The meter of syncopated auditory polyrhythms

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Subjects tapped the perceived meter or beat of polyrhythms that consisted of two conflicting pulse trains (e.g., three elements/repetition vs. five elements/repetition). The meter interpretation was based on the global rhythmic properties of a polyrhythm as well as on the temporal properties of each pulse train. The rhythmic properties of a polyrhythm restricted the range of meter interpretations. Some polyrhythms were overdetermined and allowed but one meter, while others were more ambiguous and allowed several meters. For all polyrhythms, however, the temporal interval between elements of a pulse train determined whether that pulse train would serve as the background beat. These results demonstrate the value of a hierarchic analysis of rhythm.

Rhythm is a component of nearly all human activities. It is this very ubiquity and pervasiveness of organized actions and experiences in time, however, that has made it a topic almost impossible to study directly. There is no single experimental paradigm likely to provide results that can be generalized to the full diversity of natural situations in which rhythm is important. Moreover, regardless of the paradigm or perspective chosen, rhythm has proved to be a difficult area for behavioral and phenomenological research.

The antecedent for much of the research involving the perception and reproduction of auditory rhythms is the original introspective work on subjective rhythm (Bolton, 1894). Bolton presented a perfectly isochronous pulse train composed of identical elements, and subjects reported the phenomenal grouping. Depending on the rate, listeners heard the elements naturally grouped into units of two, three, or four elements: An "accented" element was followed by one or more unaccented elements. In subsequent work, other investigators (Woodrow, 1909) varied the physical characteristics of specific elements in a pulse train, changing the duration, intensity, frequency, interelement time interval, and so on. The perceived grouping, inferred to be the perceived rhythm, demonstrated the role of each characteristic in rhythm formation.

The legacies of this work are two-fold. The first legacy is the conceptualization of rhythm as "grouping." In particular, there are units, typically two or

three elements long, out of which more complex rhythms can be constructed. This conceptualization has received its fullest exposition in the musical theorizing of Cooper and Meyer (1960), who have used poetic feet to characterize five possible "grouping" units. Each unit consists of one or more accented elements combined with one or more unaccented elements. From this perspective, Cooper and Meyer (1960) defined meter as the number of elements between more or less regularly recurring accents, and rhythm is then the way the unaccented elements are grouped in relation to those that are accented.

The second legacy is that rhythm can be studied and understood using but one "melodic line" instead of requiring multiple lines. Rhythm is grouping, regardless of whether the grouping is based on physical differences among the elements or on human motoric and perceptual predispositions. This has led to experimental paradigms constructed to study the nature of rhythm by varying an imposed grouping among the elements of an auditory, serial pattern. An optimal grouping, generating the optimal rhythm, should yield the best performance, either in accuracy of reproduction or in rate of learning.

For example, work by Handel (1973) and Restle (1972) has shown that rhythms that group related elements are easier to learn than rhythms that place related elements in different groups. The grouping 123/234/ brings about faster learning than groupings 232/341/ or 323/412/; similarly, the grouping xx/oo/xo/ brings about faster learning than the grouping xo/ox/ox/. Fraisse's (1963) extensive research on rhythm also falls within this conceptualization. For Fraisse, rhythmic organization is the placing of discrete elements into groups, making more or less similar elements equivalent by placing them close in time and distinguishing between groups of now-equivalent elements by separating the groups in time.

The musical difficulty with this type of theory is

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that it is tied to a single melodic line. Thus, it cannot deal with thick polyphonic textures in which several instruments are playing at once, entering the piece at different times, each with a different, although related, rhythm. In these cases, there may be no melodic line *per se*, and grouping and accentuation would be based on the interaction of several dimensions: timing, texture, and orchestration (see Yeston, 1976).

The psychological difficulty is the lack of an appreciation that rhythm emerges from the interaction of the hierarchical levels of music. The simple rhythmic concepts of meter, beat, accent, and phrase are not found at any single level (or melodic line) but arise out of the interactions among levels. Chomsky and Halle (1968) took this view as almost self-evident in their analysis of English stress patterns, and we would suggest that music rhythms would require an equally deep analysis since musical rhythms are equally complex.

