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The Influence of Pitch Interval on the Perception of Polyrhythms

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Research by S. Handel and J. S. Oshinsky (1981) has shown that when tapping to polyrhythms, people synchronize with different subsequences depending on the overall tempo, with a global change from the faster component at slow tempi to the slower component at medium tempi and then to the overall repeating pattern at fast tempi. In this article, similar polyrhythmic patterns are studied, adding larger pitch intervals between the two sequences. The results largely confirm the findings of Handel and Oshinsky at small pitch intervals, but at larger pitch intervals, the importance of the overall pattern decreases in favor of the slow component of the polyrhythm. This effect can be explained by the increased possibility for streaming of the two components and the decrease in peripheral interaction of the coinciding tones. The results of the experiment are modeled following the resonance model for temporal selectivity proposed by L. Van Noorden and D. Moelants (1999). The preference for certain subsequences can be explained as a resonance phenomenon with a natural frequency of 2 Hz.

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ONE way to study auditory pattern perception is to observe what subjects perceive when two auditory sequences are presented simultaneously. Depending upon the physical relation between the two sequences, they will merge into a single line or be perceived as two separate, simultaneously proceeding lines. For example, with two (alternating) tone sequences "A . A . A" and "B . B . B," one will perceive two separate sequences if the pitch[1] dis-

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[1] In this article, *pitch*, which is the name of a subjective entity, will be used for the frequency of a tone that gives an audible pitch. As we use only pure tones in this study, this will not give rise to confusion. The pitch interval is expressed in semitones, which is a physical entity. The term *frequency* will be used only in the context of the tempo of tones. The inverse of frequency is the period T.

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tance between them is large. This phenomenon has been called *fission* (Van Noorden, 1975) or *streaming* (Bregman, 1990; Bregman & Campbell, 1971). When the pitch interval gets smaller, there will be a switch to the perception of a single alternating auditory pattern “ABABAB. . . .” The precise frequency separation at which the transition between the two percepts occurs depends upon the tempo and the attention of the observer (Van Noorden, 1975).

Another example of a study that investigates the auditory perception process through the combination of two tone sequences is the work of Stephen Handel and James Oshinsky on the meter of polyrhythms (Handel, 1984; Handel & Oshinsky, 1981). In their experiments, isochronous pulse trains of which the rates form simple, noninteger ratios (e.g., 3:4 or 2:5) were presented simultaneously. The subjects were asked to tap along with the “perceived meter.” In very fast sequences, people tend to tap in synchrony with the merged, overall pattern; in very slow sequences, in synchrony with the faster pulse train; and in medium speeds, in synchrony with the slower component. One may say that, depending on the speed, the two sequences that make up the stimulus merge in perception or stay separate with a gradual change in dominance from the slow to the fast component with decreasing tempo.

Selectivity in Pitch and Tempo

These two strains of research show that both the pitch interval and the tempo difference play a role in the formation of auditory pattern percepts. The experiment presented here sets out to study the combined effect of these two factors. The choice of the stimuli is based on the polyrhythms used by Handel and Oshinsky (1981), but larger pitch intervals are added. At these larger pitch intervals, the simultaneous tones of the pattern will probably interfere less with each other. In the inner ear, a spectral analysis takes place and different nerve cells transmit different tonal components, creating “critical bands” within which there is a strong interaction between pitches. Hearing serves as an “auditory scene analyzer” that can group sounds that seem to emanate from the same source against the background of other sounds (Bregman, 1990). As it is the case for alternating sequences (Van Noorden, 1975), we also can expect that in the perception of polyrhythms, the further the two sequences are apart in pitch, the easier it will be to hear them as two different streams. On the other hand, the closer the coinciding tones are together, the more peripheral interaction one can expect. Tones that coincide in the same critical band will undergo changes (e.g., in loudness) and create beats or roughness. These effects may enhance the period of the overall combined polyrhythm pattern in the perception. Both effects reinforce each other: small pitch intervals strengthen the overall pattern, and large pitch intervals promote the appearance of the separate streams. In this article, we will see how important the influence of pitch is: Do two co-occurring rhythmic sequences create complex patterns by their mere combination or is there a need for peripheral auditory interaction? Before turning to the actual experiment, it is necessary to give a short review of the resonance theory for temporal selectivity, as it is important to understand the mechanism that is behind the perception of the patterns presented in the experiment and that will be used for the interpretation of the results.

The approach taken by Van Noorden and Moelants (1999) is to consider the human rhythm perception system as (a reflection of) a physical system. It is a characteristic of all physical bodies in nature that they react to an alternating force by a certain amount of vibration. The amplitude of this vibration depends on the strength of the alternating force, the mass of the physical body, and the force that tries to restore the body back to its original position. The mass and the restoring force together determine its resonance frequency. If the frequency of the external alternating force is close to this frequency, the body will vibrate more intensely than when the frequency is further away. The loss of motion energy during the vibration, or damping, depends on the resistance of the body. The larger the damping, the less intense will be the vibration at the resonance frequency, yet the range of neighboring frequencies where the influence of the resonance frequency is felt will be relatively broader. It should be clear that we consider the approach with the harmonic oscillator a simplification of reality. If the rhythm perception system reflects the characteristics of our physical body, one has to observe that that body is a complex system with many modes of vibration and thus shows a much more complex behavior than the simple mass-spring system that is actually modeled by the resonance curve.

