TEMPORAL CONTROL MECHANISM FOR TAPPING OF RHYTHMIC PATTERNS CONSTRUCTED BY TWO KINDS OF TIME VALUES

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ABSTRACT

In previous studies, it was shown that temporal control for equal interval tapping is governed by a memory mechanism, which preserves the information of the preceding 20 taps to determine the interval of the present tap. In the present study, subjects tapped rhythmic patterns constructed by long (L) and short (S) time values. The results of the analysis of the temporal fluctuation in the tapping showed that the 20-tap memory mechanism also governs the tapping of these rhythmic patterns. The interval unit the memory mechanism is active for is determined by the length of L and S.

1. INTRODUCTION

Musical rhythms consist of various kinds of time values. However, these rhythms are based on the sequence of equal time intervals. Various kinds of rhythms are obtained by subdivision of some parts of the sequence, and more complex rhythms can be obtained by combining some parts of the subdivided ones. In fact, the musicologists Cooper and Mayer analyzed musical works based on the concept of the equal-interval sequence with accents [1], and Fraisse reviewed psychological experiments concerned with rhythmic perception and behavior, based on the concept of the equal interval sequence [2].

Musha *etal.* suggested a new paradigm to estimate the perceptual process for the basic rhythms. They requested subjects to tap at a sequence of equal time intervals and analyzed the fluctuation of the observed inter-onset intervals (IOIs) using Fourier analysis [3]. Using this tapping method, Yamada estimated the temporal control mechanism in equal-interval tapping [4]. Yamada showed that the temporal control was excellent for periods less than 10 s, but for periods over 20 taps the controllability decreased as the period increased. Moreover, the analysis of the fluctuation, using auto-regressive (AR) models and Akaike's Information Criteria (AIC) [5], also showed the following control mechanism: The interval of the present tap is determined by the weighted sum of the preceding 20 intervals. These results suggested that the memory mechanism, which preserves information of intervals of 20 taps, governs equal-interval tapping. This was true for widespread tempi ranging from 180 to 800 ms/tap. Yamada and Tsumura also investigated the temporal controllability in equal-interval tapping as a function of musical training, using skilled and novice pianists [6]. The results showed that there were no significant differences between the two groups when they tapped with a single-finger, while the controllability of novice pianists significantly decreased when they tapped with multiple-fingers. This showed that single-finger equal-interval tapping is governed by the 20-interval memory mechanism, which is unaffected by musical training. Years of piano lessons only improve the ability to coordinate multiple finger motions.

In the present study, it is examined whether and how the 20-interval memory, which governs equal-interval tapping, also governs the tapping of rhythmic patterns, which are constructed by two kinds of time values.

2. EXPERIMENT 1

2.1. Method

A two-beat rhythmic pattern of /LSS/ was constructed, where the ratio of L to S was fixed at 2:1. Ten students from the Department of Musicology at the Osaka University of Arts participated in the experiment as subjects. The subjects tapped the rhythmic pattern with the right middle finger at tempi of L/S=300/150, 400/200, 700/350 and 1000/500 ms. The subjects were instructed to make an effort to maintain both constant intervals and intensity. In one trial of tapping, the subjects repetitively tapped the rhythmic pattern for a period of 720 intervals of L's value. To demonstrate the designated rhythm and tempo, the synthesized rhythmic pattern, which was constructed by a 73-dB, 4000-Hz tone with 6 ms triangular envelope, was presented for 20 s before each trial. One session consisted of five trials at the same tempo. These five trials for the same tempo were performed successively in one session, but each subject performed the four sessions (tempi) in a random order. A 3-min rest interval separated each trial and a 20-min rest interval separated each session.

2.2. Critical Period in the Power Spectrum of the Fluctuation

In the rhythmic pattern, two consecutive Ss can be regarded as the two halved intervals of L. The two consecutive intervals that corresponded to Ss were combined and the resulting interval was treated the same as for L. We define this process as the summation process for subdivided intervals (SPSI). The IOI fluctuation that corresponded to L was obtained by SPSI. Then, the initial 100 intervals of L were removed and the following 600 intervals were divided into three parts, and the waveform for each segment was decomposed into Fourier components by DFT with Hanning window. The power spectra of the temporal fluctuation in the tapping were averaged out for each tempo by subject.