The predominance of grouping theories of rhythm and the lack of hierarchical analysis in rhythmic theory may be due to the relative simplicity of rhythm in Western music. Analyses based on rhythms found in Western melodies, utilizing only a limited set of rhythmic possibilities, can provide only a simplified view of rhythm. There are cultures in which the rhythmic structures are the main carriers of musical information, and here rhythms are complex textures, composed of contrasting pulse trains or alternating meters. It is for this reason that the perceptual study of complex rhythms might allow new kinds of understandings of rhythmic activity to emerge.

One possible type of complex rhythm is syncopated auditory polyrhythms. Polyrhythms are defined as the simultaneous presentation of two conflicting pulse trains. For example, in a 3 by 4 polyrhythm, the tone representing the 3-pulse train would occur three times per pattern repetition (i.e., per measure), while the tone representing the 4-pulse train would occur four times per pattern repetition. Each pulse train is isochronous and unchanging, and there is a common point at which the elements of each pulse train coincide.

Polyrhythms are ambiguous in that the rhythmic structure formed by the pulse trains is dissonant. To achieve a coherent interpretation, the elements of one pulse train are differentiated to serve as the controlling meter, and the elements of the other pulse train become superimposed on the meter pulse train. The interplay between the two creates the rhythm; the conflict results in syncopation. The metric pulse train both supports a coherent interpretation and serves as part of the polyrhythm. It is analogous to a visual contour or edge: It bounds and sets off a figure, yet is simultaneously part of that figure.

To study subjects' understanding of rhythm, we have used a task almost as commonplace as listening. The act of tapping feet (or hands) along with musi-

cal rhythms is easily performed by naive subjects and typically reflects the beat structure or meter in which the music is perceived. Beats are points of subjective accentuation separated by equal time intervals at which one taps hands or feet in time with the music. In musical terms, we are asking subjects to supply a time signature. Polyrhythms permit many possible meter organizations: (1) a pulse train can define the meter, achieved by tapping each tone in that pulse train; (2) a pattern repetition can define the meter, achieved by tapping each cooccurrence of the 2-pulse trains; and (3) alternative elements of a pulse train can define the meter, achieved, for example, by tapping every second element of a 4-pulse train.

Initial work by Oshinsky and Handel (1978) used 3 by 4 polyrhythms presented at different pattern repetition rates. The results indicated that individual differences as well as stimulus factors affected the meter interpretation. Some individuals preferred a meter based on one of the pulse trains; they tapped each element of the 3- or the 4-pulse train. Others preferred a meter based on the pitch of the tones; they tapped each low or high tone. On top of these preferences, the overall presentation rates also affected the perceived meter. At one intermediate rate, neither the slowest nor the fastest, the perceived meter reversed for nearly all subjects. This suggested that meter was an absolute function of the tempo, contradicting the commonsense notion that a rhythmic figure remains invariant through transpositions in time.

The purpose of the present experiment was to investigate extensively the perceived meter for a wide range of polyrhythms and tempos. While the previous work used only 3 by 4 polyrhythms within a restricted range of presentation rates, the present experiment utilized five different polyrhythms and a wider range of presentation rates.

The results reported here confirmed that meter interpretation is based on higher order perceptual interactions among the two pulse trains and not on simple acoustical or perceptual factors. The results also demonstrated different patterns of meter interpretation for the different polyrhythms. For some polyrhythms, meter interpretation was solely a function of the timing between elements, while for the others, meter interpretation was based on several factors: presentation rate, element frequency, and pulse train preferences. In addition, the results confirmed those of Oshinsky and Handel (1978) that rhythmic structure is not independent of tempo.

METHOD

Subjects

There was a total of 29 subjects. Seventeen subjects were undergraduates at the University of Tennessee and 12 subjects were undergraduates at Indiana University. All subjects were recruited from introductory psychology classes and represented a wide range of musical training.

