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Sensitivity to Key Change in Chorale Sequences: A Comparison of Single Voices and Four-Voice Harmony

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Two experiments examined sensitivity to key change in short sequences adapted from Bach chorales. In Experiment 1, musically trained listeners identified key changes in single-voice (i.e., soprano, alto, tenor, bass) and in four-voice presentations of the sequences. There were two main findings. First, listeners judged the distance and direction of key change in single voices and in four-voice harmony with approximately equal ease. Second, for four-voice harmony but not for single voices, the direction of key change on the cycle of fifths influenced perceived distance. For an equivalent number of steps on the cycle, greater distance was associated with modulations moving in the counterclockwise, rather than in the clockwise, direction. These findings were replicated in Experiment 2, in which musically untrained listeners rated perceived distance of key change. In addition, the directional asymmetry found for four-voice harmony also was found for individual bass voices. The evidence suggests that harmony and melody operate somewhat independently in the implication of key structure. Difficulties for a strictly hierarchical model of perceived musical pitch structure are discussed and a partially hierarchical model is considered.

THIS research examines some of the implications of a hierarchical description of pitch organization in tonal music in which tones, chords, and keys represent increasing levels of abstraction. The description also suggests that pitch judgments at any given level are subject to interlevel influences. Moreover, interlevel influences between tones and keys are mediated through the level of chords; thus, the implication of key by melody is less direct than the implication of key by chords.

Although research and theory have generally supported these notions, no investigation has directly compared the relative influence of melodic and harmonic materials on perceived key. Thus, in the present study, musically trained and untrained listeners were asked to judge key structure and key modulation both in four-voiced chorale sequences and in the individual

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voices contained in the sequences (i.e., soprano, alto, tenor, or bass). In addition, the study addressed the issue of whether the perceived relationship between two keys in a modulating sequence depends on the order in which the keys occur.

Hierarchical Models of Musical Structure

The concept of hierarchical organization has been applied widely in music perception. Hierarchical descriptions have been invoked in the formalization of rules by which listeners may abstract structure from a given piece of music (e.g., Bharucha, 1984a; Deutsch & Feroe, 1981; Lerdahl & Jackendoff, 1983) or in the quantification of long-term representation of the structural properties of Western tonal music (e.g., Krumhansl & Shepard, 1979; Krumhansl & Kessler, 1982). Bharucha (1984b) has classified these two types of hierarchies as event hierarchies and tonal hierarchies, respectively. Both types include the basic principle that within a given class of elements, such as tones or chords, certain members are perceived to have greater prominence or significance than other members.

There is yet another hierarchical description. This hierarchy describes the psychological relationship among classes of elements—namely, single tones, chords, and keys. Research findings have generally attested to important links among these three levels of organization. Judgments of melodic sequences are influenced by the implied harmonic progression (e.g., Cuddy, Cohen, & Mewhort, 1981; Cuddy & Lyons, 1981; Bharucha, 1984a) and by the overall key (e.g., Cuddy et al., 1981; Cuddy, Cohen, & Miller, 1979; Cuddy & Lyons, 1981; Dowling, 1978; Krumhansl, 1979). Judgments of chords and chord sequences also are influenced by the established key (Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982; Krumhansl & Kessler, 1982).

It has been pointed out that the tonal interpretation of chords may be less susceptible than that of single tones to influences from surrounding musical contexts (Krumhansl, Bharucha, & Kessler, 1982). This observation is compatible with the further notion that, within the proposed hierarchical arrangement of pitch structure, single tones are represented at the lowest level, chords at an intermediate level, and keys at the highest level (cf. Krumhansl, Bharucha, & Kessler, 1982, p. 34; see also Bharucha, 1987; and Lerdahl, 1988).

We examine, in this paper, a strict interpretation of a hierarchical description of pitch organization.[1] In a strict hierarchical model, an individual

1. We do not identify a literal interpretation of a strict hierarchy with any particular theoretical orientation. Our aim was simply to pursue the implications of a strict hierarchical account in order to initiate a study of interclass influences.

melodic line implicates a key structure only through first implicating an underlying harmonic progression, which, in turn, implicates the relationships among keys. However, the process of deriving an implied harmonic progression from a sequence of tones may be subject to error or ambiguity. Therefore, judgments of key structure for a single-voice context (a sequence of tones) should in general be more difficult than judgments of key structure for an explicit harmonic context (a sequence of chords). The present study tested this prediction by asking listeners to judge the presence or absence of key change (i.e., modulation) in either four-voiced harmonic progressions or the individual voices contained within the progression.

The Perceived Relationship between Keys

We selected the task of judging key modulation in order to explore the notion that the perceived relationship between two keys depends on the order in which those keys occur. It has been suggested that the perceived relation between two keys in a modulating sequence is not symmetric with respect to order of occurrence (e.g., Hopkins, 1979; Rosen, 1971; Werts, 1983). In each of these discussions, there is general agreement that modulations in a clockwise direction on the cycle of fifths are somehow more natural than modulations of the same number of steps in the counterclockwise direction. Several possible reasons for this asymmetry have been advanced.