The solid lines in Fig. 1 show examples of the averaged power spectra. The spectra showed that the power decreased as the frequency increased in the low frequency region, whereas the power was constant or increased slightly as the frequency increased in the high frequency region. Fro example, in the spectrum for the tempo of L/S=300/150 ms, the critical frequency, which indicates the boundary between the high and low frequency regions, is observed around ten cycles. The power of the frequency component indicates the difficulty of temporal control for the frequency, and the correlation between the frequency, f [cycles] and period, p [intervals] is $p=200/f$. Therefore this spectral features imply that temporal control is excellent for short periods of less than approximately 20 intervals of L, but for periods over 20 intervals, the controllability decreases as the period increases. In the present study, the critical frequency was determined by the following method: The spectrum was divided into the high and low frequency regions at an arbitrary frequency. Then the regression line was estimated for each of the two regions, using the weighted least-squares method. In this method, because more points were included in the higher frequency areas than in the lower frequency areas in the same bandwidth on the logarithmic scale, the squared residual of a frequency component was weighted by the reciprocal value of the frequency. Using this method, the pair of lines that showed the minimum value in residual sum of the weighted squares was defined as the regression lines for the given dividing frequency. Then, the best regression lines for the spectrum were defined as the regression lines that minimized the residual sum of the weighted squares for all dividing frequencies. The critical frequency was defined as the point where the best regression lines intersected.

Using the weighted least-squares method described above, the critical frequency *f* [cycles] was determined for each tempo by subject. Then, the critical period *p* [intervals] was calculated using the correlation $p=200/f$. Table 1 contains the resulting critical periods. As can be seen, for the rapid tempi of L/S=300/150 and 400/200 ms, the critical period is distributed around 20 intervals of L. However, for the slow tempo of L/S=1000/500 ms, the critical period is distributed around 10 intervals of L. Table 1 also shows that, in the case of the intermediate tempo of L/S=700/350 ms, the critical period is distributed around 10 intervals for five subjects (YA, SK, MO, AU and NN), while the period is distributed around 20 intervals for the other five subjects.

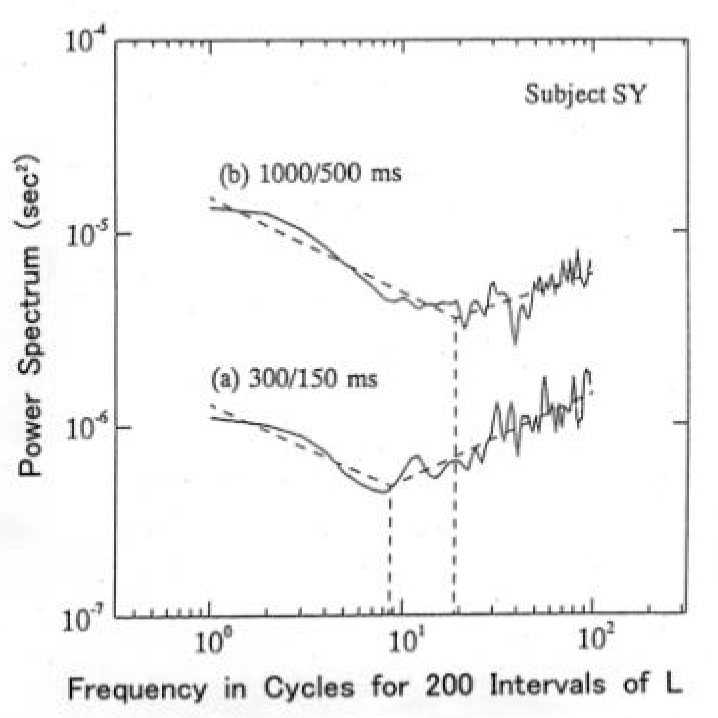

FIG. 1 Examples of the power spectra for the /LSS/ rhythm. The frequency is shown in cycles for 200 intervals of L