Polyrhythms

Five different polyrhythms were used: 2 by 3, 2 by 5, 3 by 4, 3 by 5, and 4 by 5. The frequencies of the elements were generated by separate oscillators (Wavetek Model 134), and voltage-controlled amplifiers (BRS Module AC-251) created the amplitude envelope of each element.

Within each pulse train, the duration of an individual element was equal to one-half of the onset-to-onset interval. For example, if the time for a pattern repetition was 2 sec, then the onset-to-onset interval between adjacent elements of a 5-pulse train would be 400 msec, and the duration of each element would be 200 msec. The amplitude-time envelope of each note consisted of a 40-msec linear amplitude attack, with a linear amplitude decay for the balance of the duration. For the above example, the attack time would be 40 msec and the decay time would be 160 msec. Phenomenologically, the sounds are mellow, as opposed to the more biting tones achievable with shorter attack times. The tones of the two pulse trains were either identical in frequency (507 Hz) or separated by a musical fourth such that, in half the instances, one pulse was 440 Hz (musical A4) and the second pulse was 586 Hz (musical D5), and in half the instances, the frequencies of the pulse trains were reversed.

Pattern Repetition Rates

Eleven rates of presentation were used. In terms of seconds/pattern repetition or seconds/measure, the rates were 3.0, 2.4, 2.0, 1.8, 1.6, 1.4, 1.2, 1.0, .8, .6, and .4 sec. These rates were chosen to sample exhaustively the domain. At the slow end of the continuum (3.0 sec/pattern repetition), the elements could be so separated in time that a continuing rhythm might not emerge; at the fast end of the continuum (.4 sec/pattern repetition), the elements could occur so quickly that the elements might be perceived as forming subjective groups.

Experimental Task

The distinction between rhythm and meter was described, and subjects were told to tap along with the perceived beat ("to keep time"). Subjects as a rule were not musically sophisticated, and the more common term "beat" was given the definition corresponding to meter. This distinction was illustrated with the example of a player in a marching band who plays a *rhythm* while marching to the *beat* of the music. The task was distinguished from "shadowing" the pattern (i.e., tapping every element).

On each trial, a polyrhythm was presented for 15 sec, during which time subjects merely listened. After a 5-sec silent pause, the polyrhythm was repeated, and subjects tapped a telegraph key along with the pattern to indicate the beat. The telegraph key triggered another audio oscillator, which was not audible to the subject. The clicking of the telegraph key was the only feedback available to the subject. Stimuli were presented stereophonically by one tape recorder (Sony TC-353) while a second tape recorder (Sony TC-253) simultaneously recorded the polyrhythm on one track and the subjects' responses (i.e., the tone bursts triggered by the telegraph key) on the second track.

Stimulus Presentation

The experimental session took place in a small room (3 × 4 m) lined with acoustical tile. Subjects were seated 2.5 m from two adjacent speakers, each of which presented one pulse train. All patterns were presented at a comfortable listening level, approximately 55 dB SPL.

Experimental Design

The experiment was done in two sections. The first, and major, section encompassed nearly all conditions. The second section was used to fill in missing conditions and to obtain additional data for those conditions that had ambiguous outcomes in the first section.

The first section was composed of 150 conditions: 5 polyrhythms by 10 presentation rates (ranging from 2.4-sec/pattern repetition to .4-sec/pattern repetition) by 3 frequency conditions (pulse trains

either were identical in frequency or were separated by a musical fourth). The 17 subjects recruited at the University of Tennessee were tested individually using all 150 polyrhythms in a 2-h session.

The second section was composed of 66 conditions. The 5 polyrhythms by 3 frequency conditions were presented at the 3-sec/pattern repetition rate (15 in total). The remaining conditions were chosen to obtain further data from ambiguous conditions. In total, there were 6 conditions for the 2 by 3 polyrhythm, 12 conditions for the 2 by 5 polyrhythm, 24 conditions for the 3 by 4 polyrhythm, 12 conditions for the 3 by 5 polyrhythm, and 12 conditions for the 4 by 5 polyrhythm. The 12 subjects recruited at Indiana University were tested individually on all 66 polyrhythms in a 1-h session.

