Perception & Psychophysics
1985, 37 (1), 1-7

Metrical and nonmetrical representations of temporal patterns

PETER J. ESSENS and DIRK-JAN POVEL
University of Nijmegen, Nijmegen, The Netherlands

Temporal patterns can be classified into two types: those that are conceivable in terms of a metrical framework and those that are not. In this context, a metrical framework is seen as a mental time scale used in specifying the temporal structure of a pattern. Three experiments are reported in which subjects produced or reproduced temporal patterns. The first shows that in spontaneous production subjects use intervals whose durations are in a 2:1 ratio, irrespective of the structure of the pattern. From the two other experiments, in which subjects reproduced temporal patterns with varying interval ratios, it is concluded that: (1) patterns not conceivable in a metrical framework are represented (and consequently reproduced) poorly, unless the intervals are 2:1 related, and (2) patterns conceivable in a metrical framework are represented and reproduced accurately. Implications for a theory of temporal patterns are discussed.

Temporal patterns can be represented internally in a metrical or a nonmetrical fashion. A metrical representation of a temporal pattern is one based upon a metrical framework, meaning that the pattern is mapped on a frame formed of equal time intervals. For example, the interval sequence 2 2 3 1 2 1 1 4 (numbers indicating intervals between tone onsets in arbitrary time units), with a total duration of 16 time units, may be perceived metrically as having a metrical framework with intervals of 4 time units. The temporal structure in patterns capable of metrical representation, typically those found in music, can be described by means of hierarchical trees (Jones, 1976, 1981; Lerdahl & Jackendoff, 1981, Longuet-Higgins, 1978; Martin, 1972). Models specifying how different characteristics in patterns determine their metrical interpretation have been proposed by Longuet-Higgins and Lee (1982), Povel (1984), Povel and Essens (in press), and Steedman (1977).

A nonmetrical representation will result when the listener is unable to form a metrical representation. This may be when the sequence cannot be subdivided into equal time intervals, such as the interval sequence 1 3 2 1 4 with a total duration of 11 time units. Besides divisibility, accent distribution is an important factor affecting the formation of a metrical interpretation. Two questions arise here: (1) Which patterns do actually evoke a metrical interpretation on the part of the listener, and (2) what is the nature of the time representation of patterns failing to evoke a metrical interpretation?

The research reported here was supported by a grant from the Netherlands Organization for the Advancement of Pure Research (ZWO). Part of the work reported was presented at the Joint Meeting of the British Experimental Psychology Society and the Netherlands Psychonomics Foundation, Amsterdam, July 4-7, 1984. Requests for reprints should be sent to Peter Essens, Department of Experimental Psychology, University of Nijmegen, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands.

Povel and Essens (in press) have proposed a model for the perception of temporal patterns that deals with the first question. The model has three main assumptions. First, perception of a temporal pattern is related to the structural characteristics of the pattern. Second, the model assumes that in perceiving a temporal pattern, a listener tries to generate an internal clock which is subsequently used as a measuring device to specify the temporal structure of the pattern. Third, the model assumes that the distribution of the accents perceived in the sequence determines whether a clock actually is induced and which clock this will be. The model formalized in the form of a computer program specifies the strength of induction of that clock. When clock induction is strong, most listeners will generate an internal clock and the pattern will be represented in a metrical framework. Conversely, when induction is weak, no internal clock will be generated and the pattern will be coded in a non-metrical representation. For a more detailed discussion of this distinction, see Povel & Essens (in press). In this paper, we have used the model to classify the patterns as "metrical" or "nonmetrical," that is, as patterns that either do or do not evoke a metrical interpretation.

The present study aims at giving further evidence to substantiate the distinction between metrical and nonmetrical coding. In particular, it is concerned with the question of how temporal relations are coded in a nonmetrical representation as compared with a metrical representation.

