Finger tapping strategy for pitch encoding of melodies¹

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This study was designed to investigate whether finger tapping (analogous to the piano playing) is an effective strategy for pitch encoding in the processing of melodies. Twelve female undergraduates highly trained in music were instructed to make recognition judgments of melodies following a retention interval (Inter Stimulus Interval). They were also instructed to memorize the melodies during the ISI by employing a tapping strategy. There was a blank interval in Experiment 1 and an interfering melody in Experiment 2. The findings from these experiments suggest that: (a) Tapping may be an effective strategy for pitch encoding of melodies, especially when there are interfering melodies. (b) During a longer ISI, if the subjects made an effort to repeat the tapping in order not to forget the standard series, then repeating the tapping many times could help the subjects elaborate on the encoding of melodies. Computer records of the tapping of each finger support these findings.

Key words: encoding strategy, tapping, pitch, melody, contour.

In my previous paper (Mikumo, 1992), the following theme was discussed: when we memorize a melody, what strategies do we use to encode pitch information? By analyzing the data from a preliminary questionnaire, the following results were obtained: subjects use (a) a verbal encoding strategy, in which each pitch in a melody was labeled with the name of musical note (e.g., Do, Re, Mi), then the code was rehearsed and stored in memo-

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³ These stimuli were chosen by 20 university students using the scale of “Tonality-feeling” described in Hoshino (1985), and Hoshino and Abe (1981, 1984).
parison melodies were made up of a 6-tone series, which had either a high-tonality structure (tonal melody) or a low-tonality structure (atonal melody). There were two experimental conditions: a session in which the subjects were instructed not to employ the tapping strategy and a session in which they were instructed to employ the tapping strategy during the retention interval in order to memorize the pitches of the melodies. If the recognition performance was significantly higher with tapping than without, it would suggest that tapping is an effective strategy for pitch encoding melodies.

For each group, the recognition probability data (hit rate minus false alarm rate) [Woodworth & Schlosberg, 1954] were analyzed in a two-way analysis of variance [2(Session) x 2(Melody Type)], with repeated measures on both factors. In H Group, there was a significant main effect of Melody Type \( F(1,6)=39.70, p<.001 \), and a significant interaction between Session x Melody Type \( F(1,6)=9.35, p<.05 \). In L Group, there was a main effect of Melody Type \( F(1,6)=6.66, p<.05 \), and a marginal main effect of Session \( F(1,6)=2.97, p=.09 \).

The results of this preliminary experiment showed that, for the highly trained subjects, employing the tapping strategy would be effective for pitch encoding of tonal melodies, but would disturb pitch encoding of atonal melodies. For the less well trained subjects, it would also disturb pitch encoding either type of melody (Figure 1). Thus, to encode pitch information, employing the tapping strategy might be too difficult for the less well trained subjects or for encoding atonal melodies.

Therefore, the present experiment employed highly trained in music students as subjects and melodies that had a high-tonality structure. To investigate the tapping strategy in more detail, the number of tones in a melody and the duration of the retention interval between the standard and the comparison series were varied. Moreover, during the retention interval, there was a blank interval in Experiment 1, and an interfering melody in Experiment 2.

Experiment 1

Method

Subjects. Twelve female subjects (average age: 21.3 years; age range: 19-22 years), who were undergraduate music majors, took part in this experiment. Each had had at least 15 years of formal piano studies, the average being 17.5 years (range: 15-19 years) and all were right-hand dominant.

Materials. Each trial involved a standard series followed by a blank retention interval and then by a comparison series. Both the standard and the comparison series consisted of six, eight, or ten different tones taken from an equal-tempered scale, which ranged from H3 (246.94 Hz) to E5 (659.26 Hz). The duration of each tone was 700 ms, so that the length of the 6-tone series was 4200 ms, that of the 8-tone series was 5600 ms, and that of the 10-tone series was 7000 ms. All of the series were tonal melodies in a major key, were high in tonal melodic structure, according to conventional Western rules, and involved all types of contours.

![Figure 1](image-url)  
Figure 1. Recognition probability of H Group and L Group for tonal and atonal melodies in Sessions 1 and 2 of the preliminary experiment (Session 1: not employing tapping / Session 2: employing tapping).
For this and the following experiments, six lists were prepared, each involving 36 trials, with a total of 144 trials. In each list, there were 12 trials for each melody length.