2.3. Order of the Best Auto-Regressive Model

Yamada applied AR models and AIC to the IOI fluctuation in equal-interval tapping to determine the critical phenomenon observed in the spectrum. AR models show that the present data is determined by the weighted sum of several previous data samples along with some noise (1).

$$x(i) = \sum_{k=1}^{N} a_k x(i-k) + \varepsilon_i \qquad (1)$$

Generally, the data samples fit the AR model better as the AR order, N, increases, *i.e.*, the residual of the

TABLE 1 The critical period in the power spectrum for the rhythmic pattern of /LSS/ is shown in number of intervals that correspond to the long time value, L.

Tempo	Subject										
L/S (ms)	YA	SK	MO	AU	NN	SY	HM	MY	MN	EK	Mean
300/150	19.0	21.1	23.4	21.3	16.2	23.3	19.7	18.2	13.8	20.8	19.7
400/200	25.3	20.6	23.5	17.4	24.1	21.0	24.6	17.7	26.2	21.9	22.2
700/350	7.9	10.7	10.5	8.3	6.8	20.7	20.5	16.3	19.6	17.8	13.9
1000/500	11.2	7.3	7.3	11.4	13.9	10.6	3.6	9.2	7.6	11.4	9.4

estimation decreases. The model that minimizes the AIC value has a small value in N and also a small value for the residual of the estimation [5]. Yamada defined the best AR model as the model that minimized the AIC value, and showed that the order of the best AR model was distributed around 20 [4]. In the present study, the same method was applied to the IOI fluctuation and the order of the best AR model was obtained for each tempo by subject.

Table 2 shows the order of the best AR model, which is applied to the IOI fluctuation of L for each tempo by subject. The results are consistent with Table 1: For the rapid tempi of L/S=300/150 and 400/200 ms, the order is distributed around 20, whereas the order is distributed around 10 for the slow tempo of L/S=1000/500 ms. For the tempo of L/S=700/350 ms, the order for five of the subjects is distributed around 20 and the order for the other five is distributed around 10.

The results in Table 1 and 2 show that the 20-interval memory, which governs equal-interval tapping, is also used to control the non-equal-interval tapping, and that in the case of a rapid tempo, the 20-interval memory mechanism is active for L, whereas the mechanism is active for S in the case of a slow tempo. The results of the present experiment show that the point at which the memory mechanism switches between L and S is located at a tempo of approximately L/S=700/350 ms. However, it is not clear whether the cue for the switch in the time values for which the 20-interval memory mechanism applies, is the length of L, S or a combination of both. The following experiments investigate this point.

TABLE 2 The order of the best AR model for the rhythmic pattern of /LS S/. The model was applied for the temporal fluctuation which corresponded to the long tome value, L.

Tempo	Subject										
L/S (ms)	YA	SK	MO	AU	NN	SY	HM	MY	MN	EK	Mean
300/150	18	28	20	15	23	22	19	18	24	17	20.4
400/200	22	18	25	21	14	20	20	15	15	21	19.1
700/350	8	8	12	12	10	20	20	15	16	21	14.2
1000/500	10	12	8	12	14	12	12	10	8	11	10.9

3. EXPERIMENT 2

3.1. Method

In the present experiment, two rhythmic patterns were constructed. Rhythmic Pattern A was constructed by /LS/, where L/S=540/270 ms, and Rhythmic Pattern B was /LS/, where L/S=810/270 ms. Five students majoring in music participated the experiment as subjects. The subjects tapped the two rhythmic patterns with the right middle finger. In one trial of tapping, the subjects repetitively tapped the rhythmic pattern for a period of 720 intervals of L+S. The subjects tapped five trials for each rhythmic pattern. The other experimental conditions were identical to Experiment 1. For the present experiment, consecutive intervals of L and S are combined and the IOI fluctuation of L+S was obtained. Then, the IOI fluctuation was analyzed using Fourier analysis.