EXPERIMENT 1

This experiment replicates Fraisse's (1946, 1956) and Montpellier's (1935) spontaneous tapping experiments. In those experiments, subjects tapped patterns, which were verbally described to them as sequences of groups of elements (taps). For example, a subject was asked to produce a pattern of five elements composed of a group of three elements followed by a group of two elements. According to Fraisse (1956), order of the groups (element structure) and number of elements (size) in the pattern affect the ratios of the intervals between and within groups in a produced pattern. The present experiment verifies reported effects of size and element structure on the produced intervals between the elements for an extended set of patterns consisting of groups of elements.

Method

Stimuli. All patterns used contained three groups of elements. Groups consisted of 1, 2, 3, or 4 elements. For example, the element pattern 243 consists of a group of two, followed by a group of four, followed by a group of three elements (see Table 1). Since permutations such as 112, 121, and 211 produce cyclical variations of the same basic element pattern when generated repetitively, the 63 apparent versions in fact reduce to 23 basic element patterns. Thus, the factor element structure consists of two factors: identical groups of elements varying in order (cyclical variation) and different groups in the pattern (basic element pattern). The cyclical variations of the basic element patterns were distributed over three sets, and four subjects were assigned to each set.

Procedure. The subjects were requested to repetitively tap the patterns at their own tempo such that groups of taps remained recognizable. Patterns to be tapped were shown on a card in a numerical representation (e.g., 322). The order of presentation of element patterns was random. Subjects tapped five periods of the pattern onto a response plate; each tap produced a 50-msec tone of 830 Hz. Extinction of the response tone signaled to the subject that production could be stopped. Time intervals between taps were recorded using a PDP-11/03 computer.

Subjects. Twelve subjects, psychology students, participated in the experiment. Four were musically trained, having played an instrument for at least 5 years.

Results

Examination of the performance of individuals revealed no differences related to musical training. Basically, subjects used two durations of tap intervals in the patterns, a short duration for intervals within groups (M = 320 msec) and a long duration for the intervals between groups (M = 645 msec). In Figure 1, the relation between mean long and mean short intervals for each subject is presented. Note that the scales of the x- and y-axis are 1:2 related. The figure shows that the long and short durations produced relate as 2:1. The relation between the two durations is clearly not influenced by tempo differences among subjects, showing a long-short correlation of .93.

The ratios of the long and short intervals were subjected to an analysis of variance. Each pattern produced contains three long intervals between the three groups, the third of which separates repetitions of the pattern. The position of long intervals in the pattern is referred to as "location." For each pattern, three long-short interval ratios were obtained by dividing the long intervals by the mean of the short intervals of that pattern. There are three main factors: cyclical variation, basic pattern, and location. The cyclical variation and basic patterns factors and the interactions of the three factors are not significant. The location factor is highly significant [$F(2,18) = 29.1$, $p < .0001$] with mean values of 1.96, 1.92, and 2.20

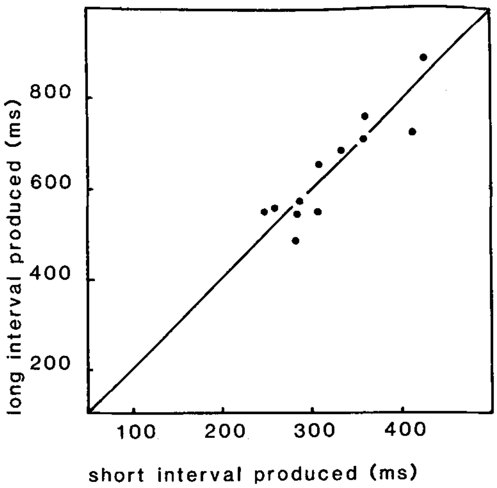

Figure 1. Produced long intervals as a function of produced short intervals for 12 subjects in Experiment 1. Points represent average values. The diagonal indicates the 2:1 long/short relation.

