DEUTSCH, DIANA, *Pitch Proximity in the Grouping of Simultaneous Tones* , Music Perception, 9:2 (1991:Winter) p.185

Music Perception
Winter 1991, Vol. 9, No. 2, 185–198

Pitch Proximity in the Grouping of Simultaneous Tones

DIANA DEUTSCH
University of California, San Diego

In this paper, a new effect of pitch proximity is reported. Subjects were presented with patterns consisting of octave-related complexes. Each pattern was composed of four tones, which constituted two simultaneous melodic lines, one of which ascended by a semitone while the other descended by a semitone. The subjects judged whether the line that was higher in pitch ascended or descended, and from these judgments it was inferred which line was heard as higher and which as lower. It was found that the patterns were perceptually organized so that the simultaneous tones formed proximal relationships. The findings provide evidence that, just as successions of tones tend to be organized perceptually in accordance with pitch proximity, so simultaneous tones tend to be organized in accordance with this principle also.

A BASIC ISSUE in the study of music perception concerns the ways in which pitches are combined into simultaneous and successive groupings, so that harmonic and melodic patterns are perceived. In considering this issue, researchers have focused on linkages between successively presented tones. Here, a strong influence of pitch proximity has been demonstrated. For example, when a series of tones is presented in rapid succession, and the tones are drawn from two different pitch ranges, the listener perceives two melodic lines, each formed of pitches that stand in proximal relationships. Further, temporal relationships are more accurately perceived between successions of tones that are proximal in pitch than between those whose pitches are spaced further apart (Bregman, 1990; Bregman & Campbell, 1971, Dannenbring & Bregman, 1976; Fitzgibbon, Pollatsek, & Thomas, 1974; Van Noorden, 1975).

Another manifestation of sequential grouping by pitch proximity occurs when simultaneous series of tones emanate from two different regions of space. Here a perceptual reorganization frequently occurs, so that again two melodic lines are perceived, each formed of pitches that stand in

Requests for reprints may be sent to Diana Deutsch, Department of Psychology, University of California, San Diego, La Jolla, CA 92093.

DEUTSCH, DIANA, ***Pitch Proximity in the Grouping of Simultaneous Tones***, Music Perception, 9:2 (1991:Winter) p.185

proximal relationships. Further, tones in one pitch range appear to be emanating from one region of space and tones in another pitch range from the other region (Butler, 1979; Deutsch, 1975a, 1975b, 1985).

A further manifestation of sequential organization by pitch proximity was demonstrated by Shepard (1964). He employed tone complexes consisting of 10 sinusoidal components that were separated by octaves, and whose amplitudes were scaled by a fixed, bell-shaped spectral envelope. Such tone complexes are clearly defined in terms of pitch class (C, C♯, D, and so on) but are poorly defined in terms of height. Shepard found that when two such tones are presented in succession, pitch proximity determines whether an ascending or a descending pattern is perceived. So, for example, the series C♯-D is always heard as ascending, and the series G-F♯ is always heard as descending (see also Charbonneau & Risset, 1973; Nakajima, Tsumura, Matsuura, Minami, & Teranishi, 1988; Risset, 1971; Ueda & Ohgushi, 1987). It can be concluded that when other cues to height attribution are weak, the perceptual system will invoke pitch proximity in making judgments of relative height for sequentially presented tones.

In contrast, very little is known concerning how simultaneous tones are grouped together. The present experiment was performed to examine this issue. This employed patterns consisting of octave-related complexes that were similar to those used by Shepard (1964). Each pattern was composed of four tones, which constituted two simultaneous melodic lines, one of which ascended by a semitone while the other descended by a semitone. Two types of pattern were constructed, which we shall call Type 1 and Type 2. For both types, assuming a perceptual organization in accordance with pitch proximity, one simultaneous tone pair formed a major second (2 semitones) while the other formed a major third (4 semitones). Assuming instead a perceptual organization that ran counter to pitch proximity, one simultaneous tone pair formed a diminished seventh (10 semitones) while the other formed a minor sixth (8 semitones).

An example of a Type 1 pattern is given in Figure 1. This was always heard as the ascending line C♯-D played together with the descending line B-A♯. However, the higher line could be heard as ascending and the lower line as descending, reflecting perceptual organization in accordance with pitch proximity (Percept A); alternatively the higher line could be heard as descending and the lower line as ascending, reflecting perceptual organization running counter to pitch proximity (Percept B). Figure 2 depicts these two perceptual organizations in musical notation.