According to Rosen (1971), the structure of the overtone series creates an imbalance in the cycle of fifths, and this imbalance is an essential aspect of all tonal music; ". . . harmonics all rise from a note, and the dominant or sharp direction, based on the successive second overtones of the previous note, outweighs the subdominant direction, which descends" (pp. 23–24). Although Rosen focuses on the hierarchy of triads within an established tonality, his reasoning suggests an imbalance at the level of keys. Keys may implicate their clockwise neighbor on the cycle of fifths more than their counterclockwise neighbor because listeners have internalized the strong acoustic connection between a fundamental frequency and its second overtone, and have mapped this acoustic connection into their representation of keys.

Werts's (1983) discussion of modulation offers two main reasons why certain changes in key are perceived to be strong progressions, and their retrograde-equivalents are perceived as weak. First, in Werts's terms, strong progressions are characterized by "efficiency" because it is possible (although not necessary) to realize the key change using fewer triads than would be required if the order of the two keys were reversed. For example, to modulate from C major to G major, the tonic of C major can be used as the pivot chord, and it is possible to move directly to the dominant seventh of G major. To modulate from G major to C major, however, where the tonic of G major is already the dominant of C major, one must move to another chord and return to the dominant if one is to introduce the accidentals needed to establish the second key (cf. Werts, 1983, p. 14). Second, strong progressions are characterized by "flexibility" because the tonic triad of the first key, when taken as the pivot chord, offers a greater number of harmonic options in the new key than does the tonic triad in the retrograde form of the same progression. The latter conclusion is based on Werts's notion of "harmonic priorities," whereby certain harmonic changes within a given key are acceptable, whereas others are only used in exceptional cases. Having classified key changes according to these considerations, Werts observed that, with only two exceptions, strong progressions always involve a key change in the clockwise direction on the cycle of fifths (Werts, 1983, p. 16).

In a historical account of cyclic representations of key relationships, Werts (1983) cites the eighteenth-century theorist Mattheson as similarly concerned with the directionality of modulations. In Mattheson's model of key relationships, clockwise modulations are in the "preferred" direction, whereas counterclockwise modulations are in the "wrong" direction. Hopkins (1979) suggests a similar idea metaphorically: "The movement through adjacent keys (modulation) could be compared to the waves of the sea; but waves are borne on a tide. A piece in a major key will tend to drift to the right (clockwise) . . ." (p. 44).

Maps of key-space, whether the conventional cycle of fifths (Piston, 1978), key regions (Schoenberg, 1911/1983) or theoretical developments based on psychological considerations (e.g., Krumhansl & Kessler, 1982; Shepard, 1982) do not contain directional asymmetries because these are intended to be static representations of the perceived key distances and are not intended to represent the dynamics of key movement during modulation. However, in reporting experimental results tracing the movement of a modulating chord progression, Krumhansl and Kessler (1982) noted that the extent of perceived movement depended on a number of factors including direction of key change on the cycle of fifths. We pursued this observation further by examining, for both single-voice and harmonic contexts, perceived key structure following modulations in both the clockwise and counterclockwise direction on the cycle of fifths.

Experiment 1: Identification of Key Change

Materials were excerpts from Bach chorale music (Leuchter, 1968)—sequences containing changes in key (modulating sequences), and sequences remaining in a single key (nonmodulating sequences). The chorales were chosen because they provide a wide selection of various types of key modulation within a well-defined compositional style.

Musically trained listeners were asked to identify key changes in terms of the number of steps on the cycle of fifths and the direction (clockwise or counterclockwise) on the cycle of fifths. Identification of key change was examined under conditions where movement was conveyed by individually presented voices and under conditions where these individual voices were combined to form four-voice harmony.

METHOD

Listeners

Thirty listeners, ranging in age from 19 to 27 years, participated in the single-voice condition. Thirty more listeners, drawn from the same subject pool and ranging in age from 20 to 30 years, participated in the four-voice harmonic condition. All listeners had received musical training at the university level or above. All had at least 10 years of private instruction on an instrument and 2 years of music theory training.[2] All reported normal hearing.

Apparatus

Tones were produced by a DMX-1000 real-time digital synthesizer, controlled by an LSI 11/23 computer. All tones contained the first five harmonic partials (the fundamental or f, 2f, 3f, 4f, and 5f), with the amplitude of each partial inversely proportional to the partial number. Frequency values for the fundamentals were determined according to the system of equal temperament with A4 equal to 440 Hz. Tones were presented individually in the single-voice condition or were combined to form chords in the four-voice harmonic condition. The output level was contoured so that the individual tones and chords were of approximately equal loudness. These contour values were obtained from the average of equal-loudness judgments provided for the purpose by several experienced listeners in the laboratory. Each tone or chord was 350 msec in duration and had rise and decay times of 22 msec each.

Listeners were tested in soundproof booths. Tones and chords were delivered binaurally through Sennheiser headphones (HDH 424), and responses were entered on the keyboard of a computer terminal. Before the experimental session began, each listener was allowed to adjust the average SPL to a comfortable listening level within the range 65 to 75 dB SPL.

