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Music Perception
Fall 1984, Vol. 2, No. 1, 40–51

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Octave Equivalence and the Immediate Recall of Pitch Sequences

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This article examines conditions under which tones standing in octave relation are treated as equivalent by the perceptual system. According to the two-channel model for the abstraction of pitch relationships proposed by Deutsch (1969, 1982), octave equivalence effects should not operate directly in the processing of melodic intervals. In an experiment to test this prediction, it was found that accuracy in immediate recall of pitch sequences was substantially lower when the tones within a sequence were distributed across two adjacent octaves than when they were all in the same octave. This finding is in accordance with the two-channel model. Its implications for musical processing, together with those of other studies on octave equivalence, are discussed.

It is generally agreed that tones which stand in octave relation are in some sense perceptually equivalent. Such equivalence is implicit in the construction and description of many musical scales. In Western musical notation, for example, a tone is represented by a letter name, which designates its position within the octave, together with a number, which designates the octave in which it occurs. Thus the symbols C_3, C_4, and C_5 represent tones that ascend by octave intervals. In one version of Indian musical notation, a tone is also represented by a letter, which designates its position within the octave, together with a dot (or dots) which designates its octave placement. Thus the symbols m̤, ṃ, m, ṁ, and m̈ represent tones that ascend by octave intervals. In Western tonal harmony, unison and octave intervals are regarded as interchangeable, and chord inversions are considered harmonically equivalent to their parent chords.

Music theorists acknowledge the principle of octave equivalence by describing tones that are separated by octaves as in the same "pitch class" (Babbitt, 1960, 1965; Forte, 1973). Schoenberg (1951) assumed that such tones could be treated as equivalent, and the coherence of much 12-tone

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music depends on the listener's ability to apprehend such equivalence. However, a number of music theorists have argued that the perception of pitch class depends on the musical context and the listener's expectations (L. B. Meyer, 1973; Benjamin, 1975, 1976; Browne, 1974). In parallel, psychologists describe tones standing in octave relation as of the same "tone chroma," while differing in "tone height" (M. Meyer, 1904, 1914; Revesz, 1913; Burns & Ward, 1982; Shepard, 1964, 1982). There is disagreement, however, concerning the brain mechanisms underlying octave equivalence, and thus concerning the conditions under which it should be apparent perceptually.

A neural network for the abstraction of pitch relationships has been proposed, from which it is predicted that octave equivalence should be perceptually manifest in certain musical situations but not in others (Deutsch, 1969, 1982). It is assumed that information first travels to a unidimensional tone height array, and from there is processed along two parallel channels. Along the first channel, there is convergence of information from neural units underlying tones that are separated by octaves. This channel gives rise to octave equivalence effects for single tones, and also to the harmonic equivalence of chords that are related by inversion. The pattern of neural convergence along the second channel is such as to mediate transposition of intervals and chords; however, convergence based on the octave relation does not occur along this channel.

One consequence of the two-channel model is that octave equivalence effects should operate directly in judgments of single tones and of simultaneously presented tones. Several experimental findings support this assumption. Where judgments of single tones are concerned, Deutsch (1973a) found that certain highly specific interference effects which operate in pitch recognition (Deutsch, 1972a, 1973b) also occurred when the interference tones were displaced exactly an octave up or down, although the effects were weaker than when these tones were in the same octave as the test tones. Further, Idson and Massaro (1976) obtained substantial backward recognition masking of single tone targets when the masking tones and the test tones were drawn from different octaves.[1,2]

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[1] However, also in accordance with the two-channel model, such cross-octave masking did not occur where judgments of melodic patterns were made.

[2] It should be noted that in similarity rating tasks in which tone height is systematically varied using a large number of values, octave equivalence effects may not necessarily be apparent (Allen, 1967; Thurlow & Erchul, 1977; Kallman, 1982). Thus, in contextual conditions that strongly emphasize the tone height dimension, listeners may base their similarity judgments on this dimension in preference to that of chroma. In terms of the two-channel model, listeners would here be referring to the primary "tone height" array in making their judgments. However, when listeners are presented with an explicit musical context, they judge tone pairs that are separated by octaves as closely similar (Krumhansl, 1979).