Three types of inter-stimulus interval (ISI) between the standard and the comparison series were prepared, depending on the melody length. The short ISI, middle ISI, and long ISI were, respectively, one and a half, two, and two and a half times as long as the melody length. Thus, in the 6-tone series, the short ISI was 6,300 ms, the middle ISI was 8,400 ms, and the long ISI was 10,500 ms. In the 8-tone series, the short ISI was 8,400 ms, the middle ISI was 11,200 ms, and the long ISI was 14,000 ms. In the 10-tone series, the short ISI was 10,500 ms, the middle ISI was 14,000 ms, and the long ISI was 17,500 ms.

Half of the trials in the comparison series and the standard series were identical, the other half being divided into two different types. Contour-preserving transformation (C) was obtained by changing one of the pitches by two semitones (higher or lower), preserving the contour of the standard, so that the exact pitch interval was not preserved. Exchanging transformation (E) was obtained by exchanging the order of two successive pitches of the standard, so that although the contour was a little different from that of the standard, the pitches were preserved. Both in Contour-preserving transformation and in Exchanging transformation, neither the first nor the last tone of the standard series was changed in pitch, and the position of the tone that was changed was counterbalanced between stimuli.

Procedure. The subjects were instructed as follows: This is an experiment on memory for melodies. In each of the trials, you will first see a trial number, then hear the first melody (standard series) which will be followed by a retention interval (ISI). Then you will hear the second melody (comparison series). The next trial will begin fifteen seconds after the second melody. The ISI is changed in each trial. The first and second melodies consist of six, eight, or ten tones. Your task will be to judge whether the two melodies are the same or different in pitch, and to indicate your judgment by answering "same" or "different", and also indicate the confidence of your decision on a 5-point scale with responses of "yes" or "no", with "very sure," "fairly sure," "unsure," "fairly unsure," or "very unsure".

In the first session, the subjects were instructed to try to memorize the melodies without employing the tapping strategy, but rather by using some other internal strategy. After the session, they were told to report their introspections about the type of encoding strategies they used. In the second session, they were instructed to employ the tapping strategy, which is analogous to playing the piano. The second session took place thirty minutes after the first. Three practice trials for each melody length were given, together with feedback, prior to each session.

If the session in which tapping is allowed is performed before the session in which tapping is not allowed, it would be difficult to eliminate the effect of motor learning in the latter session, because the motor sense of tapping tends to linger. This is why the two sessions were presented in fixed order to all the subjects.

As described above, for this and the following experiments, six lists were prepared. These lists were counterbalanced between the subjects for each session in each experiment (Experiments 1 and 2), so that the two sessions would be equally difficult (Table 1).

The tapping movements of each finger of the right hand were recorded using a computer. The tip of each finger was fitted with a small piece of aluminum foil connected to the computer through leads. When a finger was tapped on an metal sheet, the number of times and the rate (reaction time) were
Table I
Six lists for each Session in Experiments 1, 2, and 3

<table>
<thead>
<tr>
<th>Session</th>
<th>Experiment 1</th>
<th>Experiment 2 (Experiment 3)&lt;sup&gt;*&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Subjects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1, 2</td>
<td>List1</td>
<td>List2</td>
</tr>
<tr>
<td>3, 4</td>
<td>List2</td>
<td>List3</td>
</tr>
<tr>
<td>5, 6</td>
<td>List3</td>
<td>List4</td>
</tr>
<tr>
<td>7, 8</td>
<td>List4</td>
<td>List5</td>
</tr>
<tr>
<td>9, 10</td>
<td>List5</td>
<td>List6</td>
</tr>
<tr>
<td>11, 12</td>
<td>List6</td>
<td>List1</td>
</tr>
</tbody>
</table>

<sup>*</sup> Experiment 1: Blank interval condition.
Experiment 2: Interfering melody condition.
Experiment 3 is being planned. A series of musical note names will be interpolated during the retention interval between the standard and the comparison series.

Session 1: Not employing tapping.
Session 2: Employing tapping.