and standard deviations of .22, .24, and .39, respectively. A Newman-Keuls analysis shows a significant difference between the third interval ratio and the other two ratios ($p < .05$). This difference has also been reported by Fraisse (1956), who, therefore, analyzed the first two interval ratios separately from the third. To make the evaluation of the effect of size comparable with Fraisse's data, we computed the means of the first two interval ratios. Since analysis of variance showed no effects of cyclical variation, we pooled mean interval ratios over three sets and averaged them over subjects. In Table 1, the mean interval ratios for the 23 basic element patterns are presented. The table reveals that there is no positive relationship between size and interval ratio; in fact, the relation shows some negative correlation ($r = -.37$).

During the experiment, some subjects were seen to make a "dummy" tap movement about in the middle of the long interval.

Discussion

The main finding of this experiment is that, in spon-

Table 1
Mean Produced Long-Short Ratios for the 23 Basic Element Patterns in Experiment 1

Pattern		Size	M	SD	Pattern		Size	M	SD
1	112	4	2.00	.21	12	134	8	1.99	.17
2	122	5	1.94	.28	13	143	8	1.89	.21
3	113	5	1.98	.26	14	233	8	1.89	.17
4	123	6	1.99	.24	15	224	8	1.88	.18
5	132	6	2.01	.22	16	234	9	1.93	.26
6	114	6	1.98	.43	17	243	9	1.92	.18
7	222	6	1.88	.23	18	144	9	2.04	.21
8	133	7	1.97	.20	19	333	9	1.89	.16
9	223	7	1.89	.15	20	244	9	1.89	.19
10	124	7	1.95	.29	21	334	10	1.91	.15
11	142	7	2.02	.18	22	344	11	1.90	.24
					23	444	12	1.94	.32

taneous tapping, subjects produce between-group intervals that are almost twice as long as the within-group intervals. This result supports Fraisse's idea that subjects essentially use two duration categories related as 2:1. However, in contrast with Fraisse, our data show that this 2:1 relation is *independent* of number of taps in a pattern, element structure, and overall tempo. Further, also in contrast with Fraisse (1956) and Montpellier (1935), we find great consistency in the produced interval ratios. Patterns 112, 211, and 121 permit a direct comparison of our results with those of Fraisse (1956). Where Fraisse reports interval ratios of 2.64, 2.57, and 2.77, we find 1.96, 2.04, and 2.00; these differences remain to be explained.

EXPERIMENT 2

In contrast to the previous experiment, which studied the *production* of temporal patterns, this experiment is concerned with their *reproduction*. In particular, we investigated the reproduction of patterns that are assumed to be perceived in a nonmetrical interpretation.

Given the preference in spontaneous tapping for producing a 2:1 time relation and the observed dummy movements, we wanted to investigate whether subjects can use the smallest interval in a temporal pattern as a basic unit in representing other (longer) intervals in the same pattern. According to this "extrapolation hypothesis," intervals in a pattern can be coded by extrapolating the smallest interval over longer intervals and counting the number of times it fits into the larger. Note that this approach differs from specification in a metrical interpretation, in that here, instead of a higher order time unit, the smallest interval is used to specify the interval structure.

The extrapolation hypothesis suggests that patterns whose longer intervals can be expressed as multiples of the shortest interval will be more accurately reproduced than those in which they are not. Thus, the hypothesis predicts that intervals in ratio 3:1 or 4:1 will be better reproduced than, for instance, 2.5:1 or 3.5:1. Indeed, Fraisse (1956) found that 2:1 interval relations are better reproduced than those of 1.5:1 or 2.5:1, a result in support of the hypothesis. The findings of Povel (1981), on the other hand, are not in accordance with the hypothesis, since he found that patterns with intervals related 3:1 and 4:1 are not reproduced more accurately than those with 3.5:1 ratios. We verified these results in an experiment with patterns, which, unlike Povel's stimuli, contained frequently occurring short intervals. In the present experiment, subjects reproduced tone patterns in which the relation of short and long intervals were systematically varied.