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Fig. 1. Well-known melody that has been transformed so that the pitch classes are preserved but the tones are distributed across three octaves. (From Deutsch, 1984.)

Where judgments of simultaneous tones are concerned, the strong fusion effect that occurs for tones that stand in octave relation forms part of the basis of the "endless staircase" illusion (Shepard, 1964). Further, in making judgments of harmonic intervals, subjects tend to confuse intervals that are related by inversion (Plomp, Wagenaar, & Mimpen, 1973). Confusions between such intervals have also been shown to exert an indirect influence on pitch recognition judgment (Deutsch & Roll, 1974).

A second consequence of the two-channel model is that octave equivalence effects should not operate directly where judgments of melodic intervals are concerned. This gives rise to the prediction that listeners should find it difficult to recognize well-known melodies in which pitch class is preserved but the octave placement of the tones varies randomly. (This prediction does not extend to listeners who have been informed of the identity of the presented melody, or who are furnished with cues for hypothesis testing, since these listeners should be able to perform the recognition judgment by confirming the pitch classes of the individual tones; i.e., by utilizing the first channel of the model.)

In an experiment to test this prediction, Deutsch (1972b) presented listeners with a well-known melody (the first half of "Yankee Doodle"), with its tones distributed randomly across three octaves, while preserving pitch class. The listeners were asked to identify the melody but were given no cues for hypothesis testing. Recognition was found to be no better than in a control condition in which the rhythmic pattern was retained but the pitch information was removed entirely. However, when the listeners were later informed of the identity of the melody and so knew what to listen for, recognition became much easier.

The reader with access to a musical instrument may wish to repeat this study informally, for example by presenting the passage shown in Figure 1. This provides a "randomized-octaves" version of another well-known melody. The contrast is most striking between its lack of recognizability when played to a naive listener and its clear recognizability when played to a listener who has heard the untransformed version.

Further supporting evidence for the model was obtained in a study by Deutsch (1976, 1979) on consolidation of memory for melodies through repetition. Subjects listened to a standard melody, which was followed by a comparison melody. The comparison melody was either an exact transpo-

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sition of the standard, or it was inexact, while maintaining contour. Subjects judged whether or not the transposition was exact. Repetition of the standard melody, before presentation of the comparison, resulted in an improvement in comparison performance. This was also true when the repeated melody was displaced intact an octave higher or an octave lower. However, when the successive tones of the repeated melody were displaced alternately to the higher and lower octaves, while maintaining pitch class, comparison performance was worse than when the melody had not been repeated at all. It was concluded from this study that octave equivalence effects for single tones do not operate in the consolidation of melodic information.

An alternative explanation for the "Yankee Doodle effect" has been advanced by Idson and Massaro (1978). These authors pointed out that the "octave-randomizing" procedure results in an alteration in melodic contour. They argued further that the altered contour provides the listener with misleading information, and so actively interferes with the recognition process. As evidence for this view, it was shown that when contour was preserved under octave displacement, melody recognition was at a higher level than when contour was not preserved. A similar result was obtained by Dowling and Hollombe (1977).

The difficulty with Idson and Massaro's (1978) argument, however, is that contour alone acts as a salient cue for melody recognition (Werner, 1925; White, 1960; Dowling & Fujitani, 1971; Dowling, 1978b; Vicario, 1983). Thus, if the listener is able to hypothesize the identity of a melody on the basis of contour alone, he or she can then confirm the hypothesis by reference to individual pitch classes, and so without direct processing of interval information (see also Deutsch, 1978, 1982). The finding that contour preservation results in enhanced recognition performance is therefore in accordance with the two-channel model also.

Idson and Massaro (1978) proposed instead that melody recognition depends on two processes: first, recognition of the individual pitch classes, and second, recognition of contour (defined as the sequence of directions of pitch change). If their model were correct, then for melodies that have been transformed such that pitch class and contour were preserved but the octave placement of the tones was varied, recognition should be at as high a level as for untransformed melodies. However, in an experiment by Kallman and Massaro (1979), a significant decrement in recognition performance resulted from this transformation. This provides a difficulty for Idson and Massaro's model. Further, Kallman and Massaro (1979) examined the effect of preserving contour but altering pitch class by displacing each tone up or down one or two semitones. Recognition performance was considerably poorer under this transformation than where pitch class was preserved. This finding is also in accordance with the two-channel model, for just as perception of the correct pitch classes should serve to confirm a hypothe-

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sized melody, so should perception of the incorrect pitch classes serve to disconfirm a hypothesis.