Starting from the idea of perception based on a physical system, temporal selectivity can be modeled using the characteristics of such a physical oscillating system, when excited by a periodic external force. This is done (Van Noorden & Moelants, 1999) by calculating the amplitude of an oscillator with a resonance frequency f_0 and a damping factor β, activated by an external force with a frequency f_{ext} and subtracting it from it the amplitude of a critically damped oscillator with the same f_0. This gives us the "effective" amplitude A_e using the formula:

$$A_e = \frac{1}{\sqrt{(f_0^2 - f_{\text{ext}}^2)^2 + \beta f_{\text{ext}}^2}} - \frac{1}{\sqrt{f_0^4 - f_{\text{ext}}^4}}$$

If we calculate this for the whole range of external tempi, the result is a resonance curve with a peak at f_0 (Figure 1).

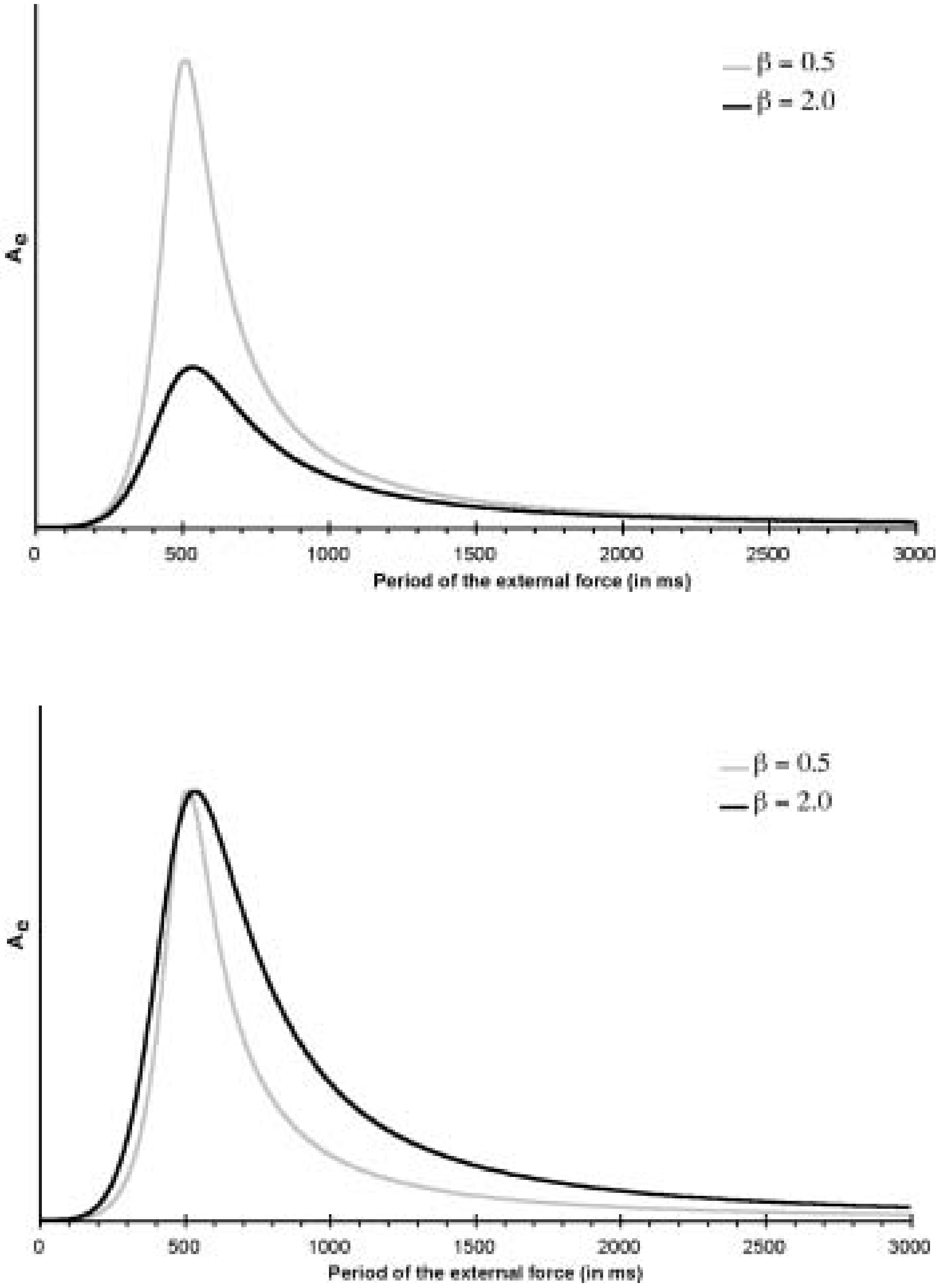

Fig. 1. Examples of “effective” resonance curves with f_0 = 2 Hz (T = 500 ms), showing the effective amplitude with the tempo of the periodic external force ranging from 0 to 3000 ms. The upper graph shows the absolute values when applying the formula, the lower graph a normalized version, with the peak at 100%. In each, two curves are shown, one with a high damping (β = 2.0) and one with low damping (β = 0.5). The lower graph shows that increasing the damping makes the peak relatively broader.