Recorded. Tones were generated using an NEC PC-9801 26k sound synthesizer board installed in an NEC PC-9801 RX computer, recorded on tape, then played over high-fidelity sound production equipment (Victor XDZ 1100 DAT). All tones were adjusted to be equal in loudness (50 dB SPL), and were presented via a loudspeaker.

Experiment 2

Method

Subjects. The subjects were those who took part in Experiment 1.

Materials. Each trial involved a standard series followed by an interfering melody and then by a comparison series. The interfering melody consisted of three to nineteen tones taken from an equal-tempered scale, which ranged from H₁ (246.94 Hz) to E₅ (659.26 Hz), and the duration of each tone was 700 ms.

The number of tones in the interfering melody depended on the duration of the ISI, which depended on the length of the standard series. The intervals between the standard series and the first interfering tone, and between the last interfering tone and the comparison series, were each 2100 ms. For the 6-tone series, therefore, there were 3 tones during the short ISI (6300 ms), 6 tones during the middle ISI (8400 ms), and 9 tones during the long ISI (10500 ms). For the 8-tone series, there were 6 tones during the short ISI (8400 ms), 10 tones during middle ISI (11200 ms), and 14 tones during the long ISI (14000 ms). For the 10-tone series, there were 9 tones during the short ISI (10500 ms), 14 tones during the middle ISI (14000 ms), and 19 tones during the long ISI (17500 ms). Four interfering melodies were prepared for each case described above, so that a total of 36 interfering melodies were prepared, all of them being tonal melodies in a major key.

Procedure. This experiment was performed two months after Experiment 1. The subjects were instructed that, in each of the trials, they would first see a trial number, then hear the first melody, which would be followed by an interfering melody of different length during the retention interval, and then by a second melody. Thirty-six interfering melodies were employed in Session 1 and Session 2.

In the first session, the subjects were instructed that they should not employ the tapping strategy, but rather use some other internal strategy, and in the second session, they were instructed to employ the tapping strategy. The other variables were the same as those in Experiment 1.

The reason why the blank interval condition (Experiment 1) preceded the interference condition (Experiment 2) was that in the former condition, the subject's individual strategy would remain free of the influence of the interfering melody. As shown in Table 1, to minimize the effect of practice, these experiments were designed so that each subject should experience four different lists for four
sessions (i.e., 2 sessions each in Experiments 1 and 2).

Results and Discussion

These experiments were designed to test four factors: two types of Sessions (Session 1: not employing tapping / Session 2: employing tapping), three melody lengths (6 tones / 8 tones / 10 tones), three ISI durations (short / middle / long), and two types of comparison series (Contour-preserving / Exchanging). Each subject was exposed to all four factors.

In these experiments the following response measures were calculated: the recognition probability for each melody length (Analysis 1), and for each ISI duration (Analysis 2); the discriminability index \(d'(\prime)\) (Analyses 1 & 2); the false-alarm rate for each comparison type (Analysis 3); and the number of times and the rate of tapping, and the latency between the end of standard series and starting the more elaborate finger tapping (Analysis 4).

Analysis 1

Analysis of the effect of the melody lengths. First, the recognition probability data (hit rate minus false alarm rate) were analyzed in a three-way analysis of variance [2(Experiment) × 2(Session) × 3(Melody Length)], with repeated measures on all three factors. There were significant main effects of Experiment, Session, and Melody Length (\(F(1,11)= 12.57, p<.005\); \(F(1,11) = 45.90, p<.001\); \(F(2,22) = 80.51, p<.001\)). There was also a marginal interaction between Experiment × Session (\(F(1,11) = 3.30, p<.10\)) (Figure 2).

The main effect of Experiment indicates that the performance in Experiment 1 was superior to that in Experiment 2. The main effect of Session indicates that in both experiments, the subjects performed better when they employed the tapping strategy than when they did not. The main effect of Melody Length indicates that the subjects performed gradually worse as Melody Length increased. The marginal interaction of Experiment × Session indicates that when several tones were interpolated during the ISI in Experiment 2, and the subjects were not employing the tapping strategy in Session 1, then their performance was significantly worse than it was in Session 1 of Experiment 1 \((p<.01)\) (Figure 2). This was especially so in the case of the 8-tone and the 10-tone series. However, had they been employing the tapping strategy in Experiment 2, their performance would not be worse than that in Session 2 of Experiment 1.