Comparison of the findings of Idson and Massaro (1978) and of Kallman and Massaro (1979) provides additional evidence for the two-channel model. In the former study, the subjects were furnished with the names of a small set of test melodies and were presented with these melodies for hundreds of trials. In this way, they were given every opportunity for hypothesis testing. In contrast, Kallman and Massaro (1979) presented subjects with each test melody only once, and they did not inform them of the names of these melodies. Recognition was at a substantially higher level in the former study than the latter. This is as expected on the two-channel model but is at variance with the model advanced by Idson and Massaro. Further evidence for the hypothesis-testing argument was provided by Dowling (1978a). He found that presenting subjects with either an untransformed melody or its name immediately before presenting an octave-randomized version resulted in a high recognition rate.

The above arguments, however, do not conclusively dispose of the conjecture that the failure to recognize melodies under octave displacement may be due to active interference produced by alterations in contour. With a recognition paradigm, if contour is altered, this could lead to active interference. Yet if contour is preserved, melodies could be recognized on this basis alone.

The present experiment was designed to circumvent this difficulty. Musically literate subjects were required to listen to novel pitch sequences and then to recall what they had heard in musical notation. Since no comparison was to be made with other sequences the involvement of contour as a cue could not arise.

The experiment made comparison between three conditions. In the first, all tones in a sequence were in a given octave. In the second, all tones in a sequence were in the adjacent lower octave. In the third, tones within a sequence alternated between these two adjacent octaves. If pitch class were indeed a perceptual invariant, one should expect no differences in performance levels between these three conditions. However, according to the two-channel model, one should expect that performance in the third condition would be at a substantially lower level than in the other two.

Method

Procedure and Conditions

On each trial, subjects were presented with a sequence of six tones, which they recalled in musical notation. Each sequence consisted of a quasi-random ordering of the first six notes of the C major scale, and was preceded by Middle C (C_4), which served both as an anchor tone and also as a warning that a new trial was about to begin.

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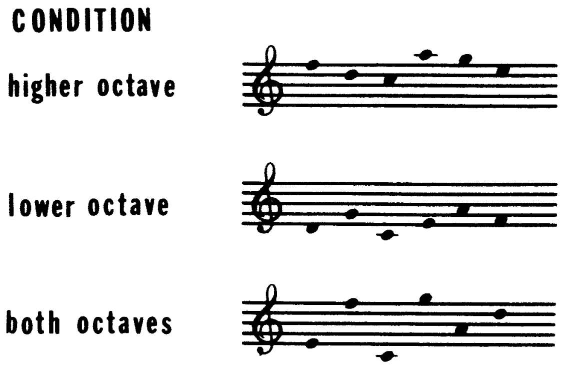

Fig. 2. Examples of sequences used in the different conditions of the experiment.

There were three conditions in the experiment, and examples of sequences in these conditions are shown in Figure 2. In the first ("higher octave") condition, all tones in a sequence were in the octave beginning on C_5. In the second ("lower octave") condition, all tones in a sequence were in the octave beginning on C_4. In the third ("across octaves") condition, tones in a sequence alternated between these two adjacent octaves. In the third condition, roughly ⅔ of the melodic intervals involved octave jumps; the other ⅓ spanned less than one octave.

There were 8 sequences in each condition, making 24 sequences in all. These were presented such that each successive group of 3 sequences contained one example from each condition, the ordering of sequences within each group being random. Sequences were presented in four groups of 6, with 2-min rest pauses between successive groups. The experimental session was preceded by 3 practice sequences, containing one example designed as in each of the three conditions. The subjects were informed that the anchor tone would always be Middle C, and were given the set of pitches to be presented, but were furnished with no other information.

Stimulus Parameters

All tones were sine waves, of equal amplitude, and 300 msec in duration. Tones within a sequence were separated by 200-msec pauses. The anchor tone was 1 sec in duration, and a 2-sec pause intervened between presentation of the anchor tone and the first tone of the sequence. A pause of 20 sec followed each sequence, during which the subjects made their notations.

