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INFLUENCE OF AGE AND MUSICAL EXPERIENCE ON TIMING AND INTENSITY VARIATIONS IN REPRODUCTIONS OF SHORT MUSICAL RHYTHMS

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Two structuring processes influence the structure of mental representations for musical rhythms: rhythmic grouping and the detection of temporal regularities based on the organisation around an underlying pulse (the metric structure). This paper investigates the influence of age and musical training on the structure of mental representations. Four groups of subjects (adult musicians, adult nonmusicians, 5- and 7-year-old children) listened to short musical rhythms and were asked to reproduce them immediately. Systematic performance variations in time and intensity were measured in order to provide an indication of the way the subjects structured the sequences. The temporal profiles provided evidence for segmentation into rhythmic groups, almost identical for all subjects, indicating the fundamental nature of this process. However, the intensity profiles varied considerably between groups, providing evidence of the importance of musical training (rather than passive acculturation) on the ability to incorporate the metric structure in a mental representation.

It is now well established that when listeners hear a sequence of auditory events they do not simply encode information about each event as it arrives, but in addition, they *organise* the information in specific ways depending on both the physical characteristics of the sequence and the perceptual and cognitive characteristics of the listener. In this paper we examine some influences of age and musical experience of listeners on the structure of their mental representations for simple musical rhythms, that is those that obey relatively strict rules concerning their temporal structure. In the present case, all events are of the same frequency but may vary in intensity.

Two structuring processes may apply in the perception of these rhythms: rhythmic grouping and metric structure. In the case of *rhythmic grouping*, a sequence is segmented into groups comprised of several events. This segmentation is usually based on the temporal proximity of events - events that occur close to each other are perceived as belonging to the same group, whereas those that are separated by a relatively longer temporal gap are perceived as belonging to separate groups (Garner & Gottwald, 1968; Handel, 1981). Each group can be processed as a unit, thus overcoming mnemonic limits. An example of the segmentation of a musical rhythm into rhythmic groups is presented in Figure 1. The intensity structure can also influence the rhythmic grouping in that a change in intensity may signal the beginning of a new group. An *organisation around underlying temporal regularities*, rather than breaking the sequence into smaller units, aids in structuring the sequence over longer time spans by detecting underlying temporal regularities in the sequence. In the case of musical sequences this often corresponds to the extraction of the underlying beat. Once identified, these regularities can be used to predict the moment at which future events are likely to occur, and attention can be directed at the appropriate moments, thus avoiding processing limits (Jones & Boltz, 1989). Regularities can lie at a low level (level 1 in Figure 1) or at one of many hierarchical levels comprised of time spans of increasing length (levels 2 to 4). If this type of organisational structure contains two or more levels it is known as the metric structure.

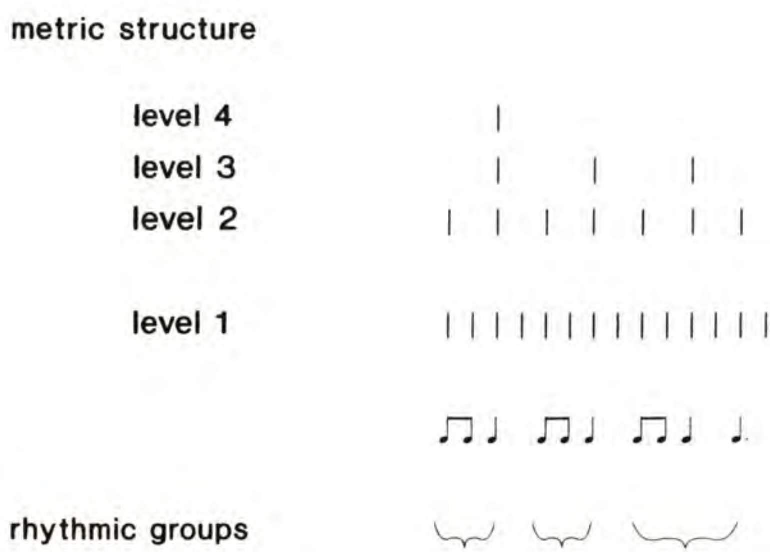

Figure 1. Example of a rhythmic sequence showing the rhythmic groups and the metric structure.