Van Noorden and Moelants (1999) have shown that this model can serve as the basis for explaining the phenomena of subjective rhythmization (Vos, 1973) and preferences in tapping to isochronous sequences (Parncutt, 1994). The results of Handel and Oshinsky (1981) show more complex interactions that might suggest that there are several resonant frequencies (Van Noorden, 1991). However, Van Noorden and Moelants (1999) have shown that the results can be explained with a single resonator model. In the modeling, the resonance frequency of the human rhythm perception system (in the case of synchronization tapping) was found close to 2 Hz. This value corresponds to the natural tempo of simple repeated movements like finger tapping, clapping, and walking (Moelants, 2002), the so-called "preferred tempo" (Fraisse, 1982). A preference for tempi around 120 bpm (2 Hz) has also been found in the distribution of tempi in different samples of music. Here we also find the typical long tail toward slow periodicities that also characterizes the physical resonance curve (cf. Figure 1). The resonance frequency corresponds thus to a moderate, natural tempo and the bandwidth of the resonance curve covers the common range of slow to fast tempi as found in large samples of music and in music theory. We will use this model as a basis for analyzing the time dependence of the data from the following experiments, and we will try to extend it with the influence of the pitch interval.

Some Pilot Observations

Handel and Oshinsky (1981) asked the subjects to tap along with the most dominant periodicity in the polyrhythm. However, temporal coherence and fission as studied by Van Noorden (1975) are primarily perceptual phenomena, and one could expect some interference of motor constraints when tapping is required in the response. In order to check this idea and to find out what is an effective range of pitch intervals, the authors made some pilot observations in which the strength of the two components and of the overall pattern was determined, not by tapping, but by a perceptual judgment.

STIMULI

To the stimuli used by Handel and Oshinsky (1981), some pitch interval conditions are added. Doing so should both allow comparison with their results and make it possible to demonstrate the effects of pitch interval. To keep the number of stimuli within limits, the number of polyrhythms was limited to three: 2:5, 3:5, and 4:5, and the stimuli were presented at the same 11 different base tempi ranging from 400 to 3000 ms (400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, 2400, and 3000 ms). At each of these tempi, three different pitch interval conditions were used: an interval of 5 semitones (a perfect fourth, corresponding to the stimuli used by Handel & Oshinsky, 1981), a small interval of 1 semitone (around the fission boundary found by Van Noorden, 1975), and a large interval of 29 semitones (a perfect fourth plus two octaves). The sinusoidal tone bursts had frequencies of 440–466, 440–586, and 220–1172 Hz, respectively and a duration of 50 ms, with 5-ms slopes for rise and release. The stimuli were presented monophonically by headphones (i.e., the same signals to both ears) at a comfortable listening level. In order to avoid effects of pitch preference on the perceptual strength, all stimuli are repeated in two different pitch positions: fast-high, slow-low and fast-low, slow-high. This makes up a total number of 3 patterns × 3 pitch intervals × 2 pitch positions × 11 tempo conditions = 198 stimuli overall.

PROCEDURE

Three horizontal sliders were depicted on a computer screen, corresponding to the fast component, the slow component, and the overall pattern. The subjects had to adjust each of the sliders to a horizontal position that corresponded to the perceptual strength of the three periods. The slider scales were linear scales from zero (left) to very strong (right). This adjustment was made for each stimulus in a random order. The time spent per stimulus was free, the whole set of 198 stimuli took 2 to 3 hours to judge. The two authors served as subjects.

RESULTS

If we look at the relative strength of the components in relation to the base tempo (Figure 2a), we see the expected pattern, with an increase in the perceived strength of the fast component and a decrease in the strength of the overall pattern as the base tempo increased. Figure 2b shows the strong influence of the pitch interval on the perceived strengths of the different components. In the case of a 29-semitone separation, the two test observers agreed that virtually no combined pattern was perceivable, whereas at the 1-semitone separation, the average total strength of the overall pattern was comparable to the strength of the slow and the fast component.

The results of the pilot experiment show that range of tempi and pitch intervals seem adequate to show the effect of pitch interval on the perceived strength of the components. However, the task of judging the perceptual strength is considered very difficult and fatiguing. The main methodological problem with this approach is that participating subjects have to know very well what to listen for. At that point, it becomes very