Tones were taken from the equal-tempered scale (International pitch; A = 435 Hz). The frequencies employed (in hertz) were C = 259, D = 290, E = 326, F = 345, G = 388, A = 435, C = 517, D = 581, E = 652, F = 691, G = 775, and A = 770.

Apparatus

Tones were produced by a Wavetek function generator, controlled by a PDP 11/23 computer, and were recorded on tape. The tape was played to the subjects on a high-quality tape recorder through loudspeakers.

Subjects

Twelve subjects were employed in the experiment. Ten were graduate students in the Music Department at the University of California, San Diego, and two were undergraduates. All subjects had had over 10 years of musical training. None had absolute pitch. The subjects were paid for their services.

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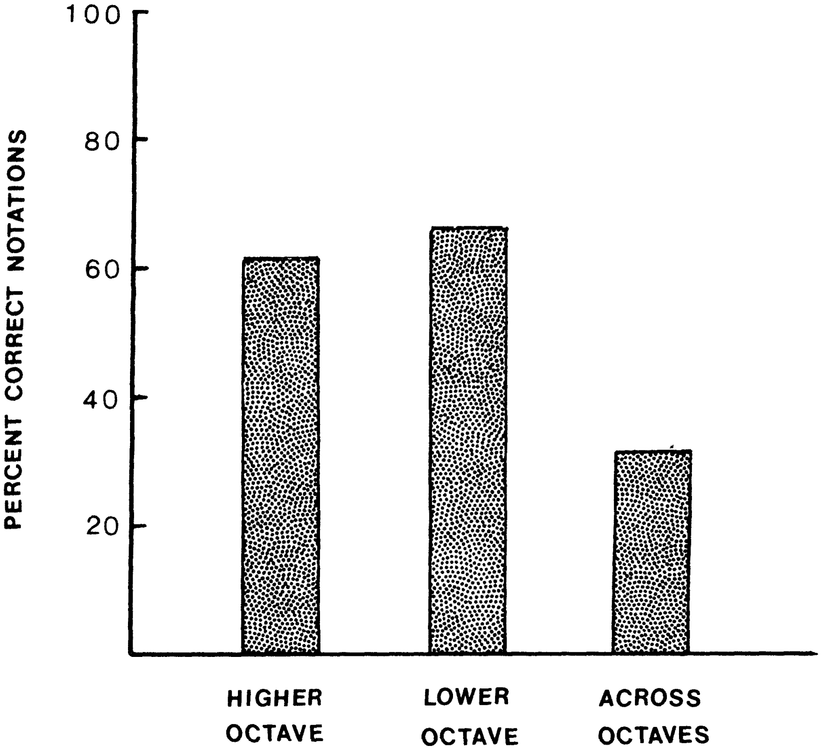

Fig. 3. Percentages of tones correctly notated in the correct serial positions in the different conditions of the experiment.

Results

Figure 3 displays the percentages of tones that were correctly notated in the correct serial positions in the different conditions of the experiment. It can be seen that performance in the across octaves condition was substantially poorer than in the other two. This effect was highly significant, both on comparing the across octaves condition with the higher octave condition ($p<.01$, two tailed, on a Wilcoxon test) and also on comparing the across octaves condition with the lower octave condition ($p<.01$, two tailed, on a Wilcoxon test). The difference between the higher octave condition and the lower octave condition was not significant ($p>.05$, two tailed, on a Wilcoxon test).

One might hypothesize that the higher error rate in the across octaves condition was due in part to errors in octave placement, that is, that the subjects were notating the correct pitch classes but were placing the tones in the wrong octaves. Accordingly, the percentages of errors in which the correct pitch class was notated, but the octave placement was incorrect, were computed for each of the three conditions. These are displayed in