Chorale Sequences

Twelve phrases were excerpted from the complete set of Bach chorales (Leuchter, 1968). The original sources are listed in the Appendix. The excerpts provided two examples of each of six modulation conditions. The occurrence of a modulation was defined according to traditional music-theoretic conventions (e.g., Piston, 1978). The six conditions were as follows: nonmodulating and ending on the tonic chord [Condition NM(I)], nonmodulating and ending on the dominant chord [Condition NM(V)], modulating to the key of the domi-

2. At this level of study, the students' exposure to traditional skill-related music courses would typically have included the following exercises: to harmonize in four parts any melody or bass line using chromatically altered chords and modulating where appropriate; to improvise or compose a passage of music modulating between any two keys; to sing at sight any tonal melody; to identify aurally all ascending and descending intervals within an octave; and to write down melodic dictation and four-part harmonic dictation.

nant [Condition M(V)], modulating to the key of the subdominant [Condition M(IV)], modulating to the key of the supertonic [Condition M(II)], and modulating to the key of the flattened seventh [Condition M(VIIb)].

All excerpts except those for Condition NM(V) ended with a perfect cadence to the tonic chord of the final key. Condition NM(V) was included as a control to emphasize the importance of listening to an entire presentation, not just to the first and final tone or chord.

After the initial selection, each chorale excerpt was simplified to a sequence of eight chords with no ornamental or passing tones. The sequences were examined, independently, by two members of faculty in the School of Music, Queen's University, who confirmed that the simplification did not violate the key or key-change deemed present in the original chorale excerpts.[3]

Figure 1 shows each of the 12 sequences in musical notation. In the figure, Sequences 1 and 2 are the examples of Condition NM(I), Sequences 3 and 4 the examples of Condition NM(V), Sequences 5 and 6 the examples of Condition M(V), Sequences 7 and 8 the examples of Condition M(IV), Sequences 9 and 10 the examples of Condition M(II), and Sequences 11 and 12 the examples of Condition M(VIIb).

Procedure

For single-voice presentations, each trial began with a melodic pattern of five notes of equal duration. This pattern was followed by a rest equal to the duration of two notes and was then followed by a second melodic pattern of eight notes of equal duration.

The first pattern contained the notes of the major tonic triad of the initial key of one of the sequences in Figure 1. It was intended to give the listener a strong sense of the initial key. Presented in ascending order, the five notes of the pattern were tonic, tonic one octave above the first tone, mediant, dominant, and tonic two octaves above the first tone. The second pattern was one of the individual voices of the sequence—soprano, alto, tenor, or bass.

Each voice from each of the 12 sequences was presented once. The order of presentation was randomly and independently determined for each listener. Listeners were informed that each voice had been extracted from a chorale sequence and that they should attempt to judge the key movement in the sequence from which the single voice was taken.

For four-voice harmonic presentations, the events of each trial were similar, except that instead of an individual voice from a sequence, the listener was presented a full four-voice sequence of eight chords of equal duration. Each of the 12 sequences in Figure 1 was presented once, with order of presentation again randomly and independently determined for each listener. Listeners were informed that their task was to identify the key movement in a sequence of chords extracted from a chorale.

All single-voice and all four-voice presentations were exactly as notated in Figure 1, that is, they were not subject to further transposition. Thus, the initial key varied unpredictably from trial to trial.

After each trial, listeners were first asked to identify the distance between the first and final key in terms of the cycle of fifths. A rating scale of 1–4 appeared on the terminal screen

3. In the process of simplifying the excerpts, the construction of the final chord was sometimes modified. The point was to provide for each condition (except Condition NM(V) two examples of the final chord. In the first example, the final (tonic) chord contained only the tonic and mediant tones. In the second, the final chord contained the tonic, mediant, and dominant tones; the dominant of the final chord was always carried by an inner voice. This procedure allowed an examination of the importance of the construction of the final chord on listeners' perception of key change. However, the effects relating to the construction of the final chord have been discussed elsewhere (see Thompson, 1986; Thompson & Cuddy, 1986, 1987) and do not bear on the findings reported in the present paper. Therefore, the influence of the construction of the final chord is not discussed here.

after each trial. The four categories of choice were (1) nonmodulating and ending on the tonic chord, (2) nonmodulating and ending on the dominant chord, (3) modulating to a key one step on the cycle of fifths, and (4) modulating to a key two steps on the cycle of fifths. If the listener judged the trial to contain a modulation, he or she was then asked to judge the direction of the key change on the cycle of fifths. For these judgments, listeners chose between "sharp" and "flat" directions, where a sharp direction indicated that the key change involved clockwise movement on the cycle of fifths (e.g., from C+ to G+) and a flat direction indicated that the key change involved counterclockwise movement (e.g., from C+ to F+). The choice of modulation direction was made by selecting 1 (sharp) or 2 (flat) on the computer terminal. None of the listeners reported feeling uncomfortable with these choice names.

