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Original Article

The Effect of Finger Tapping on The Threshold of Tempo Change Detection

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Abstract: [Purpose] To clarify whether finger tapping affects tempo change detection threshold. [Participants and Methods] Study participants included 20 healthy adults (12 males and 8 females). The sound stimulus consisted of 20 sounds, beginning from 60 beats per minute, and the tempo changed from the 13th sound to ± 0, 5, 10, and 15%. The participant heard this sound stimulus with and without tapping, and responded to the tempo change with acceleration, deceleration, or no change. This study compared the difference in the correct answer rate with and without tapping, and at different tempo change rates. [Results] The correct answer rate increased with the tempo change rate, but there was no significant difference based on the presence or absence of tapping. The tempo change detection threshold calculated from the correct answer rate had an asymmetry in the direction of the tempo change; the acceleration direction was lower than the deceleration direction. [Conclusion] The tempo change detection threshold had a tempo-dependent property, but had no effect with tapping.

Keywords: time perception, finger tapping, sensorimotor synchronization

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I. INTRODUCTION

Humans can clap and dance to music rhythms. Motor synchronization to rhythmic auditory stimulation is a type of sensorimotor synchronization (SMS). The ability to predict the timing and synchronization of the next stimulus is unique to humans, except in some birds [1] and primates [2].

Physical therapists often use SMS while treating their patients. For example, they require patients to walk in response to external sound stimuli, such as the sound of clapping, or a metronome. According to this method, a patient can overcome stiffness at the start of movement and instability during walking. Previous studies on patients with Parkinson's disease and stroke have reported that these rhythmic auditory stimuli improve patient performance [3-6].

The basal ganglia play an essential role in rhythm discrimination and perception [7]. Performance improvement in patients with Parkinson's disease by rhythmic auditory stimulation suggests a close relationship between rhythm perception and the motor system. Several studies have revealed the activity of the human motor system while they listened to music or performed rhythmic tasks [8-11]. Additionally, neurological studies have reported evidence of sensory and motor area interactions with rhythmic auditory stimulation [12-14]. Furthermore, using Transcranial Magnetic Stimulation, Stupacher et al. [15] measured

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motor excitability during passive listening. Ross [16] proposed two hypotheses for interpreting motor system activity using rhythmic auditory stimulation. One is that the motor system plays an essential role in the perception of rhythm; the other is that the activity of the motor system merely shadows or mirrors the activity of the auditory system. If the former is correct, rhythm perception with physical movement is considered more accurate than that without physical movement.

In addition, the tempo change discrimination study while tapping in Repp [17] reported an asymmetry in the tempo direction that was easier to perceive in the deceleration direction than in the acceleration direction. In the Repp study, however, the reference tempo before the tempo change was only 120 beats/min (BPM). Humans can synchronize over a wide tempo range of 94−176 BPM [16], and other previous studies have confirmed the nature of synchronized tapping over a wide tempo range. In addition, when sound stimulation as an external stimulus is used for rehabilitation in physical therapy, it is necessary to confirm the properties of tapping and tempo discrimination over a wide range of tempo, because a variety of tempo is utilized, not only 120 BPM. Therefore, in this study, the tempo of 60 BPM, which is the switching point of the mechanism controlling synchronized tapping [18], will be used to confirm whether the properties are similar to those of Repp.

The purpose of this study was to determine whether the presence or absence of rhythmic tapping movements affects the tempo change discrimination threshold, and whether the tempo change discrimination threshold differs depending on the direction of tempo change.

II. PARTICIPANTS AND METHODS

1. Participants

Twenty-two young adults (14 males, 8 females; mean age = 21.7 years; SD = 0.6) participated in this study. Participants with neurological or musculoskeletal problems were excluded. All participants were right-handed. The Research Ethics Board approved this study at the International University of Health and Welfare (Approval No. 21-Ig-50). All participants provided written informed consent before experiments were conducted.

