuation phase following the syncopation tapping, the subjects had to estimate the 1000 ms interval to determine the time between the lack of stimulus and their tap. However,

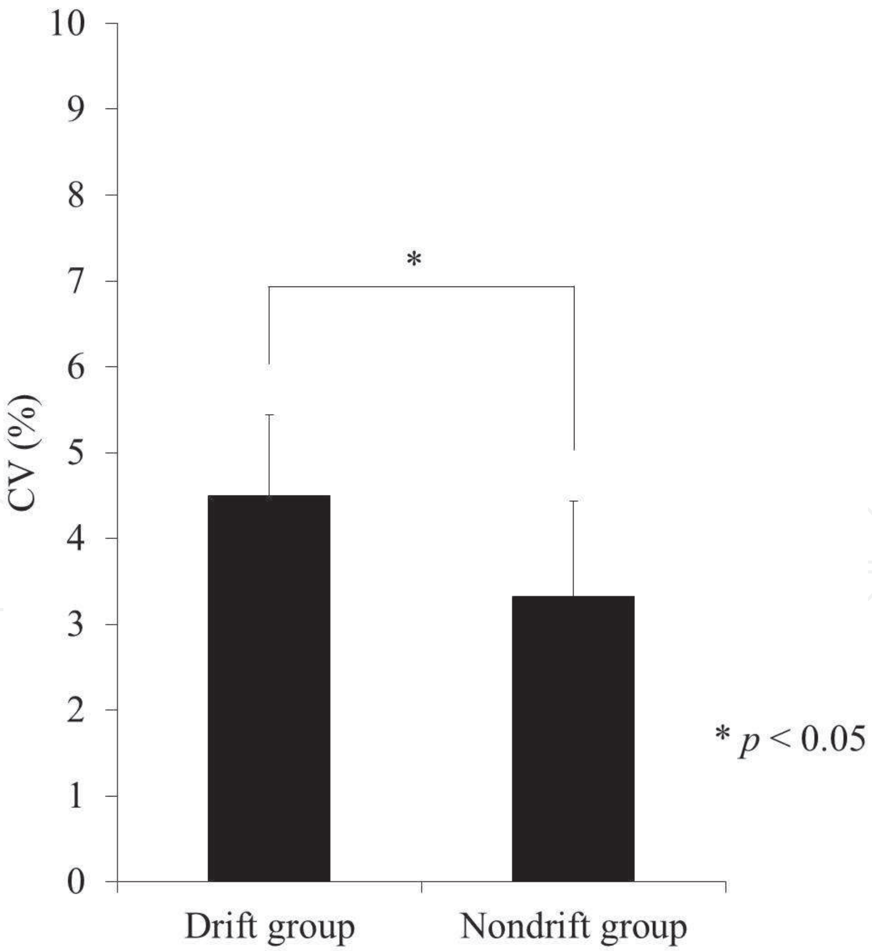

Figure 7. CV values for task 1 (1000 ms) in ITI drift and nondrift groups.