An example of a Type 2 pattern is given in Figure 3. This was always heard as the descending line D-C♯ played together with the ascending line A♯-B. However, the higher line could be heard as descending and the lower line as ascending, reflecting perceptual organization in accordance

DEUTSCH, DIANA, ***Pitch Proximity in the Grouping of Simultaneous Tones*** , Music Perception, 9:2 (1991:Winter) p.185

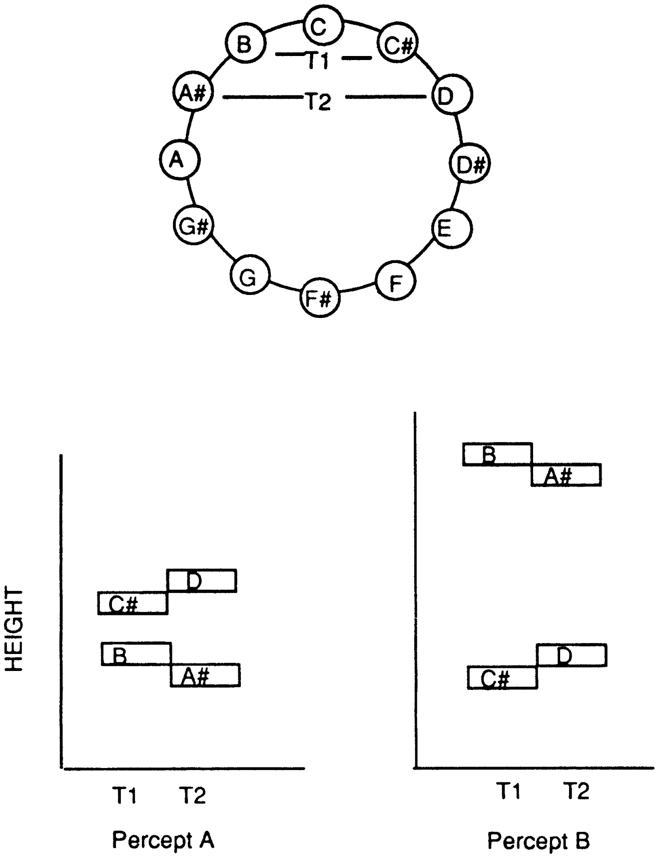

Fig. 1. Example of a Type 1 pattern (C♯-D/B-A♯), together with two alternative perceptual organizations. Tones C♯ and B are presented simultaneously at time T1, and tones D and A♯ at time T2. Listeners organize this pattern as two stepwise lines that move in contrary motion (i.e., as the ascending line C♯-D played together with the descending line B-A♯). However, the ascending line may be heard as higher and the descending line as lower, reflecting perceptual organization in accordance with pitch proximity (Percept A), or the descending line may be heard as higher and the ascending line as lower, reflecting perceptual organization running counter to pitch proximity (Percept B).

with pitch proximity (Percept A); alternatively the higher line could be heard as ascending and the lower line as descending, reflecting perceptual organization that ran counter to pitch proximity (Percept B). The alternative perceptual organizations for Type 2 patterns are also depicted in Figure 2.

On each trial one of the patterns was presented, and subjects judged whether the line that was higher in pitch formed an ascending or a descending series. From these judgments it was inferred which lines were heard as higher and which as lower. It was hypothesized that judgments

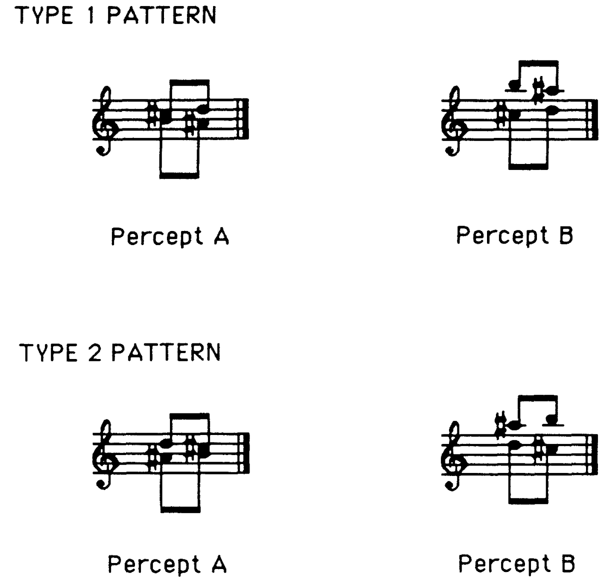

Fig. 2. Alternative perceptual organizations of the Type 1 (C♯-D/B-A♯) and Type 2 (D-C♯/A♯-B) patterns depicted in Figures 1 and 3.

would reflect perceptual organization in accordance with pitch proximity, so that for patterns of Type 1, subjects would tend to judge the higher line as ascending, and for patterns of Type 2 they would tend to judge the higher line as descending instead.

Method

STIMULUS PATTERNS

Each tone was composed of six sinusoids that were related by octaves, and whose amplitudes were determined by a fixed, bell-shaped spectral envelope. The general form of the equation describing the envelope was as follows:

$$A(f) = 0.5-0.5\cos\left[\frac{2\pi}{\gamma}\log_{\beta}\left(\frac{f}{f_{\min}}\right)\right] \quad f_{\min} \leq f \leq \beta^{\gamma} f_{\min}$$

where $A(f)$ was the relative amplitude of a given sinusoid at frequency f Hz, β was the frequency ratio formed by adjacent sinusoids (so that for octave spacing, $\beta = 2$), γ was the number of β cycles that were spanned, and $f_{\min}$ was the minimum frequency for which the amplitude was nonzero. In this way, the maximum frequency for which the amplitude was nonzero was $\gamma\beta$ cycles above $f_{\min}$. Throughout, the values $\beta = 2$ and $\gamma = 6$ were used, so that the spectral envelope always spanned exactly six octaves, from $f_{\min}$ to $64f_{\min}$.