2. Methods

The auditory stimuli in this experiment were click sounds delivered by a computer. We set its core tempo to 60 beats per minute (BPM). One stimulus sound sequence consisted of 20 sounds, and in addition to the sequence whose tempo did not change at 60 BPM, we created six types whose tempo changed. The tempo change was a step-change starting from the 13th stimulus, and the shift range was ± 5, 10, and 15% of the interstimulus onset interval (ISI = 1,000 ms). Seven sound stimulation sequences were used in the experiment. The experimental equipment consisted of a laptop computer (Panasonic CF-SV), psychology experiment software (Cedrus SuperLab5), reaction pad (Cedrus RB-740), and headphones (Audio-Technica ATH-AVC200). The laptop computer and psychology experiment software controlled the start and end of the sound stimulation sequence and recorded the data from the reaction pad at a sampling frequency of 1,000 Hz. We carried out the experiment in a quiet, private room without clocks or other devices that maintained a specific tempo. The participant took a seat in front of a laptop computer and reaction pad placed on the desk, and put on headphones. The experimenter instructed the participant to operate the reaction pad with the right index finger during the experiment.

The participant listened to the sound stimulus sequence under the following two conditions and performed a task to judge whether the tempo had changed:

1) Tap: Perform the task while tapping the third button from the right of the reaction pad in synchronization with the sound stimulus.
2) No tap: Place both hands on your lap and perform the task without moving your body.

After listening to the sound stimulus sequence, the participant responded by pressing the “acceleration,” “no change,” and “deceleration” buttons assigned to the response pad to answer according to the tempo change. The task execution order of the 14 conditions (two tapping conditions × seven sound stimulus sequences) was randomized (Fig.1).

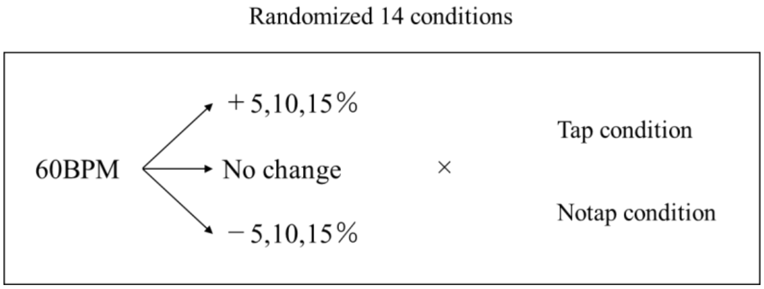

Fig. 1. Experimental conditions.

After completing all tasks, we determined the correctness of each participant's tempo change judgment for each experimental condition. Based on this data, we calculated the correct answer rate for the tempo change judgment for each experimental condition. Finally, we performed a two-way ANOVA (2 × 7) based on the inverse sine method for the correct answer rate for tempo-change judgment. The factors were the condition (Tap vs. No tap) and tempo changes (0%, ± 5, 10, and 15%). Additionally, a post hoc analysis was conducted using Ryan's method. The average detection threshold was also used to compare the difference between acceleration and deceleration thresholds. For the average detection threshold, a linear function was calculated from two points that fell before and after 50% of the correct response rate of the four change rates (no change, ± 5%, ± 10%, and ± 15%). The tempo change rate at which the correct response rate reaches 50% was determined according to the linear function calculated and was used as the average detection threshold. The method of obtaining the average detection threshold was in accordance with Repp's study [17].

Statistical analyses were performed using the statistical computing environment in R (version 4.1.2). The significance level was set at $p < 0.05$.

III. RESULTS

Table 1 shows the percentage of correct answers for each Tap and No tap condition for the 20 participants. Under many conditions, the correct answer rate was 90% or higher. However, the correct answer rate was 86% under the No tap conditions of 60 BPM and 60 BPM-10%. Furthermore, at 60 BPM-5%, the correct answer rate was 50% or less, regardless of the condition (Tap = 46%, No tap = 18%).

Table 1. Percentage of correct responses by 22 participants in each experimental condition.