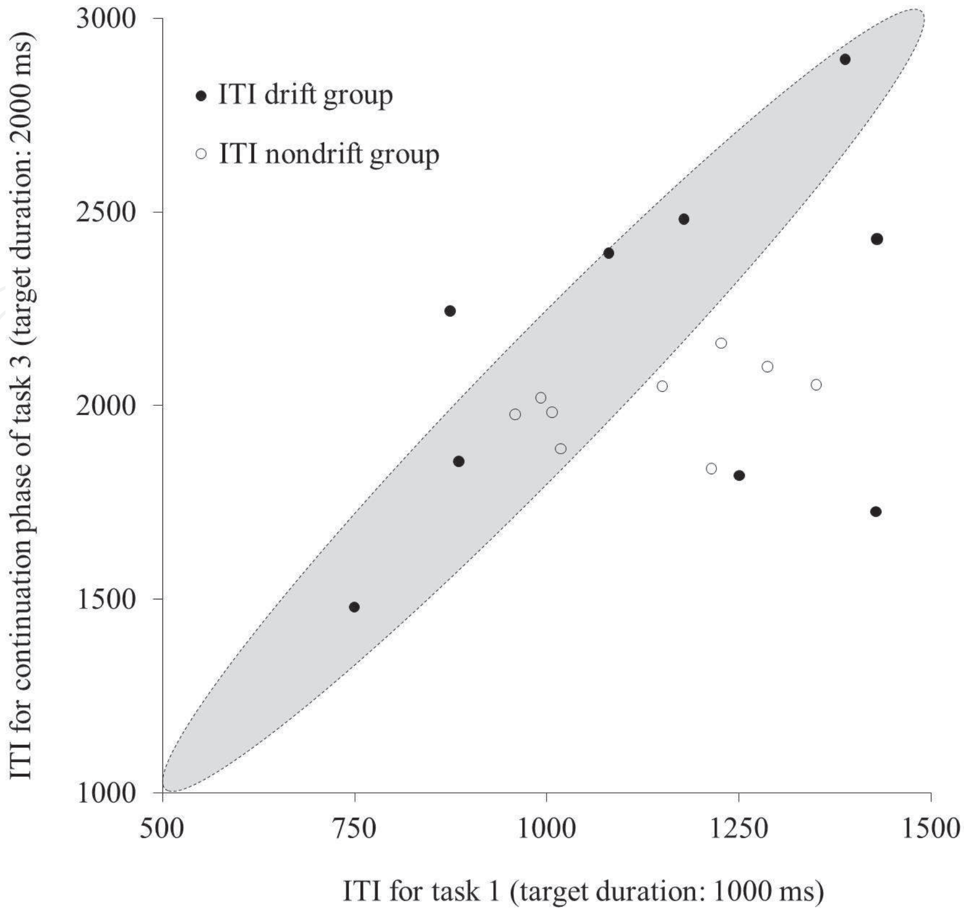

Figure 8. Correlation for the mean ITI between task 1 (target duration: 1000 ms) and the continuation phase of task 3 (target duration: 2000 ms).

since deviations from the target duration were large during the self-paced tapping for the 1000-ms interval (i.e., the ability to estimate a 1000 ms interval was poor), accurate movement in the continuation phase would be more difficult. If the syncopation tapping of the interval for 2000 ms is adopted as the pacing interval, the subjects should be able to accurately estimate the halfway point of the time interval.

For ISI > 5000 ms, estimation of temporal duration was shown to involve memory [15], which concurs with the finding in our study that reactive tapping markedly increased with an ISI of 5000 ms. Reactive tapping is one when the movement is performed after identification of a stimulus, and indicates that the prediction of the next stimulus input was difficult. Therefore, for an ISI of 5000 ms, negative asynchrony and positive asynchrony were intermingled and the SE distribution was broad. Regarding the syncopation pattern, positive asynchrony had a larger spread because participants were not able to react to the stimulus since there was no stimulus corresponding to the tap. These findings showed the 5000 ms task is performed in a nonrhythmical manner and relies on memory more than timing. True rhythm should refer only to events within the time scale of short-term memory [11]. Intervals of 5000 ms are likely too long for the facilitation of movement using pacing, as movement under both the synchronization and syncopation

http://dx.doi.org/10.5772/67428

conditions will be controlled by memory; thus, variability in the periodic movement will be large. Even though the ITI for the self-paced condition deviated considerably from the actual 5000-ms interval, the consistency of the tapping was maintained. Despite individual differences, we believe the variability represented the maximum performance for finger tapping.

3.2. Practical considerations for the use of continuation paradigm of sensorimotor synchronization in physical therapy

Investigations of clinical applications have demonstrated that pacing is effective when the ISI is shorter than 1000 ms; for example, pacing during the time when the interval of auditory stimulus was set up based on each patient's cadence. The average cadence of healthy subjects was 110 steps/min [16], which corresponds to an ISI of about 545 ms. During the sensorimotor synchronization task, the preferred tempo rates of healthy subjects were reported to be 767 ms [17]. Based on the findings of this study, it can be speculated that the pacing of periodic auditory stimuli might function in refining the precision of each individual's internal timing mechanism, particularly at an ISI of 1000 ms.

On the other hand, the consistency of tapping did not improve in a continuation phase when compared with that during self-paced tapping in any of the trials. Finger tapping produces a series of intervals whose variability is substantial, even when they are intended to be regular, and the typical standard deviation corresponds to 3–6% of the ISI within a range of 200–2000 ms [12]. The values of CV in task 1 of this study were 4.0, 3.6, and 3.5% for intervals of 1000, 2000, and 5000 ms, respectively. Although there were individual differences, this variability probably represented the innate maximum performance for finger tapping in each interval. When periodic movement was produced as they were in task 1, it indicates innate skill, which produces the consistent rhythm, even if error exists between the directed interval and ITI. Although the auditory rhythm was provided as a trigger in the pacing phase, movement in the subsequent continuation phase would be dependent on innate skill.