The subjects reported on their internal encoding strategies in Experiment 1 as follows: verbal encoding by naming the notes (6 subjects); pitch rehearsal or humming (2 subjects); and visualization strategies, in which the pitches were visualized, as a contour (1 subject), in notation (2 subjects), or position on a keyboard (1 subject).

Therefore, these findings may be interpreted as indicating that, for the subjects who were highly trained in music, employing the external motor encoding strategy of tapping...
Table 2

| Melody Length | Experiment 1 | Experiment 2
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6-tone</td>
<td>6.7 (test)</td>
<td>6.1 2.4 (.001) 6.5</td>
</tr>
<tr>
<td>8-tone</td>
<td>2.5 (.001)</td>
<td>4.2 1.3 (.01) 2.5</td>
</tr>
<tr>
<td>10-tone</td>
<td>1.7 (.001)</td>
<td>3.4 1.3 (.01) 2.4</td>
</tr>
</tbody>
</table>

- Experiment 1: Blank interval condition.
- Experiment 2: Interfering melody condition.
- Session 1: Not employing tapping.
- Session 2: Employing tapping.

Data in ( ) indicate the p-values calculated using a Z-test as suggested by Gourevitch and Galanter (1967). This example means that there is a significant difference (p<.01) in the d' data between two sessions in Experiment 2.

is more effective than using internal encoding strategies to encode and retain the pitches of the melodies, especially when there are interfering melodies. In both experiments, the effect of tapping increased somewhat as the melody length increased.

Second, the discriminability indexes (d') were calculated for three melody lengths for the two sessions in the two experiments (Table 2). This was done by using a 5-point confidence scale, in which the “Same” and “Different” judgments each had five levels of response. Accordingly, the data are divided into 10 categories. The differences in the d' data between the sessions were tested using a Z-test as suggested by Gourevitch and Galanter (1967). The results are also shown in Table 2. These results support the findings of the recognition probability data described above.

Analysis 2

Analysis of the effect of the ISI. First, the recognition probability data were analyzed in a three-way analysis of variance [2(Experiment) x 2(Session) x 3(ISI)], with repeated measures on all three factors. As shown in Analysis 1, there were also significant main effects of Experiment and Session (F(1,11)=11.60, p<.01; F(1,11)=50.85, p<.001), and a marginal interaction between Experiment x Session (F(1,11)=3.28, p<.10). Moreover, there was a tendency toward interaction between Session x ISI (F(2,22)=2.08, p=0.14), which indicates that the recognition probability in Session 1 gradually worsened as the ISI increased, whereas in Session 2, it gradually improved as the ISI increased. As shown in Figure 3, this tendency was especially prevalent in the 10-tone series, from a two-way analysis of variance [2(Session) x 3(ISI)] for each melody length in both experiments (10-tone series: Experiment 1, F(2,22)=3.36, p<.06; Experiment 2, F(2,22)=3.12, p<.07). In both experiments, there were significant differences between the long and short ISIs in Session 2 of p<.05, whereas in Session 1, there were no significant differences between the short and long ISIs (by Newman-Keuls Method).

These findings may be interpreted as indicating that, by using internal encoding strategies, the memory of the standard series became gradually obscure as the duration of the ISI increased. However, by employing the external motor encoding strategy, the
Table 3

d' for each ISI duration for each melody length of the two sessions in Experiments 1 and 2

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-tone</td>
<td>8-tone</td>
</tr>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S (ML x 1.5)</td>
<td>4.9</td>
<td>3.5</td>
</tr>
<tr>
<td>M (ML x 2.0)</td>
<td>3.1</td>
<td>1.8</td>
</tr>
<tr>
<td>L (ML x 2.5)</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Experiment 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6-tone</td>
<td>8-tone</td>
</tr>
<tr>
<td>S (ML x 1.5)</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>M (ML x 2.0)</td>
<td>4.3</td>
<td>1.6</td>
</tr>
<tr>
<td>L (ML x 2.5)</td>
<td>0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

- Experiment 1: Blank interval condition.
- Experiment 2: Interfering melody condition.
- Session 1: Not employing tapping.
- Session 2: Employing tapping.
- S (ML × 2.0) indicates that the middle ISI is twice as long as the melody length.
- Blank cells indicate that the discriminability in the Same-Different decision is so strong that d’ can not be calculated.
- Data in ( ) indicate the p-values calculated using a Z-test. This example means that there is a significant difference (p<.01) in the d’ data between the long ISI and middle ISI for 10-tone series in Session 2 of Experiment 1.