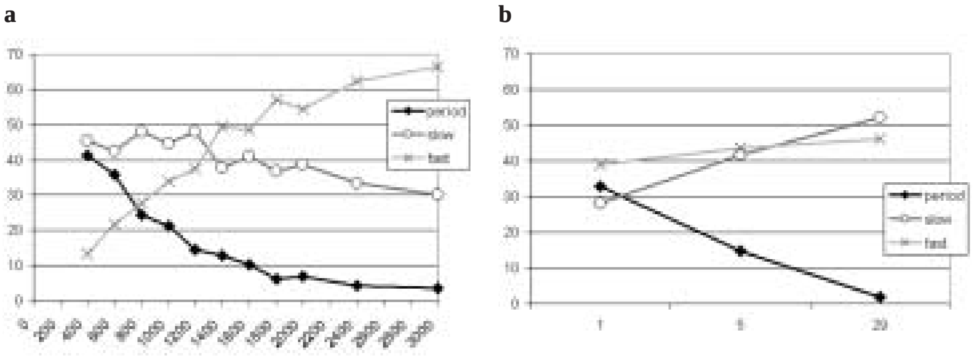

Fig. 2. Results of the pilot experiment, representing the mean strength of each of the three components, as reported by the two participants. (a) the influence of base period, ranging from 400 to 3000 ms, and (b) the influence of pitch interval, 1, 5, or 29 semitones between the components.

hard to make a good distinction between spontaneous perceptual responses and the influence of prior knowledge. It was therefore decided to go back to a tapping paradigm for a more definitive study on the influence of the pitch interval. The stimuli were exactly the same as in the pilot experiment.

Main Experiment

SUBJECTS

Twenty-six subjects participated in the experiment. They were all students, alumni, and staff members of the musicology department of Ghent University and can thus be regarded as musically skilled. Their mean age was 28 years; 15 were male, 11 were female.

SETUP

Subjects were seated in front of a PC in a quiet room. The 198 stimuli were presented through headphones. The order was varied randomly for each subject. Subjects were instructed to tap on the space bar of the computer keyboard along with what they considered to be the most appropriate regular period in the excerpt. Instructions were given both on the screen and by the experimenter. The stimuli were presented by using a pd-patch (see http://www.pure-data.org/). Each polyrhythm was presented for 20 s, after which subjects could choose to retry or to go to the next polyrhythm. In order to keep concentration, subjects were free to take one or two breaks in which they could have a drink.

ANALYSIS OF THE RESPONSES

For the classification of the responses, the use of simple statistics like mean or median intertap interval turned out to be inappropriate, mainly because of irregularities such as missing taps or multiple taps caused by holding down the key. Therefore a visual method was used, comparing dots corresponding to the responses with a grid representing the stimuli (see Figure 3).

RESULTS

In most cases (81.4%), subjects tapped to every beat of one of the two components or to the overall repeating pattern. Sometimes one or more stimulus beats are skipped or subdivided. Subdividing occurs only sporadically (0.8% of the responses), with doubling the tempo (i.e., subdividing by two) of one of the three constituents being most common (0.6% of the responses). Tapping at a slower speed by skipping stimulus tones is much more common (17.8% of the responses), with skipping one stimulus being most common (15% of the responses), tapping every four (1.6%) or every three stimulus tones (0.5%) is less common. The skipping of stimulus tones happens primarily at speeds in sequences with a period of less than 400 ms; thus skipping occurs most often with the fast component (5 stimuli in one base period) and hardly at all on the overall pattern (see Figure 4). In the following analysis, multiplications or subdivisions will be summed together with the responses following every tone of one of the three constituent patterns, as was done by Handel and Oshinsky (1981).

In 27.3% of the responses, subjects tap along the overall repeating pattern. If we look at the tempo difference, 38.4% of the responses followed the fast series (5), and the remaining 34.3% followed the slow component (2, 3, or 4). If we look at the pitch position, 34.0% synchronizes with the

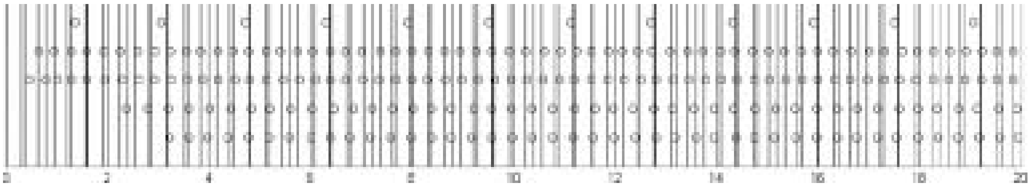

Fig. 3. Responses of 5 subjects to a 5:4 polyrhythm (base period 1600 ms, pitch interval 29). The thick lines in the grid represent the overall repeating pattern, the smaller lines the other stimulus tones. The circles represent the location of the subjects' taps, with one horizontal line for each subject. The first subject (top) taps to the overall pattern, Subjects 2 and 3 follow the fast component (5) and the bottom two subjects follow the slow component (4). Despite the variance and the similarity in intertap interval (400–320 ms), the difference between the fast and the slow component is clearly visible.