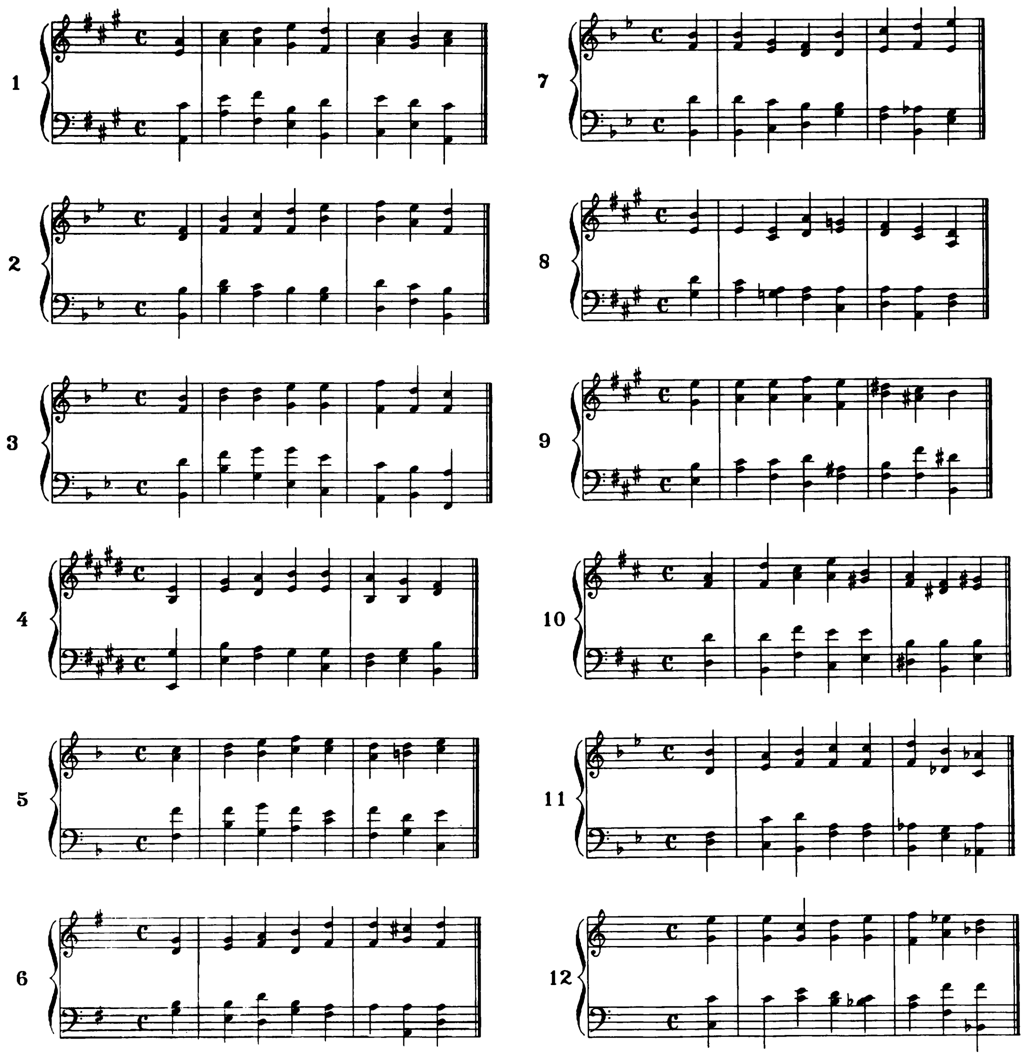

Fig. 1. Sequences used in the experiments. The sequences were simplified excerpts from the set of Bach Chorales (Leuchter, 1968).

RESULTS AND DISCUSSION

Accuracy of Distance and Direction Judgments

Percentage identified correctly was scored for both distance and direction judgments, for each voice from each sequence in the case of the single-voice condition and for each sequence in the case of the four-voice harmonic condition. A correct distance judgment was defined as the correct assignment of distance category (nonmodulating, nonmodulating but ending on the dominant, modulating one step on the cycle of fifths, and modulating two steps on the cycle of fifths). A correct direction judgment was defined as the correct assignment of direction category (nonmodulating, modulating to the sharp side, and modulating to the flat side of the cycle of fifths).

Figure 2 displays, for each of the six modulation conditions, the mean accuracy scores for modulation distance judgments. Similarly, Figure 3 displays the mean accuracy scores for modulation direction judgments. In both figures, the data for the single-voice condition are averaged across all

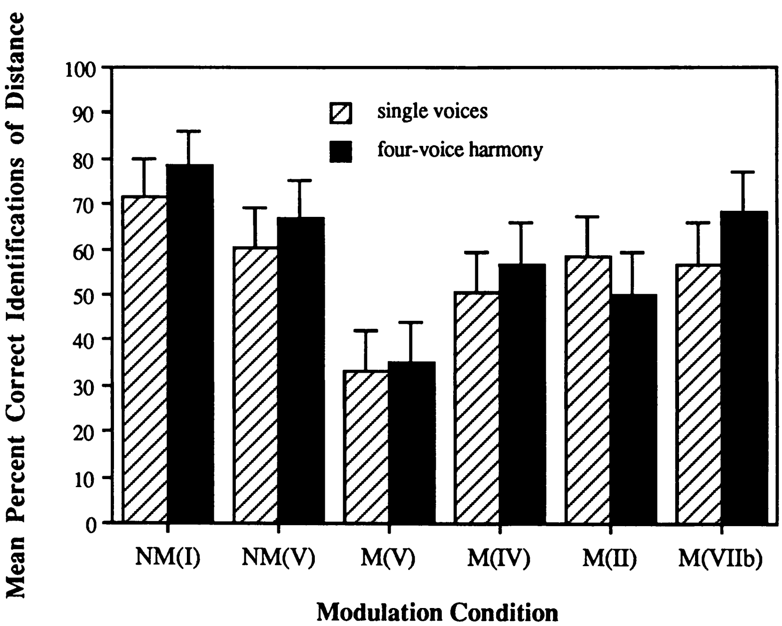

Fig. 2. Experiment 1: Accuracy of identifying distance of key change by musically trained listeners for single-voice and four-voice harmonic presentations. Data for single voices are averaged across the four voices of each sequence and across the two examples of each modulation condition. Data for four-voice harmony are averaged across the two examples of each modulation condition.