Tap condition	Tempo change condition						
	Deceleration			NC	Acceleration		
	-15%	-10%	-5%	0%	+5%	+10%	+15%
Tap	98.9	90.9	45.5	86.4	68.2	98.9	98.9
No tap	95.5	86.4	18.2	86.4	77.3	95.5	98.9

(%)

NC: no tempo change
The percentage notation of the tempo change condition (-15% to + 15%) indicates an increase or decrease in the change from the core tempo (60 BPM).

A two-way ANOVA based on the inverse sine method revealed a significant main effect of the tempo change factor ($\chi^2(6) = 101.1$, $p < 0.05$). However, we did not find any significant differences in condition and interaction effects. The post hoc analysis showed that the percentage of correct answers for the 60 BPM-5% tempo was lower than all other tempo changes, and the 60 BPM+5% was lower than all percent change except 60BPM-5% ($p < 0.05$). 60 BPM and 60 BPM-10% was lower than 60 BPM+10% and ±15% ($p < 0.05$).

Figure 2 presents the average percentages of the detection responses (acceleration, deceleration, or no change) as a function of the tempo change magnitude. For the Tap condition, the average detection threshold (the 50% cross-over points of the correct response function) was 965 ms (3.5% change in ISI) for acceleration and 1,055 ms (5.5% change in ISI) for deceleration. In contrast, for the No tap condition, the average threshold was 971 ms (2.9% change in ISI) for acceleration and 1,073 ms (7.3% change in ISI) for deceleration. Under both conditions, the average detection threshold was smaller for acceleration than for deceleration.