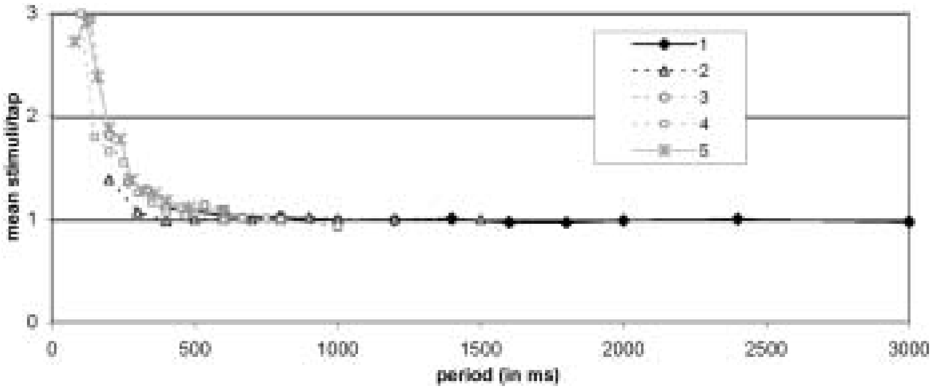

Fig. 4. Average number of stimulus tones between taps over all conditions. On the vertical axis, 1 means tapping on every stimulus tone, 2 means a tap on every other stimulus tone, and so on. The results are shown for the different pulse trains and the overall pattern (1) separately over the whole range of stimulus tempi. The agreement between the different curves shows that skipping tones is merely a function of the tempo of the pulse train with which the subjects synchronize.

high and 38.7% with the low component of the polyrhythm. In the following analysis, we will check which factors influence the choice for (a) the whole pattern, (b) the fast or the slow component, and (c) the high or the low component. Each time the influence of three stimulus set dimensions will be controlled: the base tempo (11 values between 400 and 3000), the type of polyrhythm (2:5, 3:5, 4:5), and the pitch interval between the high and the low component (1, 5, or 29 semitones). The analysis is done by comparing the average percentage of responses following the different components for each subject.

The importance of tapping to the overall pattern decreases gradually with increasing period length, from 76.1% of the responses in the 400-ms conditions to 7.7% in the 3000-ms conditions leading to a highly significant effect of base tempo, $F(10,275) = 24.48$, $p < .001$. There is a slight, but nonsignificant, increase in responses to the overall pattern with increasing density of the polyrhythm (25.0-27.9-29.1%; $F(2,75) = .35$, $p > 0.7$), whereas increasing the pitch interval (Figure 5) has a highly significant negative effect on the number of responses that follow the overall pattern (39.5-27.9-14.6%; $F(2,75) = 11.09$, $p < .001$).

When we remove the responses that follow the overall pattern, we can look at the relative importance of the fast and the slow components of the polyrhythm. The choice between fast and slow is clearly affected by the base period (the fastest period 400 ms is removed here because of the low number of responses), with a gradual change from a clear preference for the slow component (80% of the responses at 600/800 ms) to the fast component (87% of the responses at 3000 ms), and also here the effect is

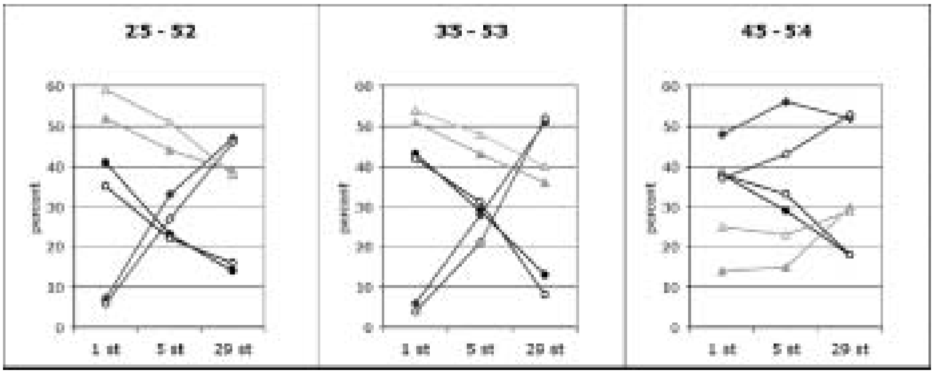

Fig. 5. Percentage of responses following the whole pattern (black filled and open circles), the slow component (dark grey, filled and open diamonds) and the fast component (light grey, filled and open triangles). The lines with filled symbols represent the conditions in which the slow component has the lower pitch position, the lines with open symbols represent the condition in which the fast component is in the lower pitch position. On the horizontal axis, the three pitch interval conditions are shown. The three panels depict the situations with the three polyrhythms: 2:5 and 5:2, 3:5 and 5:3, and 4:5 and 5:4.

highly significant, *F*(9,250) = 38.68, *p* < .001. The switch from slow to fast pattern preference can be located at the 1600-ms pattern length, where we find an almost equal division (51% slow versus 49% fast). The polyrhythmic pattern also has a highly significant effect, *F*(2,75) = 37.97, *p* < .001, with a preference for the fast component (average 61% of the responses) for the 2:5 and 3:5 patterns, but a similar preference for the slow component (68% of the responses) for the 4:5 polyrhythm. Finally, also the pitch interval (cf. Figure 5) has a highly significant effect on the choice between fast and slow, *F*(2,75) = 43.34, *p* < .001, with a strong preference for the fast component with intervals of 1 semitone (30%–70%), a 50-50 division at 5 semitones, and a preference for the slow component (60%–40%) with 29-semitone intervals.