A few studies have examined the question of the acquisition of some of these abilities. It is probable that some organisational abilities are functional at a very early age whereas others develop, either through passive acculturation (being exposed to a certain type of music) or through specific training (such as in formal music tuition). Utipis (1987) asked subjects varying in age and level of musical training to write down a musical rhythm so as to be able to remember it later. She demonstrated that some subjects "invented" a notation system that reflected primarily the rhythmic grouping structure whereas others chose a system that emphasised the metric structure. In general, dominance of the rhythmic grouping structure was observed for the younger children and those with less musical experience, whereas the metric structure was more prevalent in older children and those with more musical experience. This would suggest that the principle of grouping temporally proximal events is more fundamental than that of extracting underlying temporal regularities. This is supported by the findings of Thorpe and Trehub (1989) which demonstrate that 6- to 9-month-old infants are able to detect more easily a temporal lengthening when it occurs within a group than when it occurs between two groups, suggesting that this grouping principle is already functional at this age.

On the other hand, several studies (Dowling & Harwood, 1986; Drake & Gérard, 1989; Gérard & Drake, 1990) have shown that the ability to extract an underlying beat is also functional early. For instance, 2-year-old children are able to tap in time with the music and their spontaneous productions and reproductions of models almost always respect the underlying beat. This would therefore suggest that both the extraction of the underlying beat and rhythmic grouping are fundamental processes, but the use of these abilities to extract higher level regularities are only acquired either at a later age or with musical experience.

The problem arises as how to measure the structure of mental representations, particularly in young children. We have previously adopted a *reproduction task* which allows a direct comparison between various groups of subjects (Drake, 1993a). Problems of motor control are of course greater for younger children, but this can be overcome by comparing the performance of rhythms that vary in their structural difficulty but require a similar level of motor control. For instance, ternary rhythms are conceptually more complex than binary rhythms but are similar as regards the degree of motor control required. The data from the present article come from this previous study (Drake, 1993a) but we adopt a different means of measuring the structure of mental representations, namely *systematic performance variations*. When reproducing a rhythm, both the duration of the intervals between the onset of successive events and the intensity of the events are never exactly perfect (Clarke, 1985, 1988; Gabrielsson, 1974, 1982; Povel 1977; Semjen, Garcia-Colera & Requin, 1984; Shaffer, Clarke & Todd, 1985). Some of these variations can be attributed to random variability, but others occur in a systematic fashion in relation to the structure of the sequence. Thus, if subjects segment a rhythm in a particular way, this particular mental representation may be reflected in the way the rhythm is performed.

Such distortions have been demonstrated by Drake and Palmer (1993) who, when they asked pianists to perform both simple and complex musical sequences, observed systematic performance variations in both timing and intensity which reflected the musicians' segmentation based on both rhythmic grouping and metric structure. Two systematic performance variations were observed in relation to rhythmic grouping. The first concerns temporal distortions: the last short interval in a sequence of short intervals is systematically lengthened in relation to others in the sequence. For instance, pianists played the intervals marked with an "L" in Figure 2 about 10 % longer than the other short intervals. The second concerns intensity variations: the last event in a rhythmic group (marked with a star in Figure 2) was played louder than events within the rhythmic group. Only one systematic performance variation, that of intensity, was observed in relation to the metric structure: metrically important events (those on the first and third beat in a bar of 4/4) were played louder than other events. In the present study we wish to see whether similar performance variations are observed in subjects other than expert pianists.

The Drake (1993a) study investigated factors influencing the ease of reproduction of short musical rhythms. Four groups of subjects (adult musicians, adult nonmusicians, 5 and 7-year-old children), listened to short musical rhythms and were asked to reproduce them immediately. Eighteen musical rhythms were constructed which varied in: 1) binary or ternary subdivisions of the beat, 2) two or three different durations in each rhythm, 3) the order of succession of the intervals, 4) the presence or absence of intensity accents. A fifth factor allowed for the investigation of the role of age and musical experience. In the present paper we are interested in the role of the last two factors on mental representations of musical rhythms as evidenced by systematic performance variations. We expect different patterns of systematic variations indicating various means of segmenting the sequences depending on the characteristics of the subjects.