Memory became gradually elaborated as the duration of the ISI increased.

Second, in both experiments, the discriminability indexes (d’) were calculated for the three ISI durations for each melody length of the two sessions (Table 3). The differences in the d’ data between the three durations of the ISI for the 10-tone series were tested using a Z-test. The results are also shown in Table 3. These results support the findings that the recognition probability depends on the ISI duration.

The findings in Analyses 1 and 2 were interpreted as indicating that when the interfering melody filled the retention interval, or as the melody length increased, or the duration of the ISI increased, the subjects would make an effort to repeat the tapping in order not to forget the standard series, and that repeating the tapping many times could elaborate on encoding for the pitches of melodies.

In addition, in these experiments, four sessions (i.e., 2 sessions each in Experiments 1 and 2) were presented in fixed order, but the practice effects was negligible. The results were found to be as follows. (a) The total probability in Experiment 1 was rather greater than that in Experiment 2. (b) There was no difference between the probability of Session 2 in Experiment 2 and Session 2 in Experiment 1; moreover, the probability of Session 1 in Experiment 2 was significantly lower than that of Session 1 in Experiment 1. (c) Comparing the probability of Session 2 with Session 1, it is true that it was superior in both experiments, but the performance gradually improved as the melody length
increased, or the ISI duration increased. These findings suggest that the tapping effect was stronger than the effect of practice.

Analysis 3

Analysis of the false-alarm rate by Comparison Type. First, the false-alarm data were analyzed in a three-way analysis of variance, $[2(\text{Experiment}) \times 2(\text{Session}) \times 2(\text{Comparison Type})]$, with repeated measures on all three factors. There were significant main effects of Experiment, Session and Comparison Type ($F(1,11)=67.53, p<.001; F(1,11)=60.95, p<.001; F(1,11)=41.46, p<.001$). There were significant interactions between Experiment $\times$ Session, and Experiment $\times$ Comparison Type ($F(1,11)=35.14, p<.001; F(1,11)=5.77, p<.05$).

The main effect of Experiment indicates that the false-alarm rate in Experiment 2 was higher than that in Experiment 1. The main effect of Session indicates that the false-alarm rate in Session 1 was higher than that in Session 2. The interaction between Experiment $\times$ Session indicates that, in Session 1, the false-alarm rate in Experiment 2 was significantly higher than that in Experiment 1 ($p<.01$), whereas in Session 2, there was no significant difference between Experiment 2 and Experiment 1. Therefore, the main effects of Experiment and Session, and the interaction between Experiment $\times$ Session support the results of Analyses 1 and 2.

The main effect of Comparison Type indicates that the false-alarm rate for Contour-preserving was higher than that for Exchanging. The interaction between Experiment $\times$ Comparison Type indicates that, in Contour-preserving, the false-alarm rate of Experiment 2 was significantly higher than that of Experiment 1 ($p<.01$), and in Exchanging, there was also a significant difference between Experiment 2 and Experiment 1 ($p<.05$); the difference in the former case being somewhat little larger than that in the latter.

Second, the false-alarm data were analyzed in a three-way analysis of variance in each experiment, $[2(\text{Session}) \times 3(\text{Melody Length}) \times 2(\text{Comparison Type})]$, with repeated measures on all three factors. In Experiment 1, there were significant main effects of Session, Melody Length, and Comparison Type ($F(1,11)=6.49, p<.05; F(2,22)=7.69, p<.01; F(1,11)=11.99, p<.01$). There was a significant interaction between Melody Length $\times$ Comparison Type ($F(2,22)=4.68, p<.05$), and a marginal interaction between Session $\times$ Melody Length ($F(2,22)=2.50, p<.10$). In Experiment 2, there were significant main effects of Session, Melody Length, and Comparison Type ($F(1,11)=57.56, p<.001; F(2,22)=56.57, p<.001; F(1,11)=28.64, p<.001$), and there were significant interactions between Session $\times$ Melody Length, and Melody Length $\times$ Comparison Type ($F(2,22)=17.87, p<.001; F(2,22)=5.92, p<.01$).

