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The perceived pitch of a complex tone often corresponds to its fundamental frequency (f0). This “virtual” pitch perception should be contrasted with “spectral” pitch perception. Spectral pitch may correspond to the frequency of one isolated spectral component or to the simultaneous frequencies of a (sub)set of spectral components. In the present study, normal subjects were presented monaurally with pairs of two- or four-harmonic complex tones without energy at the f0. They were re-

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quired to judge as quickly as possible whether the pitch rose or fell. From the first to the second tone, the frequency of the lower harmonic(s) moved up or down while the (missing) f0 moved in the opposite direction. Two-harmonic tones yielded spectral pitch perception in that 85% of the responses followed the direction of the partial(s), whereas four-harmonic tones yielded virtual pitch perception, with 90% of the responses following the direction of the (missing) f0. On response latencies, spectral responses did not yield a reliable ear effect. In contrast, virtual responses were found to elicit faster responses in the right ear/left hemisphere.

Introduction

The perceived pitch of a complex tone often corresponds to its fundamental frequency (f0). This “virtual” pitch perception should be contrasted with “spectral” pitch perception. Spectral pitch may correspond to the frequency of one isolated spectral component or to the simultaneous frequencies of a (sub)set of spectral components, a perception sometimes referred to as “timbral pitch” or “brightness of timbre.” Some years ago, Smoorenburg (1970) presented normal subjects with a pair of two-harmonic tones and asked them to judge whether the pitch rose or fell. From the first to the second tone, the frequency of one partial moved up or down while the (missing) f0 moved in the opposite direction. In such a conflict situation, half the listeners used a spectral mode of pitch perception; that is, they followed the direction of the moving partial, while the other half used a virtual mode of pitch perception, following the direction of the missing f0. However, more recent psychoacoustical studies with a similar conflict situation showed that the spectral mode is used by most (90%) listeners (Hartmann, 1989, cited in Houtsma & Fleuren, 1991). One way to promote virtual pitch perception is to increase the number of harmonics, even if there is no energy at the f0. Following this reasoning, Laguittton, Demany, Liégeois-Chauvel, Semal, and Kerbaol (1994) showed that virtual pitch was indeed predominant (71% of the responses) when the conflict pair involved four-harmonic tones. They also observed a predominance of spectral responses (83%) for two-harmonic tones.

Following an early neuropsychological study done by Charbonneau and Risset (1975), a left ear/right hemisphere advantage for spectral pitch perception and a right ear/left hemisphere advantage for virtual pitch perception were expected in Laguittton et al.’s (1994) situation. However, no ear effect was found. The goal of the present study was to record response latencies as a sensitive measure of ear differences under monaural presentation.

Method

Subjects. Listeners were 32 normal young adults, 16 men and 16 women, with no musical expertise. They were all right-handed, as assessed by Oldfield’s (1971) handedness questionnaire. Sixteen subjects were assigned to

2 From this point of view, both virtual and timbral pitch are “synthetic” pitch percepts, whereas spectral pitch derived from one single component is an “analytic” pitch percept.
the two-harmonic condition and 16 others to the four-harmonic condition stimuli. Sounds were harmonic complex tones with energy at only two or four consecutivepartials. In each condition, three pairs of complex tones were used, differing in harmonic rank. In the two-harmonic condition, the first partial of the first tone was at the 4th (e.g., 800 and 1000 Hz), 6th, or 9th harmonic rank (missing f0 of 200 Hz). In the four-harmonic condition, the third partial of the first tone was at the 6th (e.g., 800, 1000, 1200, and 1400 Hz), 9th, or 12th harmonic rank. From the first to the second tone, the lower partial(s) moved in a direction opposite to fundamental, while the higher one remained the same (e.g., 800 and 1000 Hz vs. 666.7 and 1000 Hz). Each tone had a total duration of 400 msec. Tone onsets were separated by 780 msec. The pair of tones was presented monaurally. To reduce distortion, the tones were presented against a binaural background of noise. The sound intensity arriving at each ear was the same.