For both sections, the order of presentation was counterbalanced, and the two pulse trains as well as the two frequencies were presented equally often to the left and right speakers. No position preferences were found.

RESULTS

Preliminary analyses indicated that there were three main response classes that accounted for 98% of the responses: (1) The major class (80%) was responses in synchrony with the elements of one of the pulse trains, that is, tapping every element of the 2-, 3-, 4-, or 5-pulse train. (2) The second major class (12%) was responses on only the cooccurrence of the two pulses, or once per pattern repetition (once per measure). These were termed *unit* meter responses. (3) The third class (6%) was responses to every second or every third element of one of the pulse trains. The most common response was tapping every other element of the 4-pulse train, or twice per measure, but odder fractions also occurred (e.g., every other element of a 3-pulse train). Since these responses indicated the salience of a given pulse train, they were combined in the analyses with the appropriate pulse-train response (e.g., tapping every other element of the 4-pulse train was considered a 4-pulse-train response).

To determine the extent to which meter interpretation was consistent across subjects, each response was coded on the basis of the above classification. Then a subject by subject overlap correlation matrix was constructed indicating the agreement in meter interpretation among each pair of subjects. A separate overlap matrix was constructed for each polyrhythm and each group of subjects. The matrices then were partitioned by trial and error to determine whether there were clusters of subjects displaying contrasting patterns of metric interpretation. For three of the polyrhythms—2 by 3, 3 by 4, and 3 by 5—all subjects responded in the same fashion and the data were combined across subjects. For the 2 by 5 polyrhythm, there were two clusters of subjects, while for the 3 by 5 polyrhythm, there were three clusters of subjects. For the latter two polyrhythms, the data from each cluster were combined and analyzed separately. All except two subjects could be clustered, so the results reported here are based on 27 subjects.

The final step of the analysis was to determine the basis of the meter interpretation for each subject cluster. Two basic strategies emerged. The first strategy was to tap along with every element of one particular pulse train without regard to element frequency. The second strategy was to tap along with the lower pitch element without regard to pulse train.

For some polyrhythms, all subjects utilized the same strategy. For others, each cluster of subjects used a different strategy. The nature of the meter interpretation and the degree of individual consistency provide a classification scheme for the polyrhythms. In what follows below, the five polyrhythms are grouped according to these two factors.

Pulse Train Preferences:

2 by 3 and 3 by 5 Polyrythms

The meter interpretations of the 2 by 3 and 3 by 5 polyrhythms were the simplest of the lot. All subjects preferred to tap along with the quicker, more frequent pulse train (the 3-pulse train of the 2 by 3 polyrhythm; the 5-pulse train of the 3 by 5 polyrhythm) at all but the fastest presentation rates. At the faster rates, when the interelement interval of the quicker pulse train was less than 250 msec (1.2-sec/pattern repetition for the 3 by 5 polyrhythm; .8-sec/pattern repetition for the 2 by 3 polyrhythm), the preferred response changed. For the 3 by 5 polyrhythm, the preferred response switched to a 3-pulse train until the interelement interval of that pulse train also was less than 250 msec (.6-sec/pattern repetition). Then unit meter responding increased. For the 2 by 3 polyrhythm, 2-pulse train, 3-pulse train, and unit meter responding became equally preferred at the .6-sec/pattern repetition rate, while at the fastest rate (.4-sec/pattern repetition), only 2-pulse train and unit meter responding occurred. These results are shown in Figure 1.

Frequency Preferences: 3 by 4 Polyrythms

The meter interpretation of 3 by 4 polyrhythms, while a function of the pulse trains themselves, depended mainly on the element frequencies. This interplay between pulse train and frequency can be understood by considering the three possible frequency conditions.

If the tones of the two pulse trains were the same frequency (Figure 2, panel A), the 4-pulse train was slightly preferred in the range from 2.4-sec/pattern repetition to 1.6-sec/pattern repetition, there was equal preference between 1.6- and 1.0-sec/pattern repetition, and there was preference for the 2-pulse train at .8-sec/pattern repetition, which yielded to preference for unit response at the fastest rate. This is the identical pattern as found previously: preference for the more frequent pulse train at slower presentation rates, preference for the less frequent pulse train at the faster presentation rates, and preference for unit meter at the fastest rates.