The main effect of Session indicates that the false-alarm rate in Session 1 was higher than that in Session 2. The main effect of Melody Length indicates that the false-alarm rate increased as Melody Length increased (significance levels between the 10- and 6-tone series were $p<.05$ in Experiment 1, and $p<.01$ in Experiment 2). The interaction between Session $\times$ Melody Length indicates that the false-alarm rate in Session 1 increased as Melody Length increased (significance levels between the 10- and 6-tone series were $p<.05$ in Experiment 1, and $p<.01$ in Experiment 2), whereas in Session 2, there were no significant differences, even as Melody Length increased. That is, the tapping effect, which is the difference between the rate in Session 1 and in Session 2, increased as the melody length increased. Therefore, the main effects of Session and Melody Length, and the interaction between Session $\times$ Melody Length, support and make
clear the findings of Analysis 1. The main effect of Comparison Type supports the result of the first analysis of Analysis 3, as described above.

The interaction between Melody Length × Comparison Type indicates the following: In Contour-preserving, the false-alarm rate increased as Melody Length increased (significance levels between the 10- and 6-tone series were p<.05 in Experiment 1, and p<.01 in Experiment 2); whereas in Exchanging, there were no significant differences between any of the three melody lengths in Experiment 1, or the rate increased somewhat as Melody Length increased in Experiment 2 (significance level between the 10- and 6-tone series was p<.05).

Third, the false-alarm data were analyzed in a three-way analysis of variance in each experiment, [2(Session) × 3(ISI) × 2(Comparison Type)], with repeated measures on all three factors. In Experiment 1, there were significant main effects of Session and Comparison Type (F(1,11)=15.40, p<.01; F(1,11)=9.16, p<.05), but there were no significant interactions between any of the three factors. In Experiment 2, there were significant main effects of Session and Comparison Type (F(1,11)=64.10, p<.001; F(1,11)=59.40, p<.001). There was a significant interaction between Session × Comparison Type (F(1,11)=5.60, p<.05), and a marginal interaction between all three factors (F(2,22)=3.36, p<.05). The main effects of Session and Comparison Type support the results of the first and second analyses of Analysis 3.

In Experiment 2, the significant interaction between Session × Comparison Type indicates that the false-alarm rate for Contour-preserving was significantly higher than that for Exchanging in Session 1 (p<.01), whereas in Session 2, there was no significant difference between them. The marginal interaction between all three factors indicates the following: In Session 1, the false-alarm rate for Contour-preserving decreased as the ISI increased (significance level between the short and long ISI was p<.05), whereas for Exchanging, the rate increased (significance level between the long and short ISI was p<.01), as the ISI increased. In Session 2, however, there were no significant differences between the three ISIs in either Contour-preserving or Exchanging (Figure 4). This tendency toward the marginal interaction was somewhat evident in Experiment 1.

As described above, the Contour-preserving comparison series preserved the same contour as the standard series, but did not preserve the pitches. The Exchanging comparison series preserved the same pitches as the standard series, but did not preserve the contour. If the subjects used contour as a cue for melody recognition, they would tend to make false-alarms for the comparison series which has the same contour as the standard series (Contour-preserving). If the subjects used pitches as a cue for melody recognition, they would tend to make false-alarms for the comparison series which has the same pitches as the standard series (Exchanging).

From the first to the third analyses for Comparison Type, the following were found:
(a) The false-alarm rate for Contour-preserv-
ing was considerably higher in Experiment 2 than in Experiment 1. Accordingly, the subjects used contour as a cue for melody recognition, especially when the interfering melody was interpolated during the ISI.

(b) The false-alarm rate for Contour-preserving increased as Melody Length increased. Therefore, as the melody length increased, the subjects gradually came to depend on the contour as a cue for melody recognition.