Each pattern was generated under envelopes that were placed at eight different positions along the spectrum. This procedure enabled the counterbalancing for possible effects based on the relative amplitudes of the components of the tones, and also enabled the phenomenon to be explored for tones that ranged over a relatively broad region of the spectrum. The envelope peaks were spaced exactly at 1/4-octave intervals, and so encompassed a two-octave range. Specifically, the envelope peaks were C_4 (262 Hz,

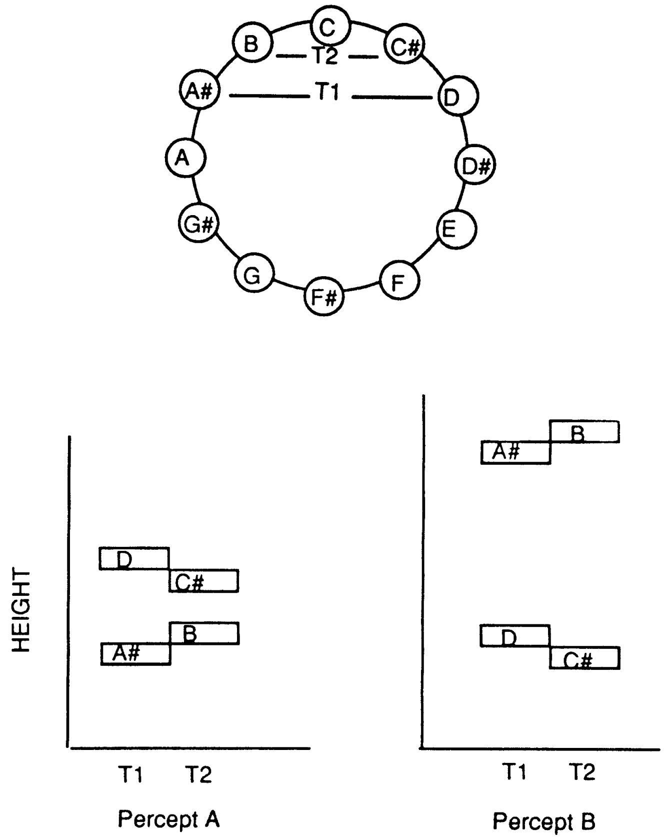

Fig. 3. Example of a Type 2 pattern (D-C♯/A♯-B), together with alternative perceptual organizations. Tones D and A♯ are presented simultaneously at time T1, and tones C♯ and B at time T2. Listeners organize this pattern as two stepwise lines that move in contrary motion (i.e., as the descending line D-C♯ played together with the ascending line A♯-B). However, the descending line may be heard as higher and the ascending line as lower, reflecting perceptual organization in accordance with pitch proximity (Percept A), or the ascending line may be heard as higher and the descending line as lower, reflecting perceptual organization running counter to pitch proximity (Percept B).

f_{min} = 32.7 Hz), $D\sharp_4$ (311 Hz, f_{min} = 38.8 Hz), $F\sharp_4$ (370 Hz, f_{min} = 46.2 Hz), A_4 (440 Hz, f_{min} = 55.0 Hz), C_5 (523 Hz, f_{min} = 65.4 Hz), $D\sharp_5$ (622 Hz, f_{min} = 77.7 Hz), $F\sharp_5$ (740 Hz, f_{min} = 92.4 Hz), and A_5 (880 Hz, f_{min} = 110 Hz). Figures 4 and 5 display spectral representations of the patterns shown in Figures 1 and 3, respectively, in both cases with the spectral envelope centered on C_5.

Twenty-four patterns (12 of Type 1 and 12 of Type 2) were generated under each of the eight spectral envelopes. The Type 1 patterns comprised the ordered pitch-class combinations C-C♯/A♯-A, C♯-D/B-A♯, D-D♯/C-B, D♯-E/C♯-C, E-F/D-C♯, F-F♯/D♯-D, F♯-G/E-D♯, G-G♯/F-E, G♯-A/F♯-F, A-A♯/G-F♯, A♯-B/G♯-G, and B-C/A-G♯. The Type 2 patterns comprised the ordered pitch class combinations C♯-C/A-A♯, D-C♯/A♯-B, D♯-D/B-C, E-D♯/C-C♯, F-E/C♯-D, F♯-F/D-D♯, G-F♯/D♯-E, G♯-G/E-F, A-G♯/F-F♯, A♯-A/F♯-G, B-A♯/G-G♯, and C-B/G♯-A. In this way, 192 patterns were created altogether. These were presented in blocks of 12, with each block composed of patterns generated under one of the spectral