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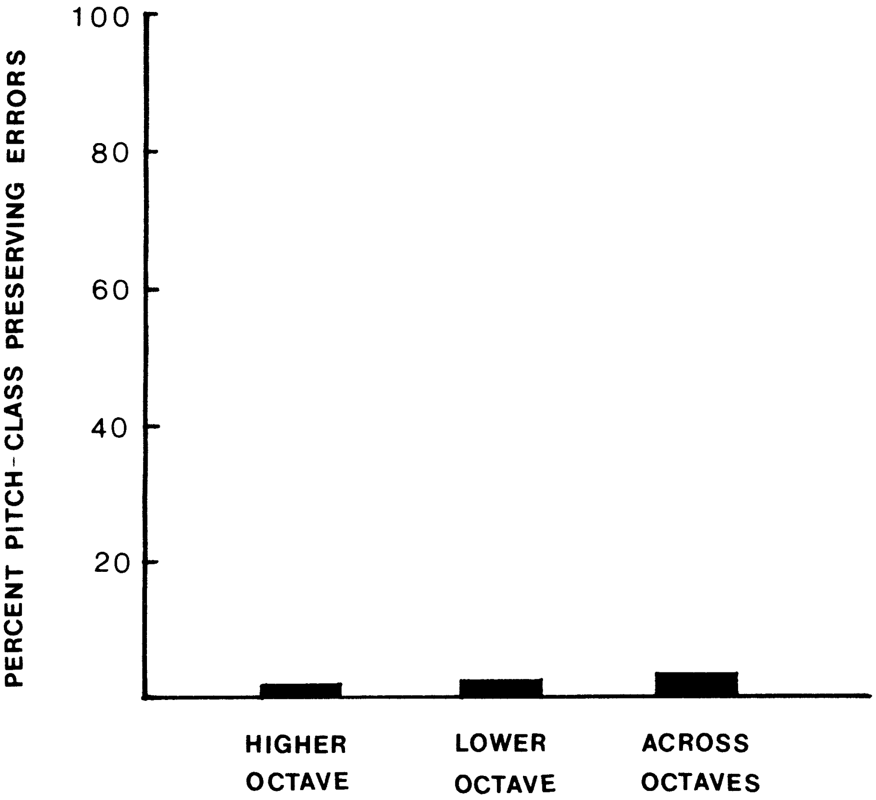

Fig. 4. Percentages of errors in which the correct pitch class was notated, but the octave placement was incorrect, in the different conditions of the experiment.

Figure 4, and it can be seen that such errors were vitually absent in all conditions. The reason for this becomes apparent on perusal of Figure 5, which displays for each condition the percentages of errors in which contour was preserved. (A contour-preserving error is defined here as one in which the direction of pitch change is preserved.[3]) It can be seen that a very high proportion of errors were of this type in all conditions. There were no significant differences between conditions on this measure ($p>.05$, two tailed, on Wilcoxon tests for all comparisons). Clearly where contour is preserved, pitch class-preserving errors can only rarely arise.

Discussion

The results of the present experiment are in accordance with the two-channel model for the abstraction of pitch relationships, from which it is predicted that octave equivalence effects should not operate directly in the

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[3] Notations for the first serial position of each sequence were necessarily excluded from this analysis.

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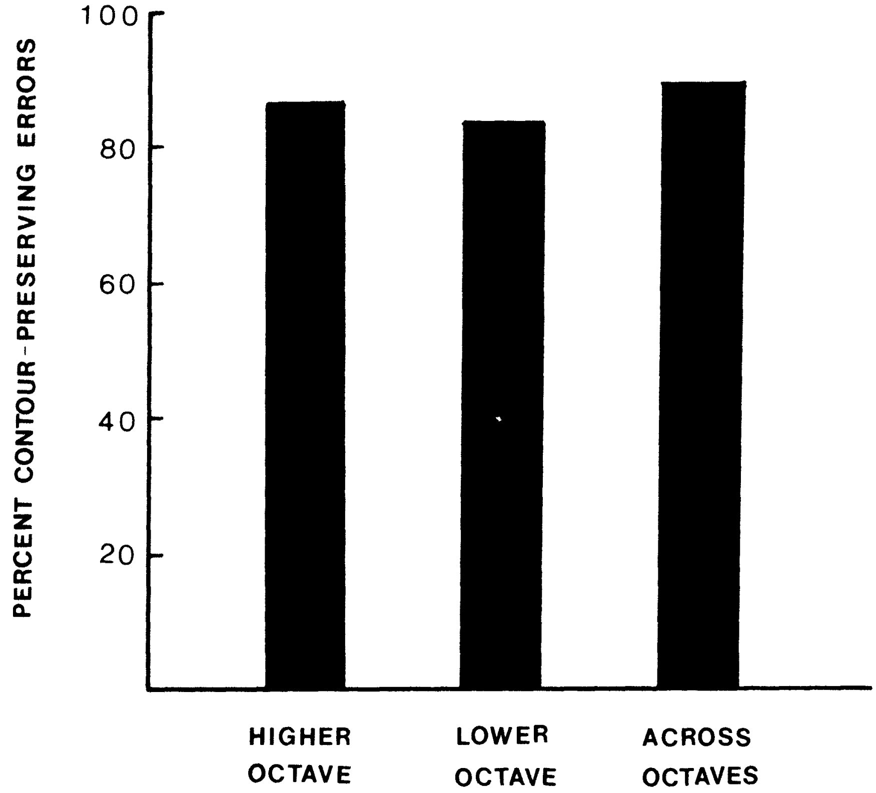