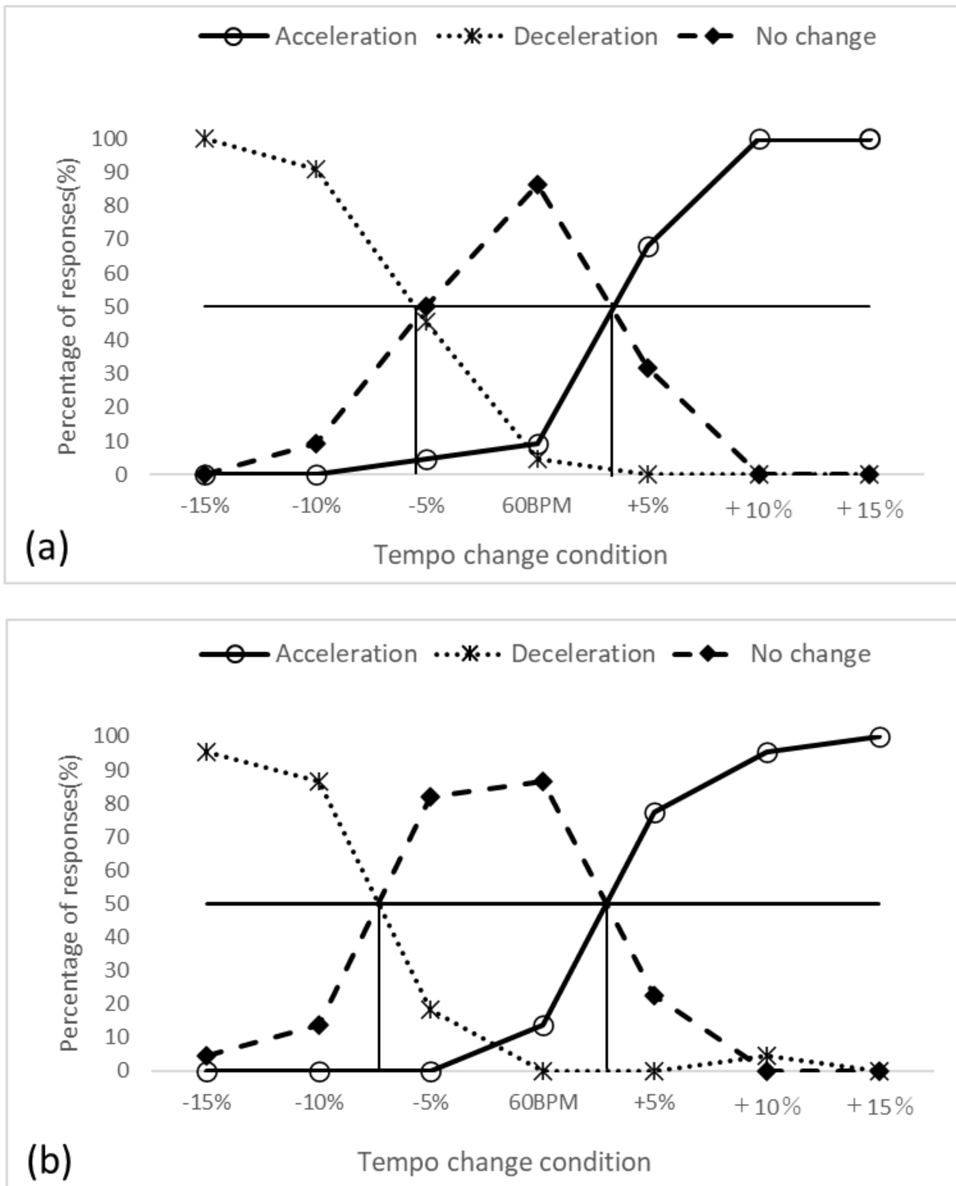

Fig. 2. Average percentages of detection responses as a function of tempo change magnitude. (a) Tap condition (b) No-tap condition.

IV. DISCUSSION

Regarding the relationship between physical movement and rhythm perception, previous studies have shown that apparent body movements affect the perceptual interpretation of ambiguous rhythms [19, 20]. However, our study found no significant difference in the correct answer rate of tempo change with or without the tapping motion. This result supports Ross's hypothesis [16] that the motor system' activity when listening to continuous sound stimuli is shadowing or mirroring as a result of rhythm perception. In contrast, Manning et al. [21] experimented with 150 BPM (ISI = 400 ms) and 100 BPM (ISI = 600 ms) as the core tempo and made the participants discriminate the tempo change (± 0, 15, 30%). They found that the perception of tempo-change discrimination was significantly better with tapping than without tapping. Differences in experimental design, especially the core tempo, may have caused the difference between their study and this study. Fraisse [22] emphasized that tapping synchronization was stable in the ISI range of 400–800 ms, with 600 ms being the most stable. Coull et al. [18] argued that synchronous tapping was controlled by timing control in the cerebellum when the ISI was less than 1,000 ms, and by the prefrontal cortex when it was 1,000 ms or more. Therefore, the core tempo of this study, 60 BPM (ISI = 1,000 ms), was the point at which the neural system switched, which might have reduced the motor system's contribution to the prediction of synchronous tapping.

In this study, the correct answer rate for tempo changes of 60 BPM ± 5% was lower than other rates of change, and it was more challenging to detect a -5% tempo change than a +5% change. The average detection threshold with a correct answer rate of 50% was higher for tempo reduction, and asymmetry appeared depending on the direction of tempo change. Repp's study [17] also showed asymmetry depending on the direction of the tempo change, but the average detection threshold was higher with increasing tempo, and the symmetry direction was opposite to that of ours. The difference in direction-derived asymmetry between the previous study and this study suggests that the threshold for tempo-change detection has a tempo-dependent property. The core tempo in Repp's experiment was 120 BPM, which was faster than the most stable 100 BPM for tapping. Conversely, our experiment's core tempo (60 BPM) was much slower than that of 100 BPM. If the asymmetry of the tempo-change detection threshold depends on the core tempo's position, the tempo change in the direction far from 100 BPM may be more difficult to discriminate. Hence, a broad tempo range experiment must be performed using the same design to prove this hypothesis.

In this study, the participants listened to eight stimulus sounds after the tempo step change and responded to the tempo change. However, this approach cannot determine when the participant perceives the tempo change with or without tapping. Therefore, to determine a slight difference in the threshold value, it is necessary to have a design that can capture the time point recognized by the participant.

In future, extensively collected data may provide new knowledge about the role of the motor system in SMS and may help develop assessments and treatments using SMS.

A part of this study was reported in 130th annual meeting of the Society of Physical Therapy Science (https://doi.org/10.1589/rika.38.S1_1).

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There are no conflicts of interest to disclose in this study.

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