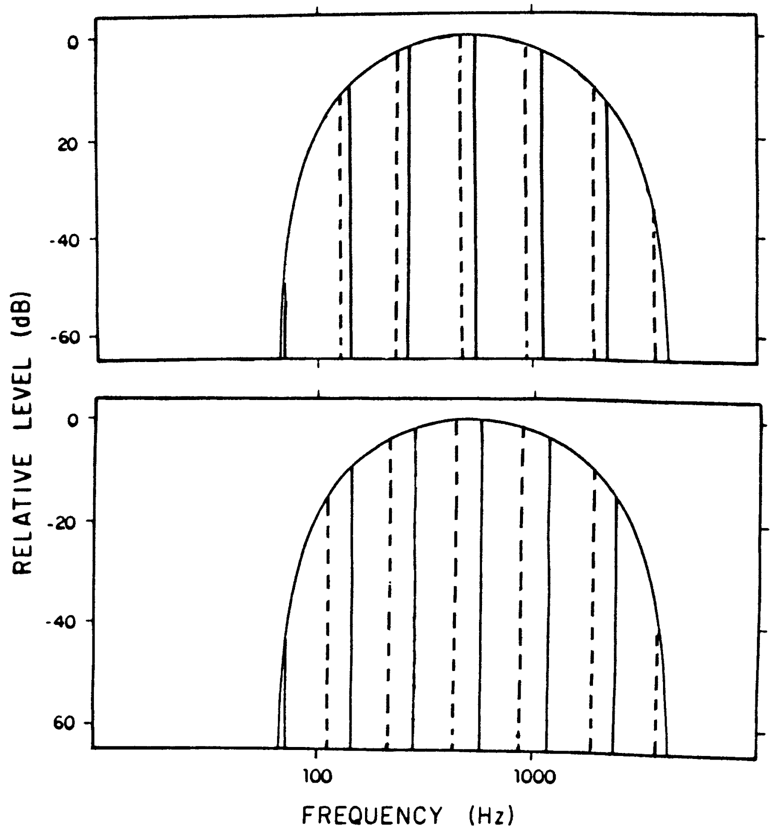

Fig. 4. Spectral representation of the tones comprising the Type 1 pattern C♯-D/B-A♯, generated under the spectral envelope centered at C_5. In the upper graph, the solid lines represent the spectral components of the tone C♯, and the dashed lines represent those of the tone B. In the lower graph, the solid lines represent the spectral components of the tone D, and the dashed lines represent those of the tone A♯.

envelopes. Two different orderings of the 24 patterns were constructed, so that each ordering comprised two blocks. The orderings were haphazard, with the restriction that the same pitch class did not occur in any two consecutive patterns. In this way, 32 blocks were generated altogether. These were presented in two sessions, with 16 blocks in each session. The entire series was presented twice, so that each subject participated in four sessions.

PROCEDURE

Subjects were tested in soundproof booths. On each trial one of the patterns was presented, and the subjects judged whether the line that was higher in pitch formed an ascending or a descending series. All tones were 500 msec in duration, with no gaps between tones within a pattern. Trials within blocks were separated by 4-sec pauses, during which the subjects made their judgments. Blocks were separated by 1-min pauses. There was a break of 5 min between the eighth and ninth blocks. A few warm-up trials were administered at the beginning of each session.

DEUTSCH, DIANA, ***Pitch Proximity in the Grouping of Simultaneous Tones*** , Music Perception, 9:2 (1991:Winter) p.185

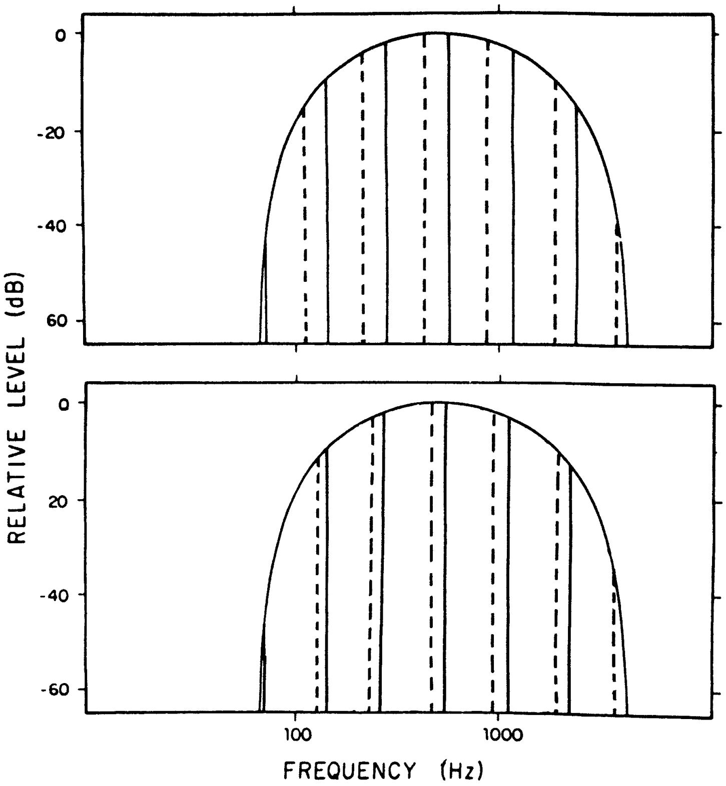

Fig. 5. Spectral representation of the tones comprising the Type 2 pattern D-C♯/A♯-B, generated under the spectral envelope centered at C_5. In the upper graph, the solid lines represent the spectral components of the tone D, and the dashed lines represent those of the tone A♯. In the lower graph, the solid lines represent the spectral components of the tone C♯, and the dashed lines represent those of the tone B.