Figure 1. The meter interpretations for the 2 by 3 and 3 by 5 polyrhythms.

If the tones of the two pulse trains differed, the lower pitch element was the preferred frequency. If the 3-pulse train was the low pitch element (panel B), it became the preferred meter at all but one presentation rate, and if the 4-pulse train was the low pitch element (panel C), it became the preferred meter except at the fastest rates. The frequency of the elements, therefore, had a powerful effect on meter interpretation overriding weak preferences based on the timing of the pulse trains.

Individual Differences in Pulse Train Preferences: 2 by 5 Polyrythms

There were individual differences in pulse train preference for the 2 by 5 polyrhythm. The meter interpretations for subjects displaying 2-pulse train and 5-pulse train preferences are shown separately in Figure 3. For the majority of subjects (78%), the 5-pulse train was much preferred until the 1.0-sec/pattern repetition rate, at which time the slower 2-pulse train became dominant. For the smaller sec-

Figure 2. The meter interpretations for the 3 by 4 polyrhythm.

ond group of subjects (22%), the 5-pulse train was also preferred at the slowest rates, but the 2-pulse train became dominant at much slower presentation rates around 1.8 sec/pattern repetition. Both clusters displayed the same qualitative pattern, but this latter group had a stronger preference for the 2-pulse train, since the transition occurred at a far slower rate for them than for the former group of subjects.

Individual Differences in Pulse Train Preferences and Frequency Preferences: 4 by 5 Polyrhythms

The 4 by 5 polyrhythms yielded the most complex pattern of outcomes. Some subjects displayed preferences for one or the other of the two pulse trains,

while other subjects displayed frequency preferences.

Panels A and B of Figure 4 show the percentage choice of the 4- and 5-pulse trains for those subjects displaying a preference for the 4-pulse train and 5-pulse train, respectively. For subjects displaying a 4-pulse train preference, the preference was roughly constant across the entire range of presentation rates. However, at rates faster than 1.0-sec/pattern repetition, at which the interelement interval was less than 200-250 msec, the response switched to tapping once per repetition or unit meter. For those subjects displaying a 5-pulse-train preference, the 5-pulse train was preferred (although not to the same degree as subjects with a 4-pulse-train preference) up to the 1.0-sec/pattern repetition rate. At this and faster rates, the 4-pulse train became preferred until the fastest rate, at which unit meter was dominant. This is the identical pattern for pulse train meters found previously.

A third group of subjects displayed preferences determined mainly by element frequency (panel C). If the tones of the two pulse trains were equal in fre-

Figure 3. The meter interpretation for the 2 by 5 polyrhythm.

Figure 4. The meter interpretations for the 4 by 5 polyrhythm.

quency, the 5-pulse train was preferred at the slower rates, while the 4-pulse train was preferred at the intermediate and faster rates. As found for the 3 by 4 polyrhythms, the low pitch was the preferred element. Thus, if the 4-pulse train was the low-frequency tone, it became preferred at all rates, but if the 5-pulse train was the low-frequency tone, it became preferred at rates down to 1.0-sec/pattern repetition (200-msec interelement interval), at which point the slower moving 4-pulse train became preferred. In all instances, unit meter was the dominant response at the faster rates.

It can be seen that the 4 by 5 polyrhythm did not yield a unique response strategy; one or more of the above strategies were utilized for the other polyrhythms. However, the complex configuration of the 4 by 5 polyrhythm did allow all of the possible strategies to emerge.

DISCUSSION

The perceived beat depended on the global rhythmic properties of the polyrhythm and the timing between

the individual elements of each pulse train, as well as on the frequency of the elements. The rhythmic properties of each polyrhythm appeared to determine the range of possible meter interpretations. The timing between elements appeared to determine the "role" of a pulse train. A pulse train may be perceived in the background at one rate, thus serving as the meter for the polyrhythm, and yet may be perceived in the foreground at a different rate, thus serving as the "rhythmic melody" of the polyrhythm. Each of these factors—the rhythmic properties and the timing between elements—will be discussed below.