METHOD

Subjects. Four groups each of 12 subjects participated in this experiment. The adult musicians had received at least five years of formal musical training and played their instruments almost every day (mean number of years = 9). The adult nonmusicians had received less than one year of formal musical training. There were two groups of children: 5-year-olds (mean = 5.5 years) and 7-year-olds (mean = 7.7 years), pupils at a small private primary school in England where they received an introduction to music through singing and playing simple instruments.

Materials. Eighteen short musical rhythms were used in the experiment but we will only consider the three simplest in the analyses presented here: The three rhythms presented in Figure 2 contained six sounded events (four short - inter-onset interval (IOI) = 450 msec, and two long - IOI = 900 msec). The stimuli were presented either without intensity accents (all the notes were played at 80 dB SPL: sound pressure level) or with intensity accents (all of the notes falling on the beat marked by "<" in Figure 2 were played at 90 dB SPL, with the others at 80 dB SPL).

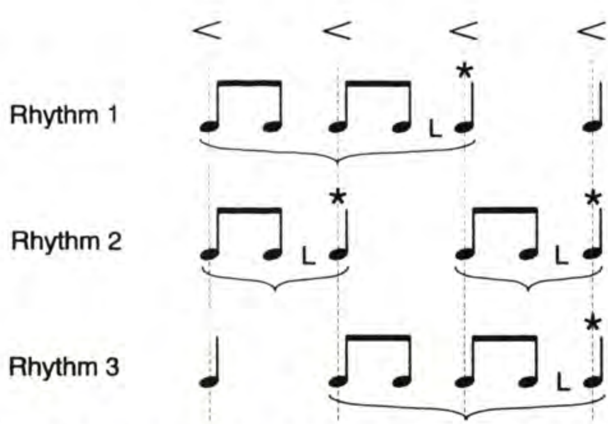

Figure 2. Three of the 18 rhythms used as stimuli, showing the position of accents in the with-accents condition. Brackets indicate the rhythmic groups, with the last event marked with a star and the last short interval marked with "L".

Apparatus. The rhythms were played on a Roland TX 505 rhythm box using a bass drum sound (which resembled the sound produced by the drum used by the subjects). Inter-onset intervals were manipulated but the onset-to-offset duration of events was constant (60 ms). The subjects reproduced each rhythm by banging a wooden stick on a drum. The reproductions were recorded on audio tape and decoded through an analog/digital converter on a BBC computer (sampling rate = 2 ms) which was programmed to calculate both the duration between the beginning of successive taps (inter-onset durations), and the maximum intensity of each tap (scale of 0-127).

Procedure. Each of the eighteen rhythms were presented to all subjects, once with accents and once without, in separate blocks in a counterbalanced order. For a given trial, the subjects heard each rhythm once and were asked to reproduce it on a drum. No mention was made about whether they had to reproduce both timing and intensity variations, and none of the subjects asked for details. There was a pause of about 5 s between the end of a reproduction and the presentation of the next rhythm. Within a session, the stimuli were presented in a counterbalanced order. Half of the subjects in each group were randomly assigned to each of the two orders (with/without, without/with accents). Subjects were tested individually in a quiet room in the school or in the laboratory. The experimental session lasted about half an hour, and students received course credit for their participation.

RESULTS

Inter-onset timing profiles. Inter-onset timing profiles were constructed by comparing the duration of each interval (onset to onset) in the reproduction with the duration of the corresponding interval in the model. The duration of each interval in the reproduction was compared with the corresponding duration in a "mechanical" performance, that is one in which each interval is a perfect integer of the others. This "mechanical norm" was calculated by dividing the total duration of the reproduction by the number of quavers in the rhythms (in this case always 6 since the last note must be ignored as its duration is unknown). A straight line through "1" is observed if a rhythm was reproduced in a mechanical fashion, a positive value is obtained if the interval is played longer than the "mechanical norm", and a negative value if it is played shorter. For example, a value of 1.1 indicates that the interval was played 10% slower than the "mechanical norm". Only reproductions considered as correct (they contain the correct number of events, and the interval ratios respect those in the model) are included in these analyses.