EQUIPMENT

Tones were generated on a VAX 11/780 computer, interfaced with a DSC-200 Audio Data Conversion System, and using the cmusic sound synthesis software (Moore, 1982). The tones were recorded and played back on a Sony PCM-F1 digital audio processor, the output of which was passed through a Crown amplifier and presented to subjects binaurally through headphones (Grason-Stadler TDH-49), at an approximate level of 72 dB SPL.

SUBJECTS

Eight subjects with normal hearing participated in the experiment, and were paid for their services. Seven of the subjects were students at the University of California, San Diego, and the author (DD) served as the eighth subject. Six subjects (YK, TK, JR, MF, AS, and DD) had had musical training; the remaining two (TH and ATS) were musically untrained.

DEUTSCH, DIANA, ***Pitch Proximity in the Grouping of Simultaneous Tones***, Music Perception, 9:2 (1991:Winter) p.185

Results

TYPE 1 PATTERNS

Figure 6 shows the percentages of trials on which the higher line was judged to be ascending, as a function of the pitch classes of the tones in the ascending line. The data are here plotted for each subject separately, averaged over all experimental sessions. It can be seen that there was a substantial tendency to judge the higher line as ascending, as predicted from the hypothesis that perceptual organization would tend to follow pitch proximity. As all subjects displayed this tendency, the effect was highly significant ($p < .005$, one-tailed, on a binomial test).

For most subjects, an absolute effect of pitch class was also manifest: A reduction in the probability of judging the higher line as ascending occurred for patterns that encompassed certain regions of the pitch-class circle. It can be seen that the strength of this influence of pitch class, and also its direction, varied substantially across subjects. This phenomenon will be discussed in detail later.

TYPE 2 PATTERNS

Figure 7 shows the percentages of trials on which the higher line was judged to be descending, as a function of the pitch classes of the tones in the descending line. Again, the data are plotted for each subject separately, averaged over all experimental sessions. It can be seen that, in contrast with Type 1 patterns, there was here a substantial tendency to judge the higher line to be descending, again as predicted from the hypothesis that perceptual organization would tend to follow pitch proximity. As all subjects displayed this tendency, this effect also was highly significant ($p < .005$, one-tailed, on a binomial test).

An absolute effect of pitch class was manifest for Type 2 patterns also. For most subjects, a reduction in the probability of judging the higher line to be descending occurred for patterns that encompassed certain regions of the pitch-class circle. As for Type 1 patterns, the strength and direction of this pitch class effect varied substantially across subjects.

Discussion

The results of this experiment show that, under certain conditions, the perceptual system will invoke pitch proximity in determining the relative heights of simultaneously presented tones. The findings provide evidence that the influence of pitch proximity is not confined to the perception of sequentially presented tones, but occurs in the perception of simultaneous tones also.