Rhythmic Properties of Polyrhythms: A Lattice of Meter Interpretations

The rhythmic configuration of each polyrhythm seemed to constrain or restrict the possible kinds of metric interpretations. Some polyrhythms allowed but one meter, yet others allowed many different meters. The range of meter interpretations provided a means to interrelate the polyrhythms. On the basis of the meter interpretations, the five polyrhythms could be placed into four groups. In turn, the four

groups could be conceptualized as being arranged in a lattice, such that the meter interpretations found for some polyrhythms represented the union or combination of the interpretations that characterized other polyrhythms.

The 2 by 3 and 3 by 5 polyrhythms were found in one group, since they produced only one type of interpretation. All subjects tapped along with the faster pulse train until a specific presentation rate, then switched to the slower pulse train, and at the fastest rates tapped only the simultaneous occurrence of elements of the two pulse-trains. It is tempting to argue that these polyrhythms are perceptually the simplest and thus they overdetermine the possible rhythmic interpretations. Unfortunately, while the 2 by 3 polyrhythm is indeed simple, the 3 by 5 sounds far more complex and syncopated. Thus, simplicity does not in itself predict meter interpretation.

There were two intermediate groups. In the first, containing the 2 by 5 polyrhythm, meter interpretation was based on the pulse trains *ser se*, but there were individual preferences in the choice of the pulse train used as the beat. This preference did not occur at all presentation rates but was found when considering the rate at which there is a transition from the faster 5-pulse train to the slower 2-pulse train. For the 5-pulse-train-preference subject cluster, the 5-pulse train was preferred down to the 1.0-sec/pattern repetition rate. In contrast, for the 2-pulse-train-preference subject cluster, the 5-pulse train was preferred only to the 1.8-sec/pattern repetition rate. We would suggest that at the slowest presentation rates, the elements of the 2-pulse train are so separated temporally (1.5 to 1.0 sec between element onsets) that they cannot be heard as a rhythmic structure. It is for this reason that subjects displaying a 2-pulse-train preference chose the 5-pulse train at the slowest presentation rates.

The second intermediate group occurs for the 3 by 4 polyrhythm. In contrast with the 2 by 5 polyrhythm, all subjects responded similarly, but the meter interpretation was determined by the frequency assignment and not only by the temporal relationship among the elements. If the frequency of the two pulse trains was identical, there was a slight preference for the 4-pulse train at the slower rates and for the 3-pulse train at the faster rates. If the pulse trains were of different frequency, the low-pitch pulse train was preferred. Thus, if the 3-pulse train was the low-pitch element, then it was preferred; if the 4-pulse train was the low-pitch element, then it was preferred. For this polyrhythm, pitch preference overwhelms weak preferences for one of the two pulse trains.

The low-pitch preference found here is not specific to the two pitches used in the present study. In work using polyrhythms composed of three pulse trains

(e.g., 3 by 4 by 5), there was a low-pitch preference using frequencies of 262 Hz (C4), 330 Hz (E4), and 392 Hz (G4).

The 4 by 5 polyrhythm yielded the most complex set of meter interpretations, encompassing all the possibilities found separately for the other polyrhythms. The largest cluster of subjects (40%) displayed a preference for the 5-pulse train, while the smallest cluster of subjects (22%) displayed a preference for the 4-pulse train. The remaining subjects (37%) varied their interpretation as a function of the pitch of the pulse trains. For the latter group of subjects, if the frequency of the two pulse trains was identical, the 5-pulse train was preferred at the slow rates and the 4-pulse train was preferred at the faster rates. If the frequency differed, the low-pitch pulse train was preferred. These results mirror those found for the 2 by 5 polyrhythms in which pulse-train preferences occurred and those found for the 3 by 4 polyrhythms in which pitch preferences occurred.