In a similar way, we can take a look at the preference of the subjects for the low and the high component. The base period (with 400 ms removed) does not have a significant effect here, *F*(9,250) = .84, *p* > .5. Also the effect of polyrhythm is not significant, *F*(2,75) = .79, *p* > 0.4, with a small preference for the low component in each of the three polyrhythmic patterns. For the pitch interval finally (Figure 5), we see preference for the low component with 1 and 5 semitones (44%–56%) and an equal distribution with the large pitch intervals. However, this effect does not reach significance either, *F*(2,75) = 2.59, *p* = .08. In fact, the effect is visible only in the 4:5 polyrhythm conditions. Here we see a clear preference for the low component at the slower tempi, with 61.1% of the responses following the low component at base periods above 1600 ms.

Modeling of the Results with the Resonance Model

Statistical analysis of the results shows several significant effects. In order to get a deeper understanding, we analyzed the distributions using the resonance model described earlier. The appropriateness of this approach is already clear when we look at a histogram of the periods of all responses (Figure 6). This distribution strongly resembles a resonance curve with a resonance period around 500 ms, with an overrepresentation of periods between 300 and 800 ms and an underrepresentation of more extreme tempi. Alternatively, standard distributions like a Gaussian distribution could be used in the modeling, but these lack the physical background that makes the resonance curve so appealing in this context.

The statistical analysis has shown that the high-low distinction has a much smaller influence on the responses than does the fast-slow distinction. Therefore, the data of the different pitch position conditions were collapsed, and the modeling will be focused on the influence of pitch distance and speed. Thus the modeling will be done looking at the choice between the whole pattern, the slow component, and the fast component for the 11 base periods in 9 different conditions: 3 polyrhythms × 3 different pitch intervals. Another measure we took to improve the clarity of the data was to remove two subjects who seemed to use a different response strategy. Instead of choosing between the three components, they

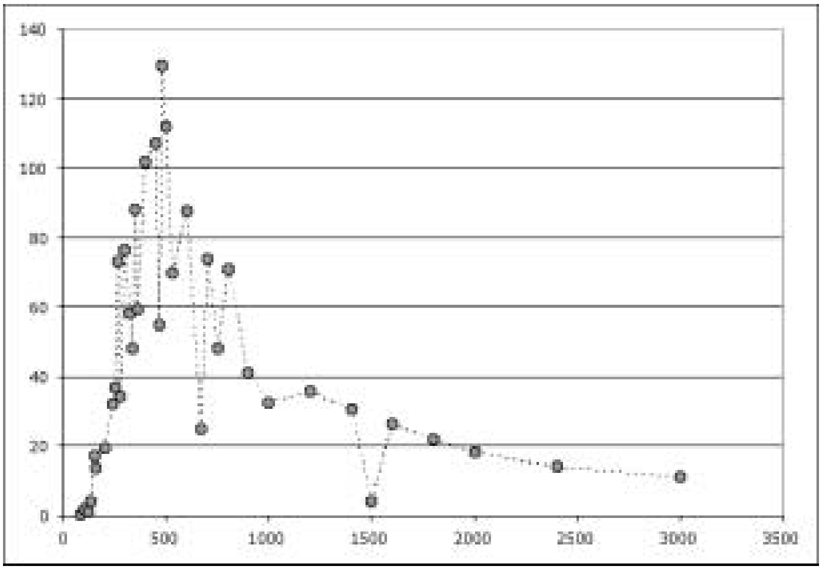

Fig. 6. Normalized histogram of all responses, representing how many times a certain interval is tapped, corrected for how many times it is present in the stimuli.

primarily tapped on the overall pattern (71.2% and 63.6% of their responses, respectively, whereas the average is 27.3%).

Figure 8 will give an overview of the results and the modeling as a function of tempo. An optimization method was used, in which the percentage of responses to each of the three periodicities was fitted to the relative strength of these periodicities on the resonance curve (cf. Figure 7). The approximations are made to each of the nine conditions separately, with the lowest possible number of parameters. The resonance period (500 ms) and the damping coefficient (β = 4.6) are the same in all conditions. The parameters that were varied were the strengths of two of the three periodicities: the overall pattern and the slow component; the strength of the fast component has been fixed at 1. The function of these strength parameters in the model is to adjust the relative importance of the periodicities, in order to deal with perceptual differences between the different patterns (for more details about the method, see Van Noorden & Moelants, 1999). An overview of the parameter values found when optimizing the fit between the results and the model is shown in Table 1. One can see that the strength of the overall pattern diminishes with increasing pitch interval. Also the higher strength of the slow component in the 4:5 polyrhythms is clearly visible in the parameter strengths. The comparison between model and results in Figure 8 shows that the model is already quite successful with a limited number of free parameters. The average deviation between results and model is 7.47%, the best fit is found in the