Figure 3 presents the average timing profiles for Rhythm 1 for the four groups of subjects. Lack of space prevents the detailed presentation of all three rhythms here but Rhythm 1 has been chosen here as it best illustrates the point in question but profiles reflecting the same organisational principles are observed for all three rhythms. First, let us consider the type of expected profiles. In the light of previously published performance studies, in relation to the rhythmic grouping structure, we would expect the last short interval preceding a long interval (indicated by an "L" and a box in Figure 3) to be lengthened in relation to other short intervals in the sequence. Such a pattern was observed for all three rhythms. A global analysis of variance on the timing variations by position (5), rhythm (3), presence or absence of accents, and group of subjects (4) revealed a global effect of position ($F(4, 316) = 77.67$; $p < .01$), rhythm ($F(3, 316) = 25.4$; $p < .01$) and group of subjects ($F(3, 316) = 54.67$; $p < .01$), but not of accents. In order to test for this specific pattern it is necessary to test each rhythm separately: Planned comparisons compared the duration of the last short interval in each rhythmic group with the duration of the preceding short interval. A significant effect was seen for three of the four groups of subjects (musicians $F(1, 78) = 23.45$; $p < .01$: nonmusicians $F(1, 78) = 87.08$; $p < .01$: 7/8 year children $F(1, 78) = 9.84$; $p < .01$; 5/6 year children ($F(1, 78) = 2.97$; $p < .08$). For the younger children, the same pattern was observed for all the subjects but there was a higher level of variability and fewer observations due to a lower number of correct reproductions in the original experiment. Thus, the expected performance variations related to rhythmic groups were observed for all the groups of subjects regardless of age and musical experience, and they were unaffected by the presence of intensity accents.

No temporal distortions have been observed previously in relation to metric structure and no significant difference was observed here when the duration of the first interval in the bar was compared with all other events.

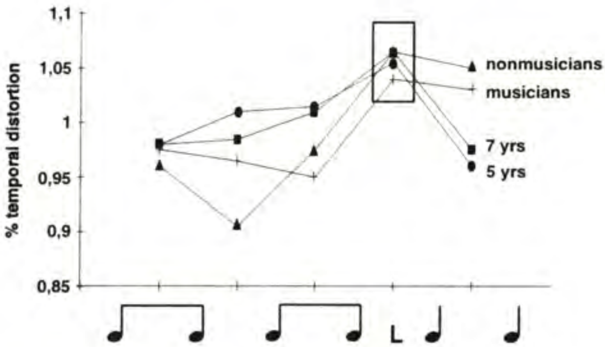

Figure 3. Mean timing profiles recorded for Rhythm 1 for the four groups of subjects. Boxes indicate the expected longer intervals.

Intensity profiles. Figure 4 presents the intensity profiles for Rhythm 2 for the four groups of subjects. Lack of space prevents the detailed presentation of all three rhythms here but Rhythm 2 has been chosen here as it best illustrates the point in question. Profiles reflecting the same organisational principles are observed for all three rhythms. Figure 4 shows that, in contrast to the timing profiles, very different profiles are obtained for the four groups of subjects. In the light of previously published performance studies, in relation to the *rhythmic grouping structure*, we would expect the last event in a rhythmic group to be played louder than other events in the sequence.

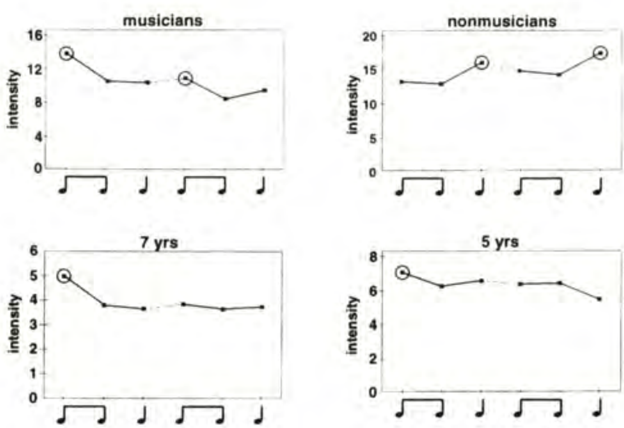

Figure 4. Mean intensity profiles recorded for Rhythm 2 for the four groups of subjects. Circles indicate significantly louder events.