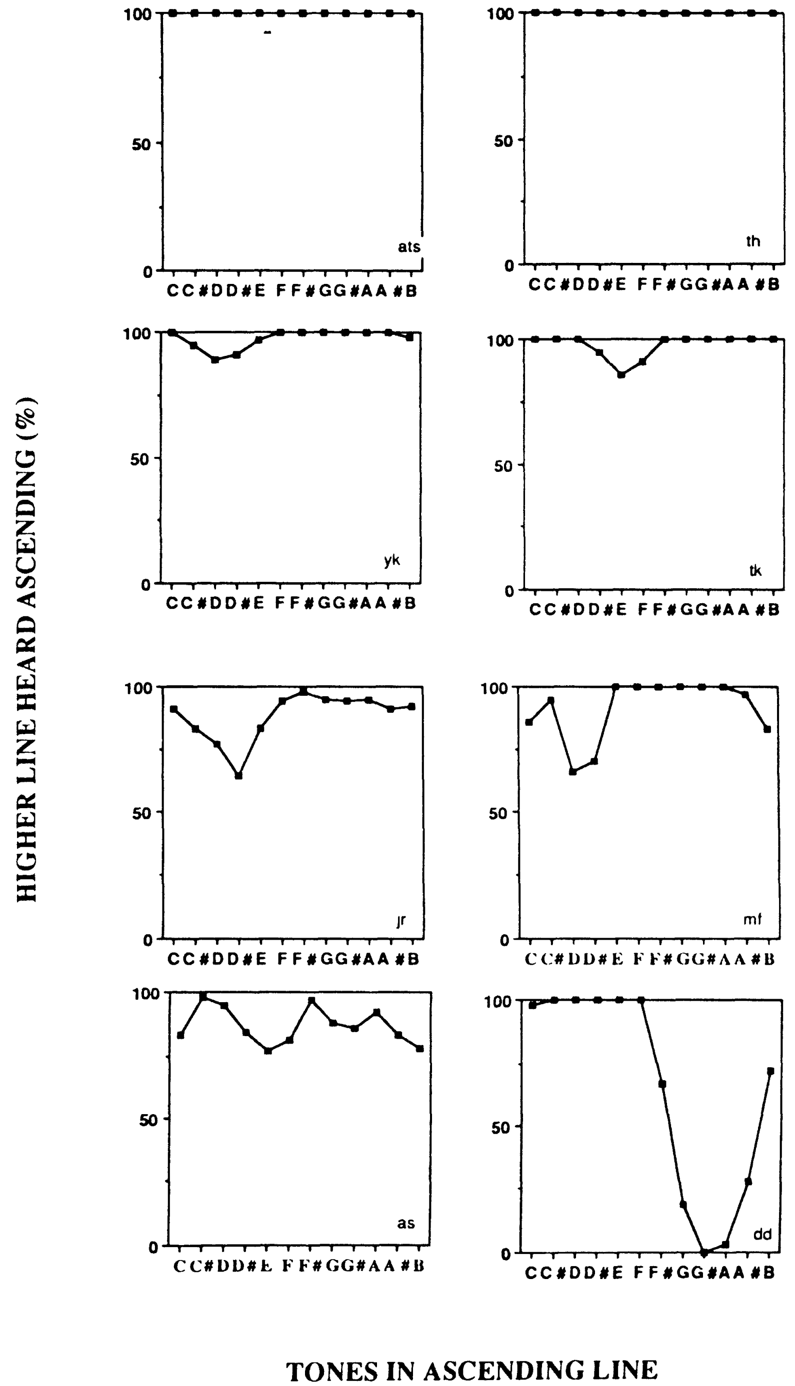

Fig. 6. Type 1 patterns. Percentages of judgments that the higher line formed an ascending series, plotted as a function of the pitch classes of the tones in the ascending line. The results are here displayed for each subject separately, averaged over all experimental sessions.

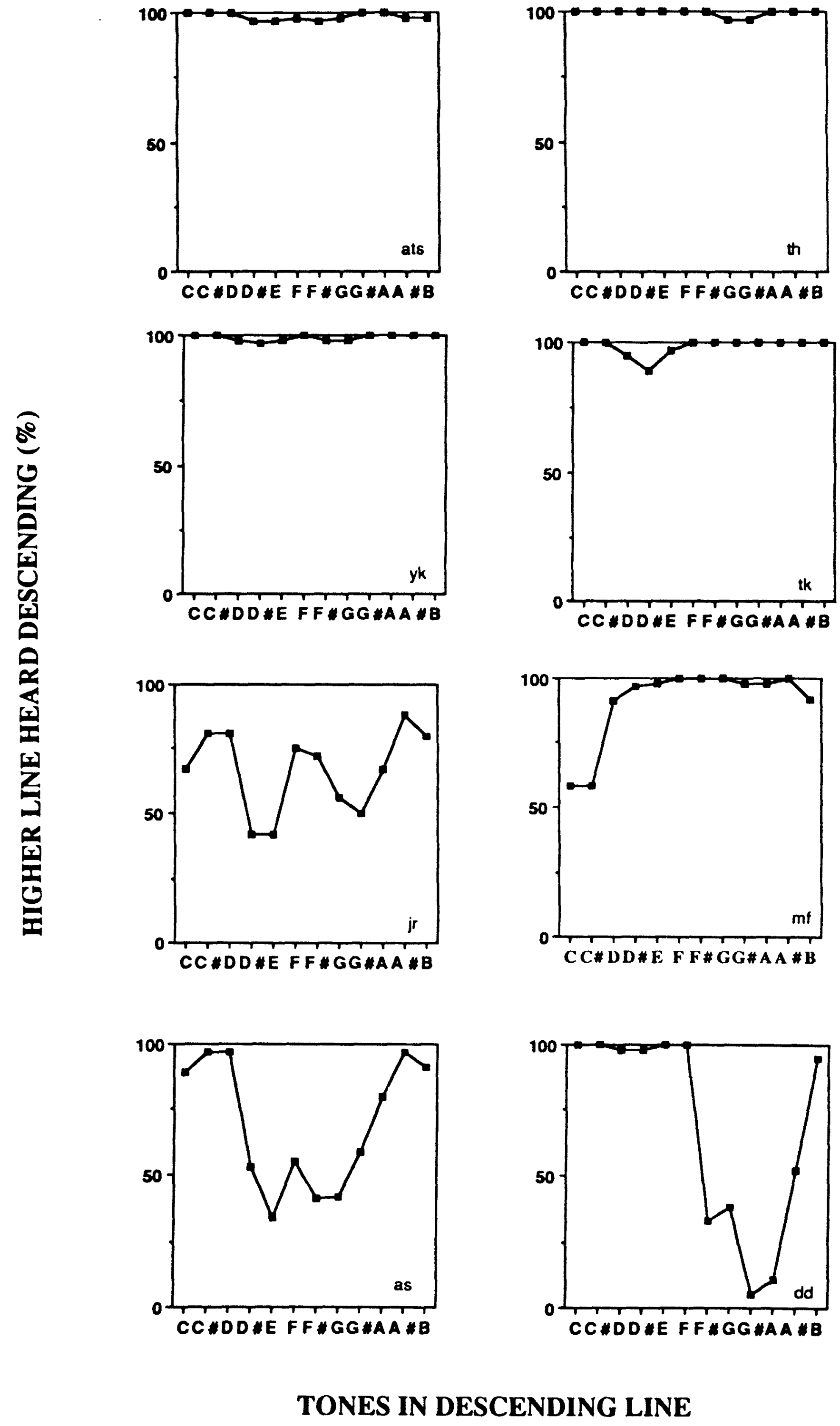

Fig. 7. Type 2 patterns. Percentages of judgments that the higher line formed a descending series, plotted as a function of the pitch classes of the tones in the descending line. The results are here displayed for each subject separately, averaged over all experimental sessions.