The relationship among the polyrhythms in terms of the meter interpretation is that of inclusion. While the polyrhythms did differ in meter interpretations, it was not the case that each polyrhythm yielded a unique type of meter. Rather, the more complex polyrhythms yielded a set of interpretations that includes as a subset those found for simpler polyrhythms. Consider the 2 by 3 and 3 by 5 polyrhythms as a base: Here, a single interpretation was found utilizing only the timing among the elements of the pulse trains. The interpretation of the 2 by 5 polyrhythm was also based on the timing among elements, but two styles of interpretation were found, reflecting that each pulse train could serve as the beat over a wide range of presentation rates. In comparison with the 2 by 3 and 3 by 5 polyrhythms, the 2 by 5 polyrhythm was inherently more ambiguous, allowing two response styles to occur: The slower or faster pulse train could serve as the meter. The interpretation of the 3 by 4 polyrhythm was based on element frequency, not only on the timing. In addition to meter based on the timing of the pulse trains, meter here is based on pitch preferences. In comparison with the 2 by 3 or the 3 by 5 polyrhythm, the 3 by 4 polyrhythm is more rhythmically complex, since both pitch and timing determine the perceived beat. In sum, both the 2 by 5 and 3 by 4 polyrhythms are in an inclusion relation to the 2 by 3 and 3 by 5 polyrhythms, albeit in different ways. The interpretations found for the 4 by 5 polyrhythms included all of those described above: Groups of subjects displayed consistent preferences for each of the pulse trains, as well as preferences for meter interpretation based on element frequency. These represent the union of meter interpretations found for the other polyrhythms.

These results illustrate the diversity of possible

meter interpretations. The rhythmic configuration of each polyrhythm acts to delimit these possibilities. The rhythmic configuration is not due to the properties of either one of the pulse trains; rather, it is due to the interaction between the two pulse trains. For example, the two polyrhythms that have the most restricted meter interpretations—2 by 3 and 3 by 5—are composed of the simplest (i.e., 2-pulse train) and the most complex pulse trains (i.e., 5-pulse train).

Interelement Timing: Background and Foreground

Although the configuration of each polyrhythm appeared to determine the range of possible interpretations, the temporal characteristic among the elements of each pulse train determined the actual meter or beat at any presentation rate. These results can be best understood by considering the way a meter structures a rhythm. The function of a meter is to provide a lattice against which the foreground elements can be structured. Thus, in general, the meter should be the "slower" moving pulse train (e.g., the 3 in the 3 by 5 polyrhythm). However, there are rates so slow that the elements of a pulse train are too separated temporally to remain coherent. The elements are phenomenologically "individual" and are not heard as a regularly recurring background. The essential periodicity or repetition of the rhythm is lost. Similarly, there are rates so fast that the elements of a pulse train are too close temporally to remain background. The elements become grouped and part of the foreground; the listener must find a slower periodicity to serve as the meter.

Consider, first, the transition from disjoint elements into a coherent beat at slow presentation rates. The fact that elements may be so separated in time that they cannot act to organize the foreground elements can be seen from the results for the 3 by 5 and 2 by 5 polyrhythms. For both of these polyrhythms, the faster 5-pulse train was perceived as the meter at the slower presentation rates, although the slower pulse train should have served as the beat, according to musical theory. We would suggest that the interelement interval must be less than 500–700 msec before the elements of a pulse train can serve to structure the polyrhythm. At greater separations, the elements are heard as being unrelated, the silent interval between the elements is perceptually salient, and the elements do not easily combine into a coherent, continuing string that could serve as a beat (Fraisse, 1963). Also, Bartlett and Bartlett (1959) have suggested that whenever the interelement interval exceeds 500 msec, memory becomes important in the synchronization of a motor response with an auditory element. This would support our suggestion that very slow-paced elements are ill-suited to carry the beat. Empirically, the 3-pulse train was not chosen with any consistency until the presentation rate reached 1.8-sec/pattern repetition or a 600-msec in-

terelement interval. This factor can be demonstrated even more strongly by considering meter choice for those subjects who preferred the 2-pulse train in the 2 by 5 polyrhythm. In spite of this preference, the 2-pulse train was not the preferred meter until the 1.6-sec/pattern repetition rate, or an 800-msec interelement interval. Similar outcomes can be found for the other polyrhythms (e.g., the 4-pulse-train preference cluster for the 4 by 5 polyrhythm), although these results are confounded by pitch preferences.