3.2. Results and Discussion

The power spectrum of the fluctuation was obtained for each rhythmic pattern by each subject, and then the critical period for each spectrum was estimated using the weighted least-mean-square method. Table 3 contains the resulting critical periods. Table 3 shows that, on the average, the critical period is approximately 20 intervals of L+S for Rhythmic Pattern A and 10 intervals for Rhythmic Pattern B. This implies that the 20-interval memory mechanism is applied for the interval of L+S in the case of Rhythmic Pattern A, whereas it is applied for (L+S)/2 for Rhythmic Pattern B. These results suggest that whether the length of L is longer or shorter than 700 ms acts as a cue for how the 20-interval memory mechanism applies to the temporal control of rhythmic tapping.

TABLE 3 The critical periods in the power spectra for Rhythmic Pattern A and B are shown in number of intervals that correspond to (L+S). Rhythmic Pattern A is constructed by /LS/ where L/S = 540/270 ms, and Rhythmic Pattern B is /LS/ where L/S = 810/270 ms.

	Subject					
Rhythmic Pattern	RG	NN	SY	KM	SK	Mean
A (L/S = 540/270 ms)	17.3	19.1	18.7	19.9	16.3	18.3
B (L/S = 810/270 ms)	9.3	10.4	10.9	7.4	9.0	9.8

4. EXPERIMENT 3

4.1. Method

Two rhythmic patterns C and D were constructed. Rhythmic Pattern C was constructed by /LS/, where L/S=780/390 ms, and Rhythmic Pattern D was /LS/, where L/S=780/260 ms. Five students majoring in music participated as subjects. The subjects tapped the two rhythmic patterns with the right middle finger. In one trial of tapping, the subjects repetitively tapped the rhythmic pattern for a period of 720 intervals of L+S. The subjects tapped five trials for each rhythmic pattern. The obtained intervals were analyzed in the same way as in Experiment 2.

4.2. Results and Discussion

Table 4 contains the resulting critical periods for L+S. Table 3 shows that, on the average, the critical period is approximately 7 intervals of L+S for Rhythmic Pattern C and 10 intervals for Pattern D. For Rhythmic Pattern C where L:S=2:1, the critical period of 7 implies that the 20-interval memory mechanism is applied for (L+S)/3, *i.e.*, for S. On the other hand, for Rhythmic Pattern D where L:S=3:1, the critical period of 10 implies that the memory mechanism is applied for (L+S)/2. These results suggest that whether the length of S is longer or shorter than 350 ms also acts as a cue for how the 20-interval memory mechanism applies to rhythmic tapping.

TABLE 4 The critical periods in the power spectra for Rhythmic Pattern C and D are shown in number of intervals that correspond to (L+S). Rhythmic Pattern C is constructed by /LS/ where L/S = 780/390 ms, and Rhythmic Pattern D is /LS/ where L/S = 780/260 ms.

	Subject					
Rhythmic Pattern	RG	NN	SY	KM	SK	Mean
C (L/S = 780/390 ms)	10.9	7.1	6.6	8.1	6.0	7.7
D (L/S = 380/260 ms)	14.6	10.6	9.2	12.6	10.7	11.5

5. CONCLUSIONS

The results from Experiment 1 show that the 20-interval memory mechanism, which governs equal-interval tapping, is also used in temporal control of non-equal-interval rhythmic tapping. Moreover, the results from Experiment 2 and 3 suggest that both the lengths of L and S act as cues for how the 20-interval memory mechanism is applied for the control of rhythmic tapping.

From the results of the three experiments, we can estimate the temporal control mechanism of tapping with rhythmic patterns, which are constructed of two kinds of time values, L and S, as follows:

1) If L is longer than 700 ms the interval of L is subdivided and an equal-interval unit shorter than L is constructed in the perceptual process, while it is not subdivided if L is shorter than 700 ms.
2) If S is shorter than 350 ms the interval of S is incorporated into an equal-interval unit longer than S, while this longer interval unit is not constructed if S is longer than 350 ms.
3) The 20-interval memory mechanism is applied for the equal-interval unit that satisfies the two conditions described above.

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