four voices and averaged across the two examples of each modulation condition. The data for the four-voice harmonic condition are averaged across the two examples of each modulation condition. The figures also show the standard error of each mean.

Figures 2 and 3 show that single-voice and four-voice harmonic conditions produced similar levels of performance within modulation conditions and similar patterns of differences across modulation conditions. Within each modulation condition, accuracy scores for the single-voice and for the four-voice harmonic conditions usually differed by less than one standard error. Across modulation conditions, accuracy of identifying modulation improved as modulation distance increased, and accuracy was higher for modulations in the counterclockwise direction on the cycle of fifths than for modulations in the clockwise direction.

The data for the single-voice and four-voice harmonic conditions were subjected to separate analyses of variance: the separate analyses permitted further breakdown of the single-voice data according to the individual voices presented. Both analyses confirmed that the differences among modulation conditions shown in Figures 2 and 3 were significant. For single

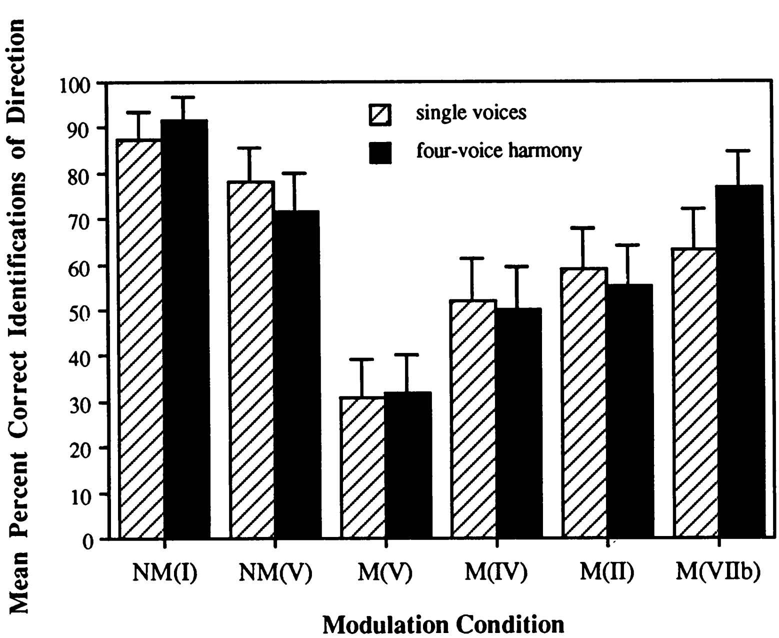

Fig. 3. Experiment 1: Accuracy of identifying direction of key change by musically trained listeners for single-voice and four-voice harmonic presentations. Data for single voices are averaged across the four voices of each sequence and across the two examples of each modulation condition. Data for four-voice harmony are averaged across the two examples of each modulation condition.

voices, the main effect of modulation condition was highly significant for both distance judgments [$F(5, 145) = 11.62, p < .001$] and direction judgments [$F(5, 145) = 42.14, p < .001$]. For four-voice harmony, the main effect of modulation condition was also highly significant for distance judgments [$F(5, 145) = 8.34, p < .001$] and for direction judgments [$F(5, 145) = 15.26, p < .001$].

In the single-voice analysis, it was found that identification accuracy was significantly dependent on the voice presented [$F(3, 87) = 11.10, p < .001$]. Table 1 displays the overall identification accuracy for soprano voices, inner voices (i.e., alto and tenor), and bass voices. There were no significant differences in identification accuracy between the two outer voices (soprano and bass) or between the two inner voices (alto and tenor). However, listeners were significantly more accurate in their judgments of outer voices than inner voices—for modulation distance [$F(1, 29) = 42.67, p < .001$] and for modulation direction [$F(1, 29) = 11.28, p < .01$]. For all voices, accuracy was well above chance accuracy of 25% for distance judgments and 33.3% for direction judgments. For comparison, Table 1 also shows the mean identification accuracy for the four-voice harmonic condition.

It was argued that a strict hierarchical model of pitch structure would predict greater identification accuracy for sequences of chords than for individually presented voices. However, accuracy of judging both distance and direction of modulation was at least as high when just the individual soprano and bass voices were presented as it was when full harmonic sequences were presented. This finding presents some difficulty for a strict hierarchical model, because it suggests that information about key structure may be equally available at the levels of chords and single tones.