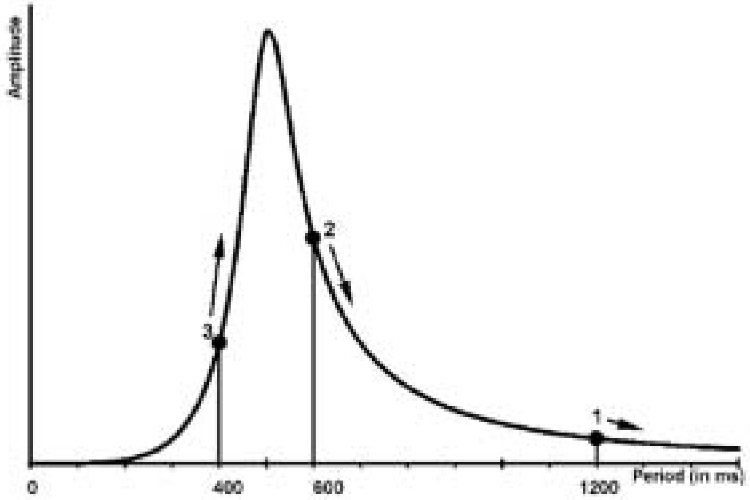

Fig. 7. Example of a resonance curve with the indication of the relative resonance strengths of the components of a 2:3 polyrhythm at a pattern period of 1200 ms. At a somewhat longer pattern period, the fast component (3) will become dominant, as indicated by the arrows.

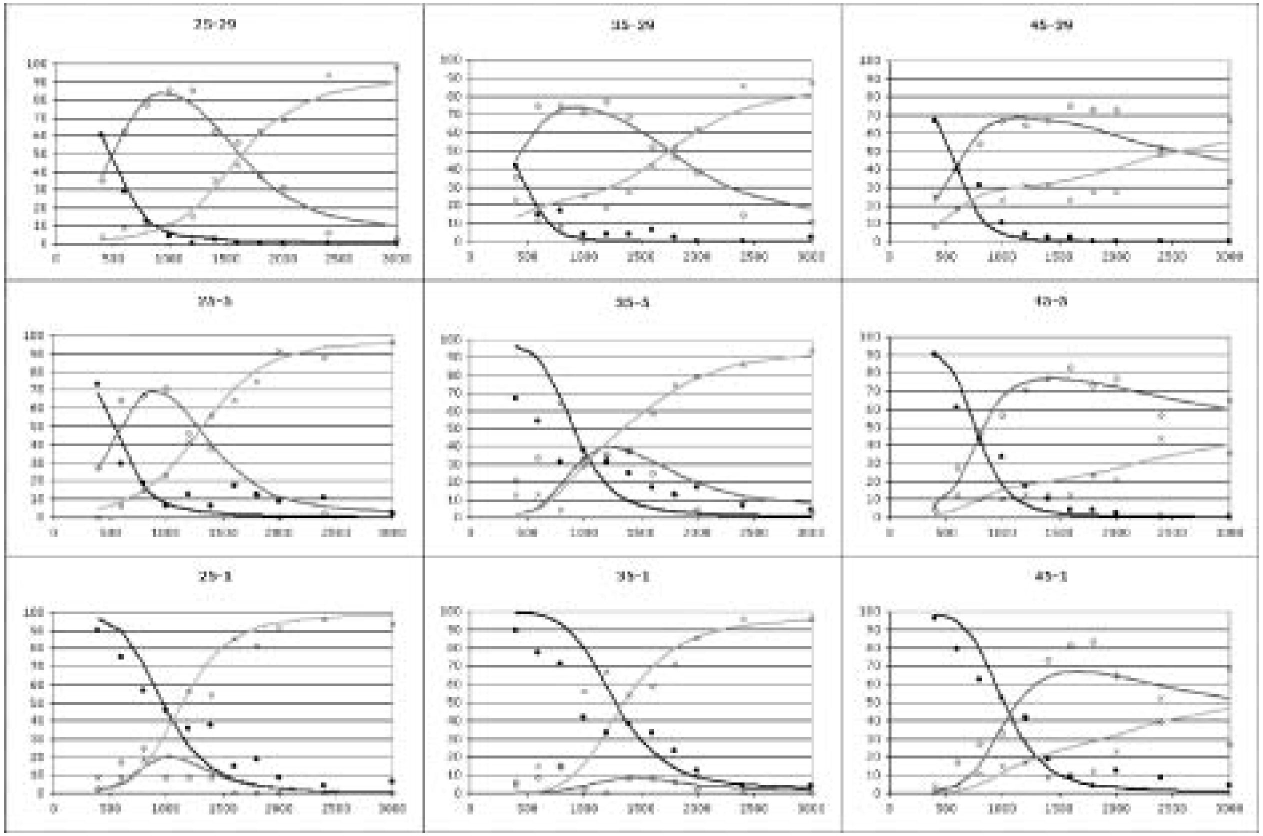

Fig. 8. Overview of the results (dots) and the modeling with the resonance model (lines), for 3 polyrhythms (2:5, 3:5, and 4:5, from left to right) by 3 pitch intervals (1,5, and 29 semitones, from bottom to top). Black dots and line represent the overall pattern; the white squares and dark gray line, the slow component; and the crosses and light gray line, the fast component. The corresponding parameter settings of the model are shown in Table 1.