A global analysis of variance on the intensity profiles by position (6), rhythm (3), presence or absence of accents, and group of subjects (4) revealed a global effect of rhythm ($F(2, 316) = 20.1$; $p < .01$) and group of subjects ($F(3, 200) = 10.67$; $p < .01$), but not of accents and position. In order to test for this specific pattern it is necessary to test each rhythm separately: Planned comparisons compared the intensity of the last event in each rhythmic group (marked by a star in Figure 4) with the intensity of other events in the sequence. A significant effect was only seen for the adult nonmusicians ($F(1, 10) = 22.02$; $p < .01$) who played events at the end of rhythmic groups louder than other events.

In relation to the *metric structure*, previous studies have observed that events in more important metric positions are played louder than events in other metric positions. To test for this pattern the intensity of events falling on the first and third beat in the bar was compared with the intensity of all other events. A significant effect was only seen for the musicians who played events in these positions louder than events in other positions ($F(1, 10) = 5.31$; $p < .01$).

It would therefore appear that the intensity profiles of adult musicians are related to the metric structure whereas those of adult nonmusicians are related to the rhythmic grouping structure. But what about the children? The examination of the profiles suggests that they play the first event in the sequence louder than other events. A post-hoc analysis confirms this observation ($F(1, 40) = 19.50$; $p < .01$), indicating that, for children, the intensity profiles reflect an organisation around the overall sequence to be reproduced rather than around either the rhythmic grouping or metric structure.

Discussion

The study of systematic performance variations in both time and intensity has demonstrated consistent patterns in relation to the structural characteristics of the rhythms which vary from one group of subjects to another, providing evidence for differing mental representations.

The same *temporal* distortions were observed here as previously: the end of a rhythmic group is emphasized with the last note delayed in onset by increasing the duration of the preceding interval by between 10 and 20 %. This phenomena was observed in all the groups of subjects, independent of their age or musical experience, indicating that the same organisational processes of segmentation into groups are involved.

However, as regards the *intensity* variations, different patterns were observed depending on the age and musical experience of the subjects: the adult musicians highlight the metric structure of the sequence by playing events in important metrical positions louder, and the adult nonmusicians highlight the rhythmic group by playing the last event in the rhythmic group louder. In contrast, the only intensity accents produced by both groups of children do not emphasize any structural features but rather reflect the way the children organise the response: they play the first event in the sequence louder than the others irrespective of the rhythmic structure.

We thus provide evidence of the fundamental nature of the rhythmic grouping structure since this organisational principle remains constant irrespective of age and level of musical experience. However, a more complex type of organisation, that of the metric structure, is only evidenced in adult musicians, indicating that it is highly dependent on formal musical training rather than passive acculturation. The mental representations of younger children and adult nonmusicians are more influenced by surface features of the rhythms. Similar findings were presented by Smith (1983) who found that musicians organised simple rhythms around a metric structure whereas nonmusicians organised their reproductions around rhythmic groups.

In the Drake (1993a) study, rhythms presented with regularly occurring intensity accents were reproduced correctly more frequently than those without accents. However, in the present analyses of the performance variations no significant difference was observed between the timing and intensity profiles recorded in response to rhythms presented with and without intensity accents. These two observations suggest that higher order regularities such as regularly occurring intensity accents may facilitate the creation of an appropriate mental representation of the rhythm, but are not involved at the stage when the mental representation is "*decoded*" to produce the reproduction.

Finally, the question of the origin of these performance variations must be addressed. Another series of studies investigating the question of whether these systematic performance variations are related to perceptual or motor constraints suggests that the temporal, but not the intensity variations are related to perceptual constraints since listeners are less sensitive to temporal distortions at the end of rhythmic groups than elsewhere (Drake, 1993b). Listeners' sensitivity to changes in intensity remains constant irrespective of the position in the sequence.

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