Procedure. Each subject was tested individually in a soundproof room using high-quality headphones. The subject was asked to listen to two consecutive tones and to indicate as quickly as possible with their right hand whether the pitch rose or fell, using a toggle switch. After six practice trials, six blocks of 36 trials each were presented; the first four were experimental and the last two were control blocks. The ear of presentation alternated every block, with the target ear for the first block counterbalanced across subjects. A control block also consisted of 36 trials, but the missing f0 moved in the same direction as the moving partial(s).

Results

Five subjects did not reach the 80% correct performance criterion in the control trials. These subjects were unable to attribute a pitch direction to the two complex tones in a nonconflict situation and thus were replaced. In the two-harmonic condition, 85% of the responses were spectral; that is, they followed the direction of the moving partial, whereas in the four-harmonic condition, 90% of the responses were virtual, following the direction of the (missing) f0 (see Fig. 3). No ear effect emerged on these responses, as in the previous study (Laguitton et al., 1994).

The latencies for the spectral responses in the two-harmonic condition were submitted to a 2 (ear of presentation) × 3 (harmonic rank) analysis of variance (ANOVA). This analysis yielded no main effect of ear of presentation (F < 1). Mean response latencies were 610 and 626 msec for the left and right ear, respectively (see left panel of Fig. 4). The main effect of harmonic rank was significant, F(2, 30) = 3.9, p < .05. Response latencies were 603, 590, and 661 msec for the 4th, 6th, and 9th harmonic ranks, respectively. The two-way interaction did not reach statistical significance.

A detailed acoustical description of the stimuli appears in Laguitton et al. (1994).
Fig. 3. Percentage of responses following the direction of the moving partial(s)—“spectral” pitch perception mode and percentage of responses following the direction of the (missing) fundamental—A “virtual” pitch perception mode, for two- and four-harmonic complex tones.

Fig. 4. (Left) Response latencies (in milliseconds) for predominant “spectral” responses in the two-harmonic condition, as a function of ear of presentation. (Right) Response latencies (in milliseconds) for predominant “virtual” responses in the four-harmonic condition, as a function of ear of presentation.
The latencies for predominant virtual responses in the four-harmonic condition were submitted to a separate ANOVA. This analysis yielded a main effect of ear of presentation, $F(1, 15) = 4.88, p < .05$. Mean response latencies were 500 and 450 msec for the left and right ear, respectively (see right panel of Fig. 4). The main effect of harmonic rank was also reliable, $F(1, 15) = 5.54, p < .01$. Response latencies were 416, 477, and 531 msec for the 6th, 9th, and 12 harmonic ranks, respectively. The two-way interaction did not reach statistical significance.

Discussion

For virtual pitch response latencies in the four-harmonic condition, a right ear advantage was found, suggesting a left hemisphere lateralization for perceiving pitch in a virtual mode. For spectral pitch response latencies in the two-harmonic condition, we observed a left ear advantage tendency (although not statistically reliable). These results parallel those previously obtained by Charbonneau and Risset (1975) in the context of melodies. Our findings in the four-harmonic condition are difficult to reconcile with previous neuropsychological evidence in both normal (Paquette, Bourassa, & Peretz, in press) and brain-damaged (Zatorre, 1988) subjects, suggesting that the pitch of three- to four-harmonic complex tones without energy at the f0 is computed in the right hemisphere. The presence of background noise may account for this discrepancy. Indeed, Bourassa (1993) reported the disappearance of a left ear advantage for pitch perception of complex tones without energy at the fundamental when background noise was added to the tones. Assessment of the role of noise in the present situation is currently under study in our laboratories.

References

Paquette, C., Bourassa, M., & Peretz, I. Left ear advantage in pitch perception of complex tones without energy at the fundamental frequency. Neuropsychologia, in press.