TABLE 1

Experiment 1: Mean Accuracy for Identification of Distance and Direction of Modulation after Single-Voice and Four-Voice Harmonic Presentations

	Accuracy (%) across All Modulation Conditions	
Presentation	Modulation Distance	Modulation Direction
Soprano voice only	61.9	65.0
Inner voices	48.5	58.6
Bass voice only	61.7	64.7
Four-voice harmony	59.2	62.8

The Asymmetry of Judged Distance between Keys

As previously mentioned, identification accuracy was higher for modulations occurring in the counterclockwise direction than it was for modulations occurring in the clockwise direction. To examine this finding further, the average ratings of distance for clockwise modulations were compared with the average ratings of distance for counterclockwise modulations. For each modulation condition, judgments of modulation distance from 1 to 4 were treated as indicative of the perceived distance between the two keys in the sequence.

Of course, such treatment raises the objection that listeners were asked to identify key change, not to judge distance per se. However, the categories of choice for distance of modulation were ordered by increasing amount of change. Thus, the scale can be assumed to be ordinal. It could not be assumed, however, that neighboring categories were equidistant and consequently a nonparametric statistical analysis was performed (Wilcoxon t).

For single voices, modulations to a key one step on the cycle of fifths received lower ratings of distance, on the average, if the key change involved a clockwise movement on the cycle of fifths (mean = 2.4) than if the key change involved counterclockwise movement on the cycle of fifths (mean = 2.7; $Z = -3.55$, $p < .01$). This asymmetry should be interpreted with caution, however, because modulations to the dominant key often were confused with nonmodulation ending on the dominant chord. Therefore, ratings for the former may have been artificially low. For modulations to a key two steps on the cycle of fifths, no significant differences between direction of modulation were found for any one voice, for the average of all four voices, or for just those voices in which nondiatonic tones were introduced during the key change. The average rating for both directions of modulation was 3.4. Therefore, the data for the single-voice condition did not provide convincing evidence for directional asymmetry.

For four-voice harmony, modulations to the dominant received lower overall distance ratings (mean = 2.3) than modulations to the subdominant (mean = 2.6). This effect was significant [$Z = -2.06$, $p < .05$] but is again to be considered with caution because of the frequent confusion between modulations to the dominant key and nonmodulation ending on the dominant chord. For modulations two steps on the cycle of fifths, modulations involving clockwise movement were given lower overall distance ratings (mean = 3.3) than modulations involving counterclockwise movement (mean = 3.6; $Z = -2.42$, $p < .05$). This finding implies that the psychological distance between keys in a four-voice harmonic sequence depends on the order in which they occur. When the order suggested clockwise movement around the cycle of fifths (i.e., movement to a key with more sharps or less flats), the keys were psychologically closer than when the order suggested movement in the opposite direction.

As pointed out above, however, the dependence of identification on modulation direction is difficult to interpret because of the presence of the control condition and because listeners were not specifically asked to judge the psychological distance between keys. The second experiment eliminated the control condition and asked listeners to provide direct ratings of perceived distance between the first and final keys.

Experiment 2: Judgments of Key Distance by Untrained Listeners

The design of Experiment 2 was similar to that of Experiment 1. The same materials were used. In the single-voice condition, listeners were presented one of the individual voices of a simplified chorale excerpt. In the four-voice harmonic condition, listeners were presented the full four voices of the excerpt. In both conditions, they were asked to identify the presence or absence of modulation by rating the extent of perceived key change on a seven-point rating scale. As noted above, the control condition of Experiment 1 was dropped.

Experiment 2 differed from Experiment 1 in listener selection. The musically trained listeners of Experiment 1 had a fairly extensive background in traditional music theory. It is possible that the key-distance effects found in Experiment 1 were partly attributable to preconceived notions about the cycle of fifths, rather than to perceived distances between keys. Therefore, listeners with such training in music theory were excluded from Experiment 2.

METHOD

Listeners

Twenty-four listeners, ranging in age from 18 to 40 years, participated in the single-voice condition. Twenty listeners, ranging in age from 18 to 30 years, participated in the four-voice harmonic condition. Listeners had very little or no formal training in traditional music theory, but most listened to classical music on a regular basis. None of the listeners participated in both conditions. All listeners reported normal hearing.

Apparatus and Stimuli

For single-voice presentations, tones were produced by a Yamaha DX11 FM synthesizer, controlled by a Macintosh II computer. The waveform of tones was set to algorithm 4 of the synthesizer's preset complex waveforms and was similar to the waveform used in Experiment 1. For harmonic presentations, the apparatus and stimuli were identical to those used in Experiment 1.

Sequences and Procedure

Chorale sequences were identical to those of Experiment 1. Sequences from Condition NM(V)—nonmodulating ending on the dominant chord—were dropped. The events of each trial were identical to Experiment 1.

In the single-voice condition, listeners were tested in four groups of six listeners each. Listeners heard each trial through stereo speakers. The order of presentation of trials was randomized independently for each of two groups; the order was reversed for the remaining two groups.

Procedures for the four-voice harmonic condition were identical to Experiment 1, except that each of the 10 four-voice sequences was presented twice. The order of the 10 sequences was independently randomized for each listener and was followed by a second independent random order of the sequences.