DEUTSCH, DIANA, *Pitch Proximity in the Grouping of Simultaneous Tones* , Music Perception, 9:2 (1991:Winter) p.185

The question may then be raised of whether the present effect is based on proximity between tones along the pitch-class circle, or rather proximity between the spectral components of the tones. The analogous issue was raised by Burns (1981) with respect to the sequential proximity effect first described by Shepard (1964). Burns employed tone complexes whose components were spaced at non-octave intervals. He obtained findings that were similar to those of Shepard, and concluded that this sequential proximity effect was spectral rather than pitch class in origin (see also Nakajima et al., 1988; Risset, 1971; Schroeder, 1986). However, it should be noted that phenomenologically, tone complexes whose components are spaced at octave intervals produce more salient and unambiguous proximity effects than do those whose components are spaced at non-octave intervals. It appears reasonable to conjecture, as do Nakajima et al. (1988), that proximity effects may operate along both the spectral and pitch-class dimensions simultaneously.

Because in the present experiment the tones within each complex were related by octaves, the proximity effect reported here could also be based on spectral factors, or on pitch class, or on both. In order to illustrate the potential contribution of spectral factors, the relationships between the spectral components of Type 1 patterns are displayed in Figure 4. This shows the spectral composition of the pattern C♯-D/B-A♯, generated under the envelope centered on C_5. In the upper graph, the solid lines represent the spectral components of the tone C♯, and the dashed lines represent those of the tone B. It can be seen that grouping of the spectral components by proximity would lead to the perception of C♯ as higher and B as lower. Analogously, in the lower graph, the solid lines represent the spectral components of the tone D, and the dashed lines represent those of the tone A♯. It can be seen that here, grouping of the spectral components by proximity would lead to the perception of D as higher and B as lower. Thus if the listener were basing his judgments on spectral cues, he would hear the higher line as consisting of C♯ followed by D, and therefore as ascending. And indeed, just such a result was obtained.

The identical argument holds for Type 2 patterns. Figure 5 illustrates this point by showing the spectral composition of the pattern D-C♯/A♯-B, generated under the envelope centered on C_5. The upper graph here corresponds to the lower graph in Figure 4, and the lower graph here corresponds to the upper graph in Figure 4. Thus, assuming that the subjects were basing their judgments on spectral proximity, the pattern depicted here should be heard with the higher line consisting of D-C♯, and so as descending. Again, such a result was indeed obtained.[1]

---

[1] We may note on perusal of Figures 4 and 5, that the sequential proximity effects obtained here can also be explained on the basis of spectral cues.

DEUTSCH, DIANA, ***Pitch Proximity in the Grouping of Simultaneous Tones***, Music Perception, 9:2 (1991:Winter) p.185

We now turn to a discussion of the absolute effects of pitch class that were here superimposed on those of proximity (see Figures 6 and 7). The findings obtained here can be related to other findings by Deutsch and coworkers that show that the perceived height of a tone can be related to its absolute position along the pitch-class circle (Deutsch, 1986, 1987, 1988; Deutsch, Kuyper, & Fisher, 1987; Deutsch, Moore, & Dolson, 1984, 1986). Of particular relevance is the study of Deutsch (1988), which employed tones that were identical in structure to those used here and which also employed patterns composed of four such tones. As in the present experiment, each pattern consisted of two simultaneous melodic lines, one of which ascended by a semitone while the other descended by a semitone. The tone pairs comprising these two melodic lines were diametrically opposed along the pitch-class circle, so that harmonically the pattern could be described either as a fifth (seven semitones) followed by a fourth (five semitones), or as a fourth (five semitones) followed by a fifth (seven semitones). Thus, in contrast to the patterns employed in the present experiment, neither spectral proximity nor proximity along the pitch-class circle could be used as cues for making judgments of relative height for the simultaneously presented tones.

As in the present study, listeners always organized the tones sequentially in accordance with pitch proximity, so that they heard two melodic lines, one of which ascended by a semitone while the other descended by a semitone. However, depending on the pitch classes employed, either the ascending line was heard as higher and the descending line as lower, or the descending line was heard as higher and the ascending line as lower. Furthermore, subjects differed substantially in terms of which tones they heard as higher and which as lower.