Fig. 5. Percentages of errors in which contour was preserved in the different conditions of the experiment.

processing of melodic intervals. It was shown that accuracy in immediate recall of pitch sequences was substantially lower when the tones within a sequence were distributed across two adjacent octaves than when they were all in the same octave. This reduced accuracy was not due to errors in octave placement, since the proportion of errors in which pitch class was preserved but octave placement was incorrect was extremely low in all conditions. The proportion of contour-preserving errors was in contrast very high; however, the involvement of contour as a cue cannot explain the poor performance that occurred when tones within a sequences were distributed across octaves.

These results, combined with those reviewed in the Introduction, lead to the conclusion that the musical context and the expectations of the listener are critical determinants of whether or not octave equivalence effects will be perceptually manifest. In this experiment, subjects were presented with tonal sequences in which the pitches were ordered quasi-randomly, and no extraneous cues were provided for hypothesis testing. Under these conditions, when processing of intervals across octaves was required, poor perfor-

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mance was obtained. In contrast, tonal music provides a context in which octave equivalence may be readily manifest. First, the frequent use of octave doubling, direct octave jumps, and so on, enables listeners to perceive transitions across octaves directly. Second, melodic patterns in tonal music are hierarchically organized in such a way as to follow laws of figural goodness such as proximity, good continuation, and closure (L. B. Meyer, 1973; Deutsch & Feroe, 1981; Lerdahl & Jackendoff, 1983; Narmour, 1983). This form of melodic patterning therefore capitalizes on general (and perhaps innate) tendencies of our processing systems, so that when jumps across octaves occur, these are to tones whose pitch classes have already been strongly implied by the preceding tones. Third, when listeners are presented with an unfamiliar tonal piece, they are able to draw on a large body of learned conventions concerning chord progressions, key relationships, and so on, and thus are able to make extrapolations based on these conventions (L. B. Meyer, 1967; Krumhansl, 1983).

For the case of atonal music, listeners are at a comparative disadvantage. First, there is no general set of learned conventions on which they can draw to make extrapolations (Babbitt, 1950). Second, precepts such as the avoidance of octave doublings prevent them from being able to perceive transitions across octaves directly. The extent to which listeners will be able to recognize octave equivalence in an atonal setting will therefore depend heavily on the contextual cues built into the composition (rhythm, contour, timbre, dynamics, and so on). Such points have also been made by L. B. Meyer (1967), Benjamin (1975, 1976) and Browne (1974).

Finally, much has recently been written concerning the dangers of assuming that correspondences necessarily exist between structures as defined compositionally and as apprehended perceptually. The issue of octave equivalence provides a clear case in point. It also illustrates the related point that certain compositionally defined structures may or may not be perceptually apprehended, depending on the knowledge and expectations of the listener. This is not true for all types of musical configuration. The octave and scale illusions (Deutsch, 1975) are examples of patterns that cannot be correctly apprehended even when the listener is provided with full information. In contrast, octave equivalence in melodic structures may either be perceptually very salient or be totally lost, depending on the body of information that the listener contributes to the percept.[4]

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[4] This work was supported by United States Public Health Service Grant MH21001. The experiment was reported to the meeting of the Acoustical Society of America, San Diego, November, 1983 (Deutsch, 1983).

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