In both the single-voice and the four-voice harmonic conditions, listeners were asked to rate the distance between the first and final keys of each test sequence on a scale of 1 to 7. Although none of the listeners was formally trained in traditional music theory, most were familiar with the concept of key. For listeners not familiar with this concept, a brief explanation was provided. This explanation included reference to the scale, do-re-me-fa-sol-la-ti-do, and to the sense of stability associated with the first note of the scale. Listeners were informed that there were no right or wrong answers and that they should try to use the entire range of the response scale.

RESULTS AND DISCUSSION

Ratings of Key Distance for Single Voices and Four-Voice Harmony

Figure 4 displays, for both single-voice and four-voice harmonic conditions, mean ratings of key distance for each modulation condition. For single voices, each bar in the figure represents the mean rating across all four voices and the two examples of each modulation condition. For four-voice harmony, each bar in the figure represents the mean rating across the two examples of each modulation condition. The standard error of each mean is also shown.

The figure shows that the mean ratings of perceived distance between the first and final key were similar for the single-voice and four-voice harmonic conditions. Mean ratings for the different modulation conditions increased as distance on the cycle of fifths increased.

Statistical analyses of the data for both the single-voice and four-voice conditions revealed that differences among modulation conditions were significant. For single voices, there was a significant main effect of sequence [$F(9, 207) = 20.88$, $p < .001$]. Orthogonal contrasts showed that voices from sequences remaining in the same key were given significantly lower ratings than voices from sequences that changed key [$F(1, 23) = 77.03$, $p < .001$]. Voices from sequences modulating one step on the cycle of fifths were given significantly lower ratings than voices from sequences modulating two steps on the cycle of fifths [$F(1, 23) = 45.46$, $p < .001$].

For four-voice harmony, listeners' ratings also were significantly influenced by the sequence [$F(9, 171) = 11.83$, $p < .001$]. Orthogonal con-

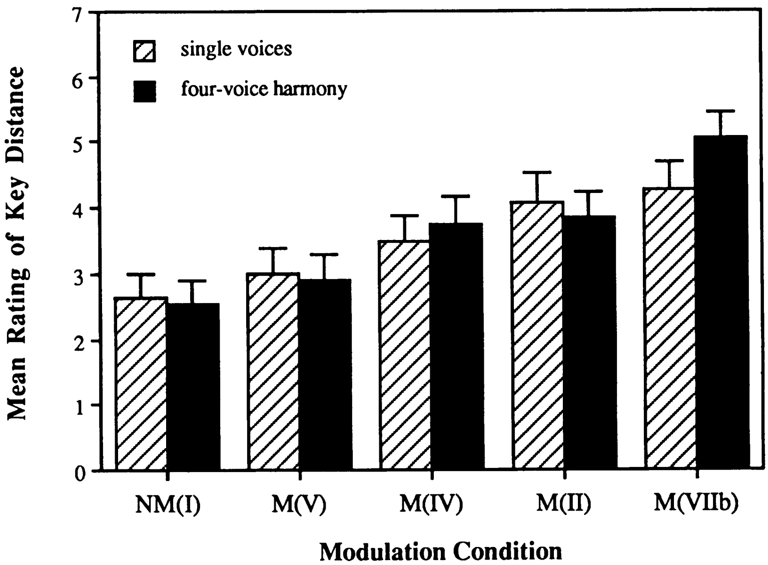

Fig. 4. Experiment 2: Mean ratings of modulation distance by musically untrained listeners for single-voice and four-voice harmonic presentations. Data for single voices are averaged across the four voices of each sequence and across the two examples of each modulation condition. Data for four-voice harmony are averaged across the two examples of each modulation condition.

trasts again showed that nonmodulating sequences were given significantly lower ratings than modulating sequences [$F(1, 19) = 19.38, p < .001$] and sequences modulating to a key one step on the cycle of fifths were given lower ratings than sequences modulating to a key two steps on the cycle of fifths [$F(1, 19) = 99.82, p < .001$].

The Asymmetry of Perceived Key Distance

Table 2 presents mean ratings of key distance for individual voices and for the four-voice harmonic condition. Table 2 suggests that an asymmetry of perceived key distance with respect to direction of modulation occurs for bass voices, but not for other individually presented voices. Within modulating sequences, the effect of modulation direction on listeners' judgments was significantly different for bass voices than for other individually presented voices [$F(1, 23) = 23.07, p < .001$].

Table 2 also confirms the finding of Experiment 1 that there is a directional asymmetry for four-voice harmony. Sequences modulating in a clockwise direction on the cycle of fifths were given lower ratings, on the average, than sequences modulating in the opposite direction [$F(1, 19) = 13.14, p < .005$].

The data and statistical analyses suggest that an effect of modulation direction occurs for harmonic presentations of the sequences and for the bass

TABLE 2
Experiment 5: Mean Ratings of Key Distance after Single-Voice and Four-Voice Harmonic Presentations

	Nonmodulating	Modulating		
Presentation	Mean	Clockwise	Counterclockwise	Mean
Soprano voice only	2.6	3.8	4.0	3.9
Inner voices	2.4	3.5	3.5	3.5
Bass voice only	3.1	3.3	4.4	3.9
Four-voice harmony	2.5	3.4	4.4	3.9

voices contained in the sequences. Indeed, the means presented in Table 2 suggest that the effect of modulation direction was almost identical under the latter two conditions of presentation. It may be noted that the bass voice of four-voice harmony frequently carries the root of chords and may therefore be more strongly associated with chord structure than are other voices.