The findings of Deutsch (1988) showed that when subjects were denied the opportunity to organize simultaneous tones in accordance with pitch proximity, the perceived heights of these tones were strongly influenced by their pitch classes. However, the experiment left undetermined whether this effect of pitch class would still operate when the competing cue of pitch proximity was introduced. The results of the present experiment show that this can indeed be the case. However, for most of the subjects it appeared as a considerably weaker effect. Thus, subjects ATS, TH, YK, and TK displayed minimal pitch-class effects, subjects JR, MF, and AS displayed moderate effects, and only one subject (DD) displayed a strong pitch-class effect.[2] It should be noted that, in contrast with the influence

---

[2] All subjects had participated in other experiments on relationships between pitch class and perceived height, for patterns in which proximity could not be invoked as a cue, and had exhibited clear pitch-class effects.

of proximity on the perception of pitch relationships, the influence of pitch class on perceived height cannot be attributed to spectral cues (Deutsch, 1987, 1988).

In conclusion, this study has demonstrated a new effect of pitch proximity on the perceptual organization of tonal structures. Just as successions of tones had been shown earlier to be organized in accordance with pitch proximity, so simultaneous tones have here been shown to be organized in accordance with this principle. The influence of this new phenomenon on perception of music outside the laboratory remains to be investigated.[3]

References

Bregman, A. S. *Auditory scene analysis.* Cambridge, MA: MIT/Bradford, 1990.

Bregman, A. S., & Campbell, J. Primary auditory stream segregation and perception of order in rapid sequence of tones. *Journal of Experimental Psychology*, 1971, *89,* 244–249.

Burns, E. Circularity in relative pitch judgements for inharmonic tones: The Shepard demonstration revisited again. *Perception and Psychophysics*, 1981, *30,* 467–472.

Butler, D. A further study of melodic channeling. *Perception and Psychophysics*, 1979, *25,* 264–268.

Charbonneau, G., & Risset, J. C. Circularité de jugements de hauteur sonore. *Comptes Rendus de l'Académie des Sciences, Série B*, 1973, *277,* 623.

Dannenbring, G. L., & Bregman, A. S. Stream segregation and the illusion of overlap. *Journal of Experimental Psychology: Human Perception and Performance*, 1976, *2,* 544–555.

Deutsch, D. Two-channel listening to musical scales. *Journal of the Acoustical Society of America*, 1975a, *57,* 1156–1160.

Deutsch, D. Musical illusions. *Scientific American*, 1975b, *233,* 91–104.

Deutsch, D. Dichotic listening to melodic patterns and its relationship to hemispheric specialization of function. *Music Perception*, 1985, *3,* 127–154.

Deutsch, D. A musical paradox. *Music Perception*, 1986, *3,* 275–280.

Deutsch, D. The tritone paradox: Effects of spectral variables. *Perception and Psychophysics*, 1987, *41,* 563–575.

Deutsch, D. The semitone paradox. *Music Perception*, 1988, *6,* 115–132.

Deutsch, D., Kuyper, W. L., & Fisher, Y. The tritone paradox: Its presence and form of distribution in a general population. *Music Perception*, 1987, *5,* 79–92.

Deutsch, D., Moore, F. R. M., & Dolson, M. Pitch classes differ with respect to height. *Music Perception*, 1984, *2,* 265–271.

Deutsch, D., Moore, F. R., & Dolson, M. The perceived height of octave-related complexes. *Journal of the Acoustical Society of America*, 1986, *80,* 1346–1353.

Fitzgibbon, P. J., Pollatsek, A., & Thomas, I. B. Detection of temporal gaps within and between perceptual tonal groups. *Perception and Psychophysics*, 1974, *16,* 522–528.

Moore, F. R. M. The computer audio research laboratory at UCSD. *Computer Music Journal*, 1982, *6,* 18–29.

Nakajima, Y., Tsumura, T., Matsuura, S., Minami, H., & Teranishi, R. Dynamic pitch perception for complex tones derived from major triads. *Music Perception*, 1988, *6,* 1–21.

---

[3] This work was first reported at the First International Conference on Music Perception and Cognition, Kyoto, Japan, October 1989. It was supported by grants from the Digital Equipment Corporation and from the UCSD Biomedical Research Support Group.

DEUTSCH, DIANA, **Pitch Proximity in the Grouping of Simultaneous Tones** , Music Perception, 9:2 (1991:Winter) p.185

Risset, J. C. Paradoxes de hauteur: Le concept de hauteur sonore n'est pas le même pour tout le monde. *Proceedings of the Seventh International Congress on Acoustics, Budapest*, 1971, *20S*(10), 613–616.

Schroeder, M. R. Auditory paradox based on fractal waveform. *Journal of the Acoustical Society of America*, 1986, *79,* 186–189.

Shepard, R. N. Circularity in judgments of relative pitch. *Journal of the Acoustical Society of America*, 1964, *36,* 2345–2353.

Ueda, K., & Ohgushi, K. Perceptual components of pitch: Spatial representation using a multidimensional scaling technique. *Journal of the Acoustical Society of America*, 1987, *82,* 1193–1200.

Van Noorden, L. P. A. S. *Temporal coherence in the perception of tone sequences.* Unpublished doctoral dissertation, Technische Hogeschool Eindhoven, The Netherlands, 1975.