On the other side of the coin, there are rates at which the elements are so tightly packed temporally that the pulse train must become part of the foreground; the elements of the pulse train are no longer heard separately. The elements are heard in groups, and the pulse train becomes part of the rhythmic melody of the pattern. For these polyrhythms, this transition point is about 200 msec; that is, if the interval between successive elements of a pulse train is less than 200 msec, listeners must find a slower periodicity to serve as the meter. Empirically, the use of the 5-pulse train decreased sharply at the 1.2- or 1.0-sec/pattern repetition rate for the 2 by 5, 3 by 5, and 4 by 5 polyrhythms; the use of the 4-pulse train decreased sharply at the .8-sec/pattern repetition rate for the 3 by 4 and 4 by 5 polyrhythms, and similarly, the use of the 3-pulse train decreased sharply at the .6-sec/pattern repetition rate for the 2 by 3, 3 by 4, and 3 by 5 polyrhythms. At the fastest rates, subjects either tapped alternate elements of a single pulse train or tapped on the cooccurrence of the two pulse trains, once per measure.

While the ability to synchronize the motor tapping response to the elements of a pulse train may be the ultimate limiting factor in some situations, this limitation does not explain the present transition at an interelement interval of about 200 msec. Although there is large subject variability, the bulk of published research on synchronization to a repeating, isochronous auditory signal suggests that performance breaks down at a faster rate, approximately 6 or 7 elements/sec (Bartlett & Bartlett, 1959; Michon, 1967; Miles, 1937). Thus, the meter changeover to a slower rate is not due merely to a motor constraint. Supporting the view that this transition is a perceptual effect is work on subjective rhythm. Harrell (1937) attempted to find the presentation rate of isochronous pulses that led to the best grouping into twos, threes, fours, fives, and sixes. Although the presentation rate must increase in order to generate larger sized groups, this increase is relatively modest. The optimal interelement interval for groups of two was 227 msec, while the optimal interelement interval for groups of five was 190 msec. These intervals closely match the 200-msec interelement interval found in the present study at which the individual elements of the pulse train no longer

serve as the beat. This suggests that, at faster rates, the elements of a pulse train are perceived as grouped, with subjectively accented and unaccented elements, and therefore cannot serve directly as the meter. The subunits, however, can serve as the meter, and this leads to tapping every second, third, or fourth element or tapping every pattern repetition.

This is not to argue that the perceived meter is based simply on the timing between elements. Rather, it represents an impression, a perceived organization. Timings that become the meter in one polyrhythm or musical context may not be perceived as the meter in a different polyrhythm or context. Moreover, the timings found here, defining the transitions between elements and meters and between meters and groupings, should not be construed as being fixed or invariant. Instead, they occur within the rhythmic configurations produced by these polyrhythms.

Rhythm in General

These results illustrate the advantage of a hierarchical conceptualization of rhythm. With polyrhythms of this order of complexity, the meter or beat is not due to a pattern of accented or unaccented elements, and it is not inherent in either pulse train. The beat emerges from the interplay between the pulse trains. This allows the identical pulse train to serve different functions, depending on the properties of other pulse trains.

We think it critical that rhythmic theory leave behind notions based on simple accented/unaccented rhythmic units. Analyses of this sort always involve post hoc considerations based on the theorist's intuitions about the intentions of the composer. While an appeal to musical intentions may prove successful in a small number of instances, it will clearly limit the ultimate generalizability of any theory.

One final point should be made. Rhythm cannot be abstracted from presentation rate or tempo. Rhythm does not remain invariant across changes

in tempo; rather, the rhythm emerges at a specific tempo. This contradicts the commonsense notion of constancy of rhythm across accelerations and decelerations. While an object may expand or contract without changing its perceived shape, rhythm is far more labile, since it results in dramatic perceptual changes at slower or faster rates. This point further supports the argument that there are no ultimate rhythmic units.

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