TABLE 1

Parameter Values for Optimal Fitting of the Results with the Resonance Model

Pitch Interval (semitones)	Overall Pattern				Slow Component				Fast Component		
	2:5	**3:5**	**4:5**	**Mean**	**2:5**	**3:5**	**4:5**	**Mean**	**2:5**	**3:5**	**4:5**
29	0.060	0.006	0.015	0.027	0.475	0.416	0.983	0.625	1	1	1
5	0.029	0.017	0.112	0.053	0.147	0.175	1.735	0.686	1	1	1
1	0.202	0.537	0.469	0.403	0.021	0.033	1.317	0.457	1	1	1
Mean	0.097	0.187	0.199	0.161	0.214	0.208	1.345	0.589	1	1	1

2:5 polyrhythm × 29 semitones pitch interval condition, with an average difference of 4.29%, and the modeling is least successful for the 3:5 polyrhythm × 5 semitones condition, with an average difference of 12.94%. There are, however, differences that could be better approached by using more parameters, such as the skipping of tones in tapping, as discussed earlier (Figure 4). For reasons of clarity, we will not do this at this moment.

In nearly all subgraphs, one can see the dominance of the overall pattern at the fastest sequences, whereas at the slow side, the fast component dominates. In the middle region, the slow component dominates except at the smallest pitch interval in the 2:5 and 3:5 polyrhythms. The transition between the dominance of the different series is more gradual the smaller the ratio between the two components: the transition regions in the 4:5 polyrhythms are rather broad. This can be understood to be a consequence of the fact that the tempi of the 4 and 5 components are not that different. In fact, one can see that the 4 component dominates the 5 component in nearly the whole range. The strength of the slow component in the 4:5 polyrhythms is so strong that it remains dominant even in the 1-semitone intervals, unlike in the other two polyrhythms. The range and values for the pitch intervals between the tones seem to be chosen appropriately. The results for the 5-semitone case appear to be more or less in the middle between the results for 1 and 29 semitones. The most apparent effect of increasing the interval is the diminishing importance of the overall pattern, this merely in favor of the slow component.

General Discussion

These experiments form an extension of the experiments by Handel and Oshinsky (1981), adding a larger pitch interval between the components of the polyrhythms. The stimuli used here differed in other ways from those of Handel and Oshinsky (1981). We decided to present the stimuli monophonically via headphones (i.e., the same signals to both ears), whereas Handel and Oshinsky presented the stimuli through loudspeakers standing side by side (without specifying the distance in between). Although, to our knowledge, differences between these methods of presentation have not been studied scientifically, the direction may have provided an important cue. Direction might explain why Handel and Oshinsky did not find a substantial difference between their two pitch interval conditions (0 and 5 semitones).

Despite a general agreement, we found considerable differences between subjects, but unlike Handel and Oshinsky (1981), we could not distinguish specific groups. Rather, the responses were spread along a continuum. Two of the 26 subjects responded clearly in another way, giving many more responses on the overall pattern. It is as if, for them, the frequency difference of the tones is less important. The question remains whether this could be a consequence of a deficit in hearing or a different setting in attention, focusing on the dynamic accents created by the co-occurrence of two sounds. If the latter is the case, further work is necessary in order to develop a general theory of auditory pattern perception.

One of the main effects found is the increase in tapping on the slow component and the decrease in tapping on the overall pattern if the pitch interval increases, notably in the 2:5 and 3:5 polyrhythms. This effect can be expected on the basis of streaming: at large pitch intervals, the perceptual strength of a combined pattern will be weak and also possible auditory interaction of the coinciding tones of the two subsequences will be weak. The number of responses to the overall pattern will thus decrease with increasing pitch interval. It is also to be expected that these responses will move in first instance to the slow component, as this is the nearest in tempo at each of the overall pattern rates. With the 4:5 polyrhythms, the results are somewhat different. The slow component is dominant also in the 1- and 5-semitone conditions and, at the slow tempi, we see that the pitch position has a clear influence, with a preference for the low component. This preference could perhaps be explained by a certain amount of peripheral masking of the higher by the lower component.

Finally, we can compare the results of the main experiment with the results of the pilot experiment. Although the pilot study was performed only by the authors and therefore the results cannot be taken as proof, the preliminary findings are interesting enough to discuss the differences. In both studies, we see a transition from a larger strength of the slow component in the fast sequences to a larger strength of the fast component in the slow sequences. Also in the pilot experiment, we see very clear transitions in the 2:5 and 3:5 polyrhythms, with the switch from slow dominance to fast dominance around the 1600-ms base period. But for the 4:5 polyrhythms, both layers are considered almost equal in strength, while the very strong appearance of the 4 component in the tapping experiment does not replicate in the perception experiment. In the 1-semitone case, the slow component is less suppressed, as it is in the tapping task for the 2:5 and 3:5 condition. But most remarkable is the fact that in the perceptual judgments, the overall pattern disappears from the responses at the 29-semitone pitch interval. If we apply a similar modeling using the resonance curve with $f_0 = 2$ Hz to the results of the pilot experiment, we see that the damping constant β approaches the critical damping. This means that the system merely functions as a kind of band-pass filter, without a real resonance peak. Apparently, the tapping mechanism provides us with a stronger resonance. If these findings hold true in a larger experiment, it can be the beginning of an explanation of why musicians tend to use foot tapping in order to keep to a regular beat. The distinctions between the tapping and the perceptual situation are in fact very interesting, as they may provide us with some insight into the different stages between the production and perception of music.[2]

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