General Discussion

The first experiment showed that musically trained listeners are sensitive to both the distance and direction of key change in sequences adapted from chorale excerpts—not only for four-voice harmony, but also for each of the individual voices contained in the harmonic progression. The second experiment revealed that listeners without formal training in traditional music theory also are able to provide reliable judgments of key changes in both single voices and four-voice harmony. Judgments of key change generally were consistent with the theoretical relationships between keys described by the cycle of fifths.

Both experiments showed that, for four-voice harmonic sequences, judgments of key change in a modulating sequence were affected by the order in which the keys occurred. When a key change involved clockwise movement around the cycle of fifths, the first and final keys were perceived to be more closely related than when a key change involved counterclockwise movement around the cycle of fifths. The asymmetry of distance judgments has been anticipated by music theorists, as noted earlier in this paper and also by Krumhansl and Kessler (1982).

Various accounts of the asymmetry of key distance have been offered, such as explanation at the level of the overtone series (Rosen, 1971) or explanation at the level of compositional constraints on chord progressions (Werts, 1983). Presumably, knowledge of the conventions of the tonal style is invoked in the perceptual interpretation of key change. However, to assess these and other explanations adequately first requires that the effect be examined with a wider representation of tonal music.

Despite this necessary caution concerning specific explanations, there is an important implication arising from the directional asymmetry of key distance. The directional asymmetry reliably obtained with four-voice harmony was obtained but weakly, if at all, with single voices. (The directional asymmetry found for bass voices in the second experiment is an exception, but this effect was not obtained in the first experiment.) A failure to obtain directional asymmetry for single voices would not be surprising if single voices were poor conveyors of key and key-change information. In that case, sensitivity to direction would be expected to be unreliable as well. But single voices, especially outer voices, yielded key judgments that were as discriminating as the judgments obtained from four-voice harmony. It would appear that, within the chorale style, information regarding key change is equally available at both the levels of chords and single voices. Directional asymmetry, however, is contained in the information conveyed by chords.

The present results challenge a strict description of a hierarchial organization in which melody conveys key structure by implicating an underlying harmonic progression. Individual voices may convey information about harmonic constraints (e.g., Cuddy et al., 1981), but also may convey other sources of information about pitch structure. Thus, the principles that govern processing of single tones and chords may be somewhat independent (see Krumhansl, Bharucha, & Kessler, 1982, p. 35).

A plausible alternative is that the relationship between tones, chords, and keys may be represented as a partial hierarchy. Although partially hierarchical models have not been applied to musical pitch before, evidence by McNamara (1986) and others suggests that spatial information is encoded as a partial hierarchy, rather than as a strict hierarchy. In a partial hierarchy, relations that may be inferred from knowledge of other levels of structure may be encoded explicitly as well. For instance, the spatial relation between two cities may be inferred from spatial knowledge of the countries to which they belong, but their relation also may be encoded explicitly, that is, without reference to superordinate spatial relations.

The idea of explicit encoding of relations at each level suggests that musical relationships may be evaluated either with or without reference to other levels in the hierarchy. For example, the relationship between two individual tones may be heard in accordance with their intervallic function (e.g., Browne, 1981) and/or in accordance with the relationship between the chords to which they belong. Incorporating such an encoding redundancy into models of musical pitch perception would suggest that listeners are able to evaluate key relationships in a single melodic line without reference to an implied harmonic progression, although the use of inference from knowledge of harmony may also be possible. However, all key-related effects found with chord sequences, such as directional asymmetry, need not be evident in judgments of single voices.[4–6]

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Appendix

Sources for the Chorale Sequences (Leuchter, 1968)

1. Chorale # 9: "Allein Gott in der höh' sei ehr' " (God in the heaven's honor), bars 1–3.
2. Chorale # 172: "Was Gott thut, das ist wohl gethan" (That which God does, is well done), bars 1–3.
3. Chorale # 61: "Herr Christ, der einig' Gott's sohn" (Christ, only-begotten son of God), bars 6–8.
4. Chorale # 117: "Mach's mit mir, Gott, nach deiner güt' " (Dispose of me, God, according to your kindness), bars 1–3.
5. Chorale # 196: "Wie schön leuchtet der morgenstern" (How beautifully the morning star glows), bars 3–5.
6. Chorale # 33: "Ermuntre dich, mein schwacher geist" (Wake up, languished spirit), bars 1–3.
7. Chorale # 252: "Es spricht der unweisen mund" (The foolish men say), bars 1–3.
8. Chorale # 143: "O Gott, du frommer Gott" (Oh God, pious God), bars 3–5.
9. Chorale # 22: "Christ, unser Herr, zum Jordan kam" (Christ, our Lord, has come to the Jordan), bars 14–16.
10. Chorale # 258: "Gelobet seist du, Jesu Christ" (Be glorified, Jesus Christ), bars 5–7.
11. Chorale # 1: "Ach Gott und Herr" (Oh God and Lord), bars 5–7.
12. Chorale # 104: "Jesu, nun sei gepreiset" (We praise you, Jesus), bars 1–3.