Method

Stimuli. The stimuli in this experiment consisted of sequences of tones composed of 830-Hz square waves with a duration of 50 msec, including 5-msec rise and fall times. Using four element structures from the previous experiment (322, 233, 433, and 344), patterns were formed in which between-group intervals were varied. (The term "interval" always refers to tone-onset interval). The duration of within-group intervals was 250 msec; long (between-group) intervals were 1.5, 2, 2.5, 3, 3.5, or 4 times the short interval. Figure 2 shows a sample pattern. The total number of stimuli was thus 24: 4 (element structures) × 6 (interval ratios). A fifth element structure (341) was used for training purposes.

Procedure. The subjects were requested to repetitively reproduce the presented patterns as accurately as possible. The patterns were repeatedly presented through earphones, and, as in Experiment 1, the element structure was depicted on a card. Presentation order was random. The subjects were able to listen to each stimulus and practice by tapping in synchrony with it as long as they wished. Afterwards the subjects stopped stimulus presentation by pushing a button, and tapped five periods of the pattern on a response plate. Each tap produced the same tone as used in the stimulus, thus making stimulus and response stage auditorily compatible. Stimulus generation and response registration were controlled by means of a PDP-11/03 computer.

Subjects. Twenty subjects, psychology students, participated in the experiment. Ten were musically trained, and none had participated in Experiment 1.

Results

Mean reproduced long intervals were obtained by averaging the first two between-group intervals; mean reproduced short intervals were obtained by averaging over all within-group intervals. Examination of performance of individuals yielded no differences related to musical training. In Table 2, the results are presented averaged over subjects and element structures for the six interval ratios. The results for the short intervals show a positive effect of interval ratio on the duration of the short intervals. Short intervals are lengthened with patterns with interval ratios greater than 2:1, considerably shortened in patterns with interval ratios 1.5:1, and slightly shortened in patterns with 2:1 ratios. The variation in the reproductions of the long intervals, as expressed

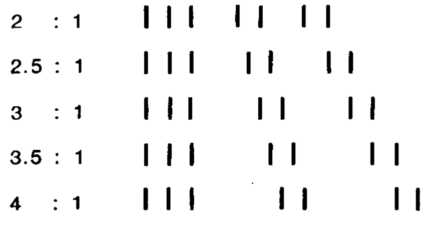

Figure 2. Six temporal patterns formed of element structure 322 with various interval ratios. Vertical lines indicate tones of 50 msec. Shortest tone onset interval is 250 msec.

Table 2
Mean Reproduced Long and Short Intervals (in Milliseconds) and Standard Deviations in Experiment 2

	Long Interval		Short Interval	
Interval Ratio	M	SD	M	SD
1.5:1*	450	46.5	230	11.9
2.0:1	520	45.6	245	11.2
2.5:1	615	81.3	254	15.3
3.0:1	682	84.3	253	11.9
3.5:1	762	110.3	257	14.6
4.0:1	848	133.2	262	17.2

**Unit = 250 msec.*

Table 3
Mean Deviations of Reproduced Long and Short Intervals in Percentage of Presented Intervals in Experiment 2

	Long Interval		Short Interval	
Interval Ratio	M	SD	M	SD
1.5:1*	20.8	11.2	9.0	3.7
2.0:1	8.2	6.4	5.9	2.5
2.5:1	11.2	7.5	6.7	3.8
3.0:1	12.7	7.5	6.1	2.4
3.5:1	15.6	9.6	6.9	4.2
4.0:1	17.6	10.3	7.8	5.4

**Unit = 250 msec.*

by the standard deviations, becomes progressively greater with interval ratio, while the deviation of the mean reproduction from the presented sequence rises progressively.