In conclusion, in physical therapy, the accuracy of periodic movement with an ISI of 1000 ms can be improved using auditory pacing. In addition, the consistency of periodic movement is mainly dependent on each individual's innate skill, and thus improvement in consistency based on pacing is unlikely. The limitation of this study was that the periodic movement of intervals around 1000 ms was not examined in detail. In the future, it is expected that the periodic movement of short intervals will be evaluated to examine not only the instant effect of pacing but also the training effect on longitudinal intervention.

Author details

Masanori Ito*, Yuki Takahashi, Satoshi Fujiwara and Naoki Kado

*Address all correspondence to: itou@sumire-academy.ac.jp

Department of Physical Therapy, Kobe College of Rehabilitation and Welfare, Kobe-shi, Hyogo, Japan

References

[1] Safranek MG, Koshland GF, Raymond G. Effect of auditory rhythm on muscle activity. Physical Therapy. 1982;**62**(2):161–168.

[2] McIntosh GC, Brown SH, Rice RR, Thaut MH. Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. Journal of Neurology, Neurosurgery, and Psychiatry. 1997;**62**(1):22–26. DOI: 10.1136/jnnp.62.1.22

[3] Thaut MH, McIntosh GC, Rice RR. Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation. Journal of Neurological Sciences. 1997;**151**(2):207–212. DOI: 10.1016/S0022-510X(97)00146-9

[4] Takahashi Y, Fujiwara S, Ito M, Kado N, Suzuki T. Influence of subliminal rhythm shift on reactive periodic movement. Rigakuryoho Kagaku. 2013;**28**(2):249–252. DOI: 10.1589/rika.28.249

[5] Takahashi Y, Fujiwara S, Ito M, Kado N, Suzuki T. Influence of subliminal rhythm shift with a lengthened interval on reactive periodic movement. The Journal of Japanese Physical Therapy Association. 2014;**41**(5):306–311.

[6] Takahashi Y. The influence of auditory stimulation rhythm shift prediction on electromyographic reaction time [thesis]. Osaka: Graduate School of Kansai University of Health Sciences; 2013. 193 p.

[7] Takahashi Y, Fujiwara S, Ito M, Kado N, Suzuki T. Difference in rate of rhythm shift of auditory stimulation on rhythmical reactive periodic movement. Journal of Kansai Physical Therapy. 2014;**14**:49–58. DOI: 10.11354/jkpt.14.49

[8] Ito M, Kado N, Suzuki T, Ando H. Influence of pacing by periodic auditory stimuli on movement continuation: comparison with self-regulated periodic movement. Journal of Physical Therapy Science. 2013;**25**(9):1141–1146. DOI: 10.1589/jpts.25.1141

[9] Fujiwara S, Ito M, Kado N, Suzuki T, Shimada T. Influence of varying the interstimulus interval on electromyographic reaction time during exercise using a rhythmic auditory stimulus – effect of increasing the stimulus number and changing the interstimulus interval. Journal of Kansai Physical Therapy. 2010;**10**:71–76. DOI: 10.11354/jkpt.10.71

[10] Chapman JP, Chapman LJ, Allen JJ. The measurement of foot preference. Neuropsychologia. 1987;**25**(3):579–584.

[11] Thaut MH. Rhythm, music, and the brain: scientific foundations and clinical applications. 1st ed. New York: Routledge; 2008. 247 p.

[12] Madison G. Variability in isochronous tapping: higher order dependencies as a function of intertap interval. Journal of Experimental Psychology: Human Perception and Performance. 2001;**27**(2):411–422. DOI: 10.1037//0096-1523.27.2.411

[13] Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia. 1971;**9**(1):97–113. DOI: 10.1016/0028-3932(71)90067-4

[14] Miyake Y, Onishi Y, Pöppel E. Two types of anticipation in synchronization tapping. Acta Neurobiologiae Experimentalis (Wars). 2004;**64**(3):415–426.

[15] Fraisse P. Perception and estimation of time. Annual Review of Psychology. 1984;**35**:1–36. DOI: 10.1146/annurev.ps.35.020184.000245

[16] Neumann DA. Kinesiology of the musculoskeletal system: foundations for physical rehabilitation. 1st ed. St. Louis: Mosby; 2002. 597 p.

[17] Thaut MH, Kenyon GP. Rapid motor adaptations to subliminal frequency shifts during syncopated rhythmic sensorimotor synchronization. Human Movement Science. 2003;**22**(3):321–338. DOI: 10.1016/S0167-9457(03)00048-4