(c) In Session 1, the false-alarm rate for Exchanging gradually increased, but the rate for Contour-preserving gradually decreased, as the ISI duration increased; In Session 2, there were no significant differences even as the ISI increased, in either Exchanging or Contour-Preserving. In other words, when the subjects did not employ the tapping strategy, they would use contour as a cue for the short duration of the ISI, whereas they would use pitch as a cue for the long duration of the ISI; when they did employ the tapping strategy, however, finger movement would be an effective cue for melody recognition, even as the duration of the ISI increased.

**Analysis 4**

**Analysis of finger movement.** The tapping movement made by each finger was recorded using a computer. Three response measures were calculated: (a) The number of times that tapping was repeated during the retention interval (ISI). (b) The tapping rate for each finger. (c) The latency between the end of the standard series and starting the elaborate finger tapping movement.

The number of times that the tapping was repeated during the retention interval filled with interfering melodies (Experiment 2) was greater than that in the blank retention interval (Experiment 1). In other words, as shown in Figure 5, the rate of tapping for each finger increased as the melody length increased, and the duration of the ISI increased. Moreover, tapping was faster in Experiment 2 than in Experiment 1. The data in Figure 5 support the interpretation of Analyses 1 and 2.

As shown in Figures 6 and 7, the latency, as described above, in Experiment 2 was shorter than it was in Experiment 1, and it became shorter as the melody length increased. These findings indicate that, to repeat the tapping many times, the subjects would start the tapping as early as possible.

Measuring the duration of the latency period would be an important indicator of the cognitive process, because in this period auditory stimuli are first perceived, then they pass through various auditory information processing stages, until they are replaced by the elaborate finger tapping movement to encode the stimuli. Moreover, the latency period could be reduced to some extent according to the effort made by the subjects.
According to the tapping data, other results were also found. When the comparison and the standard series were the same, the subjects continued the tapping while matching a tone with a tap, one by one, until they heard all the tones of the comparison series, i.e., there was an exhaustive scanning (Sternberg, 1966). When the comparison series was different from the standard series: in the case of Contour-Preserving, once again, there was an exhaustive scanning. In the case of Exchanging, however, the subjects tended to stop tapping, or could not continue to move their fingers, when they listened to a pitch that was different from the standard series, i.e., a self-terminating search (Sternberg, 1966) took place (Figure 7). In other words, when the subjects employed the tapping strategy (in Session 2), they were better able to detect a different pitch in Exchanging than in Contour-preserving. Therefore, the false alarm rate for Exchanging in Session 2 was considerably lower, even as the ISI increased (Figure 4).

Conclusions

This study investigated whether or not finger-tapping would be effective as a pitch encoding strategy. The findings of these experiments are as follows:

First, for the subjects who were highly trained in music, employing the external motor encoding strategy of tapping could be more effective than using internal encoding strategies to encode and retain the pitches of the melodies. Second, the tapping became more effective, especially when there were interfering melodies, as the melody length increased, and as the ISI increased. This is because, in these situations, the subjects would make an effort to repeat the tapping in order not to forget the standard series and, by repeating the tapping many times, were able to elaborate on the encoding of melodies. Third, to repeat the tapping many times, the subjects would start the tapping earlier, i.e., they would reduce the latency period as much as possible. Fourth, when not employ-
ing the tapping strategy, contour and pitch are independently handled as different features, and either of them being an effective cue for melody recognition (Deutsch, 1977; Dowling 1971, 1972, 1978; Dowling & Fujitani, 1971; Kallman & Massaro, 1979). When employing the external motor encoding strategy of tapping, movement of the fingers would instead elaborate on the internal cues of contour or pitch.

Internal encoding strategies (e.g., humming, visualization, verbal encoding, etc.) could not be observed by measuring the number of rehearsal times and the rehearsal rate, or the duration of latency between the end of the auditory stimulus and starting the rehearsal. On the other hand, the external encoding strategy of tapping could be observed and analyzed by these measures.

At the beginning of this paper, four types of pitch encoding strategies were described. These strategies would not necessarily be used independently as a pitch encoding strategy, but occasionally, several strategies would be employed simultaneously. For example, in this experiment some subjects employed the tapping strategy while muttering the note names to themselves. An experiment to investigate these relations is planned in the near future.

References


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