The ratios of the reproduced long and short intervals are shown in Figure 3. From this figure, we see reproduced interval ratios greater than 2:1 becoming progressively smaller and the interval ratio 1.5:1 becoming systematically greater. The interval ratio 2:1 is reproduced somewhat greater than 2, M = 2.12, which is consistent with the findings of Fraisse (1956) and Povel (1981). At first sight, the interval ratio 2.5:1 seems to be reproduced fairly accurately: M = 2.43. The high standard deviation, however, indicates that this interpretation is unwarranted.

Another measure of the accuracy of reproduction is obtained by summing the absolute differences between intervals in the reproduced pattern and the presented pattern. This measure indicates the deviation with respect to the norm (presented pattern). If expressed as a percentage of the norm, the measure can be used to compare performance in the different interval ratios. Table 3 shows the deviations averaged over subjects and element structures for the mean reproduced long intervals and short intervals separately. These two sets of deviations were subjected to separate analyses of variance, with interval ratio and element structure as main factors. The interval ratio factor is significant [$F(5,95) = 11.3$, $p < .0001$, for the long-interval deviations and $F(5,95) = 4.0$, $p < .01$, for the short-interval deviations]. The element structures differ significantly from each other [$F(3,57) = 3.9$, $p < .01$, for the long interval deviations and $F(3,57) = 12.9$, $p < .001$, for the short interval deviations]. In addition, a nearly significant interaction of interval ratio × element structure is observed for the short-interval deviations [$F(95,285) = 6.0$, $p < .02$]. A Newman-Keuls analysis for the deviations of the long intervals showed that the successive steps of the gradually increasing deviation do not significantly differ from each other ($p > .05$). The differences between interval ratios 2:1 and 3:1, however, is found to be significant. For the deviations of the short intervals, a Newman-Keuls analysis showed the only significant difference to be between interval ratios 1.5:1 and 2:1 ($p < .05$). Most of the subjects complained about the difficulty of the patterns with interval ratios of 1.5:1.

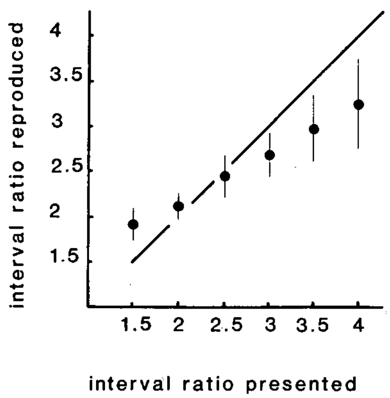

Figure 3. Mean reproduced interval ratios as a function of presented interval ratios. The diagonal indicates perfect reproduction. Vertical lines represent standard deviations.

Discussion

The reproduction data do not support a distinction between the representation of patterns containing integer-ratio intervals (e.g., 2:1, 3:1, and 4:1) and those containing noninteger-ratio intervals (e.g., 1.5:1, 2.5:1, and 3.5:1) in a nonmetrical context. From this result, we may conclude that the smallest interval is not used in specifying the time structure of the patterns. Patterns containing 2:1 interval relations are clearly reproduced best in comparison with the other patterns. This is in conformity with the findings of Experiment 1. There we found that, in spontaneous tapping, subjects consistently use two distinct time categories, long and short, with long intervals about twice as long as short intervals.

A special case is formed by the interval ratio 1.5:1. A typical comment by subjects was that successive groups in these patterns were hard to distinguish. Moreover, in their reproductions, subjects lengthened the long intervals and shortened the short intervals, a tendency in accordance with Fraisse's (1956) "principle of distinction."

EXPERIMENT 3

In this experiment, we compared accuracy of reproduction of patterns that theoretically evoke different representations. Patterns evoking a metrical representation are generally reproduced more accurately than those that do not (Povel, 1981). This finding was obtained with a limited set of simple temporal patterns. Moreover, the patterns evoking a metrical interpretation and those evoking a nonmetrical one differed strongly in their element structure. Therefore, in this experiment, we compared the reproduction of patterns in two conditions: one that evokes a metrical representation and one that does not.

Method

Stimuli. Using five element structures (322, 332, 421, 413, and 422), two sets of patterns were formed in which the interval ratios were either 2:1 in Set 1 or 3:1 in Set 2. The duration of short intervals within the groups was 200 msec; thus, long intervals were 400 msec in Set 1 and 600 msec in Set 2. The patterns consisted of tones of 50-msec 830-Hz square waves, with 5-msec rise and fall times. The stimuli are shown in Table 4 in a real-time fashion, with dots indicating the relative onset intervals. For example, the first pattern of Set 1 consists of the onset intervals (in milliseconds) 200 200 400 200 400 200 400.

Patterns used in the metrical condition were formed by lengthening the patterns from the nonmetrical condition (see Table 4). These patterns were presented to subjects in combination with a low-pitch isochronic tone sequence to ensure metrical coding. This isochronic sequence consisted of 50-msec 125-Hz square waves, with 5-msec rise and fall times and onset intervals of 800 msec.

Procedure. The task for the subject was to repetitively reproduce the presented pattern as precisely as possible. The patterns were presented through earphones in a repetitive fashion. The experiment was performed in two parts: The stimuli of the nonmetrical condition were reproduced first, and then, after a short pause, the stimuli of the metrical condition were reproduced. The subjects practiced the task before each part of the experiment. Presentation order was random. The subjects listened to each stimulus and practiced tapping for as long as they wished. After stopping stimulus presentation, they reproduced four periods of the pattern on a response plate. Each tap produced the same tone as used in the stimulus. If variability of performance of a pattern was such that standard deviation exceeded 15% of the mean, the subject was asked to repeat the trial.

Subjects. Seventeen subjects, psychology students, participated in the experiment. Eight were musically trained, and two had participated in Experiment 2.

Table 4
Two Sets of Stimuli from Experiment 3

	Nonmetrical	Metrical
	Set 1: Interval Ratio 2:1	
1.	III.II.II.|	III.II.II...I...| I...I...I...I...|*
2.	III.III.II.|	III.III.II..I...| I...I...I...I...|
3.	IIII.II.I.|	I.IIII.II.I.I...| I...I...I...I...|
4.	IIII.I.III.|	I..IIII.I.III...| I...I...I...I...|
5.	IIII.II.II.|	I..IIII.II.II...| I...I...I...I...|
	Set 2: Interval Ratio 3:1	
1.	III..II..II..|	I.III..II..II...| I...I...I...I...|
2.	III..III..II..|	I.III..III..II..| I...I...I...I...|
3.	IIII..II..I..|	I.IIII..II..I...| I...I...I...I...|
4.	IIII..I..III..|	I.IIII..I..III..| I...I...I...I...|
5.	IIII..II..II..|	I.IIII..II..II..| I...I...I...I...|

Note—I *represents a tone of 50 msec. Smallest onset interval is 200 msec. Dots indicate relative interval duration.* | *indicates first tone of next period.* **low-pitch isochronic sequence, 125 Hz.*

Table 5
Mean Reproduced Long and Short Intervals (in Milliseconds) and Standard Deviations in Experiment 3

	Long Interval		Short Interval	
Condition	M	SD	M	SD
	Set 1: Interval Ratio 2:1*			
Nonmetrical	404	26.1	199	6.6
Metrical	417	22.2	202	7.7
	Set 2: Interval Ratio 3:1			
Nonmetrical	558	63.1	207	7.3
Metrical	584	43.1	204	7.1

**Unit = 200 msec.*

Results

Analysis was carried out on that part of the reproduced patterns that was identical in the metrical and nonmetrical conditions. Mean reproduced long intervals were obtained by averaging the first two between-group intervals; the mean reproduced short intervals were obtained by averaging the within-group intervals. Examination of the performance of individuals yielded no differences related to musical training. In Table 5, the results are presented averaged over subjects and element structures for the long and short intervals separately.

First we look at the reproduction of short intervals. In Sets 1 and 2, reproductions do not differ from the presented interval durations. Reproductions of the long intervals, however, show a condition effect. In Set 1 (2:1), the difference from the presented interval duration is slightly greater under the metrical condition. In Set 2 (3:1), the difference from the presented interval duration is considerably smaller under the metrical condition. In both sets, performance is more consistent in the metrical condition, as indicated by the lower standard deviation.

To describe accuracy of reproduction, we have also used the deviation measure, which may give a better picture of the actual differences between conditions. This measure was obtained by summing the absolute differences between the mean reproduced long intervals and the norm. Data for the two sets are shown in Figure 4 for the nonmetrical and metrical conditions separately.

The figure shows that, for the patterns of Set 2, deviations are much lower in the metrical condition than in the nonmetrical condition. The deviations in the patterns of Set 1 do not differ under the two conditions. The deviations were subjected to analyses of variance for the two sets of patterns separately, with condition and element structure as main factors. For Set 1, the condition factor

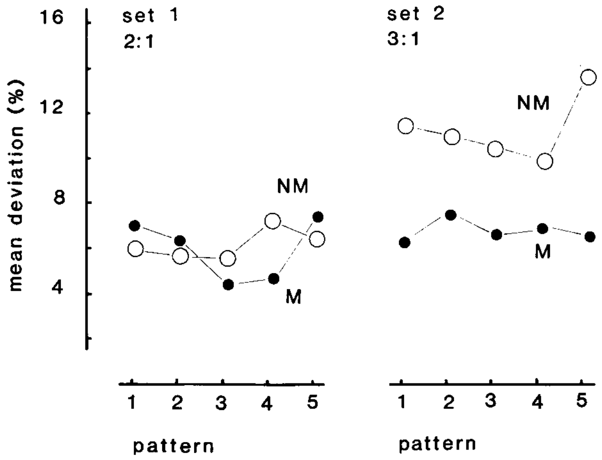

Figure 4. Mean deviation scores as a percentage of the presented intervals for the metrical (M) and nonmetrical (NM) conditions in the two sets.

is not significant; element structure is nearly significant [F(4,64) = 2.78, p = .03]. A significant interaction of condition × element structure is observed [F(4,64) = 3.87, p < .01]. For Set 2, patterns with interval ratio 3:1, the condition factor is highly significant [F(1,16) = 42.0, p < .0001], and the interaction of condition × element structure is nearly significant [F(4,64) = 2.58, p < .04]. Analysis of variance of the combined results of Set 1 and Set 2 in the metrical condition indicated that there was no significant difference between the scores of Set 1 and Set 2 in the metrical condition.

Discussion

This experiment shows that metrically interpreted patterns are much better reproduced than nonmetrically interpreted patterns, except for those having 2:1 interval ratios. The latter are reproduced with broadly the same accuracy under both metrical and nonmetrical conditions. The data suggest that accuracy of reproduction of metrically interpreted patterns is not related to their interval relations, since accuracy in the metrical condition is the same for both sets.

The main finding of Experiment 2—decrease of accuracy for interval relations other than 2:1—is replicated in this experiment (nonmetrical condition), using a different set of patterns. In order, the reproduced interval ratios for 2:1 and 3:1 patterns are 2.12 and 2.70 in Experiment 2 and 2.03 and 2.70 in Experiment 3. Certain differences in the results do appear, however. Compared with the data of Experiment 2, variability is much lower in Experiment 3. Mean deviations for the patterns with 2:1 and 3:1 interval relations (see Table 3) are 8.2 and 12.7 (Experiment 2) and 6.1 and 11.2 (Experiment 3), respectively. This difference may be due to the accuracy constraints in Experiment 3.

A remark is in order regarding the procedure used in this experiment. Because the metrical condition always followed the nonmetrical condition, one could argue that the improvement of accuracy in the 3:1 condition is due to a learning effect. However, pilot experiments with the two parts separately showed essentially the same results as those reported here.

A puzzling aspect concerns the data of Set 2. Although best performance is found under the metrical condition, subjects did not realize exact 3:1 interval ratios, their mean interval ratio being 2.86. A possible explanation for this may be found in the complexity of the patterns in the metrical condition.

GENERAL DISCUSSION

The main conclusion from the findings reported in this study is that two types of representations should be distinguished: one metrical and the other nonmetrical. With the exception of patterns consisting of intervals relating 2:1, we found that metrically represented patterns are much better reproduced than those nonmetrically represented. In terms of the internal clock model of Povel and Essens (in press), our conclusion is that if an internal clock is used as a basis to specify the temporal structure of a pattern, an adequate representation results. If no clock is used, temporal structure is not represented adequately; detailed information about the relative durations of intervals will be lacking.

Patterns with 2:1 interval ratios appear to be of special kind: (1) In spontaneous production, subjects use two types of intervals, which stand in a 2:1 relation; (2) for nonmetrically represented patterns, we find that accuracy of reproduction is much better for those containing 2:1 intervals than it is for other interval ratios; and (3) accuracy of reproduction of metrically and nonmetrically interpreted patterns with 2:1 interval relations is similar.

The findings reported here have implications for a theory of temporal patterns. First, with repect to the possible subdivisions of the metrical unit, three ways of filling that unit can be distinguished: empty, filled with equal intervals, and filled with unequal intervals. In an earlier model, Povel (1981) restricted unequal subdivisions that are properly represented to relations of 2:1. The finding that subdivisions with unequal intervals relating 3:1 or 2:1 are reproduced with similar accuracy indicates that relations other than 2:1 are also permissible within the internal clock model. Second, the findings reported in this paper have shown that the internal representation of a temporal pattern critically depends on whether or not a metrical interpretation is evoked.

REFERENCES

Fraisse, P. (1946). Contribution a l'étude du rythme en tant que forme temporelle. *Journal de psychologie normale et pathologique*, **39**, 283-304.

Fraisse, P. (1956). *Les structures rythmiques*. Louvain: Publications Universitaires de Louvain.

Jones, M. R. (1976). Time, our lost dimension: Toward a new theory of perception, attention, and memory. *Psychological Reveiw*, **83**, 323-355.

Jones, M. R. (1981). A tutorial on some issues and methods in serial pattern research. *Perception & Psychophysics*, **30**, 492-504.

Lerdahl, F., & Jackendoff, R. (1981). On the theory of grouping and meter. *The Musical Quarterly*, **67**, 479-506.

Longuet-Higgins, H. C. (1978). The perception of music. *Interdisciplinary Science Reviews*, **3**, 148-156.

Longuet-Higgins, H. C., & Lee, C. S. (1982). The perception of musical rhythms. *Perception*, **11**, 115-128.

Martin, J. G. (1972). Rhythmic (hierarchical) versus serial structure in speech and other behavior. *Psychological Review*, **79**, 487-509.

Montpellier, G. de. (1935). *Les alterations morphologiques des mouvements rapides*. Louvain: Institut Superieur de Philosophie.

Povel, D. J. (1981). Internal representation of simple temporal patterns. *Journal of Experimental Psychology: Human Perception and Performance*, **7**, 3-18.

Povel, D. J. (1984). A theoretical framework for rhythm perception. *Psychological Research*, **45**, 315-337.

Povel, D. J., & Essens, P. J. (in press). The perception of temporal patterns. *Music Perception.*

Steedman, M. J. (1977). The perception of musical rhythm and metre. *Perception*, **6**, 555-569.

(Manuscript received July 24, 1984;
revision accepted for publication November 26, 1984.)