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Perceived Key Movement in Four-Voice Harmony and Single Voices

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Listeners with a moderate amount of musical training rated the distance between the first and final key of short chorale excerpts under one of four presentation conditions. The distance between keys, or modulation distance, was either zero, one, or two steps in either the clockwise or counterclockwise direction on the cycle of fifths. Presentation conditions were four-voice harmonic sequences excerpted from the complete set of Bach chorales, single voices of the latter sequences, four-voice harmonic sequences simplified to block chords, and single voices of the latter sequences. Consistent with earlier findings (Thompson & Cuddy, 1989), judgments for both four-voice harmonic presentations and single-voice presentations revealed a close correspondence between modulation distance and judged distance. Ratings for harmonic sequences within a given key distance, however, showed influences of direction of modulation and of harmonic progression that were not reflected in ratings for single voices. The findings suggest that harmony and melody follow somewhat different principles in the process of identifying key change.

In harmonized music, influences on the perception of key structure and key change are notably complex. Both melodic and harmonic structure contribute to a listener's sense of key. It is difficult to isolate their separate influences, however, because the tonal implications of melody and harmony are highly correlated.

In a previous report, we addressed this problem by investigating a strict hierarchical description of key (Thompson & Cuddy, 1989). In this description, a melodic line implicates key structure by first implicating an

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underlying harmonic progression, which, in turn, implicates key structure and key movement. Because the process of deriving an implied harmonic progression from a sequence of tones may be subject to error or ambiguity, the strict hierarchical description predicts that judgments of key structure should in general be more difficult for single voices than for harmonic sequences.

Before Thompson and Cuddy (1989), investigators had not explicitly tested a hierarchical conception of tones, chords, and keys by asking listeners directly to judge key movement in both harmonic sequences and in single voices. However, demonstrations of top-down influences involving a variety of other judgments have generally supported a hierarchical description of key structure. For example, it has been shown that key context influences judgments of chords or chord sequences (Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982; Krumhansl & Kessler, 1982) and melodies (e.g., Cuddy, Cohen, & Mewhort, 1981; Cuddy, Cohen, & Miller, 1979; Dowling, 1978; Krumhansl, 1979). Moreover, judgments of melodies are influenced by the implied harmonic progression (Bharucha, 1984; Cuddy, Cohen, & Mewhort, 1981; Cuddy & Lyons, 1981). These results are consistent with the notion that, within a hierarchy of musical structure, keys are represented at the highest level, chords at an intermediate level, and single tones at the lowest level (Bharucha, 1987; Krumhansl, Bharucha, & Kessler, 1982, p. 34; Lerdahl, 1988).

Thompson and Cuddy (1989) investigated the perception of key structure and key movement by asking listeners to judge the distance between the first and final key of excerpts adapted from Bach chorales. Five types of sequences were included in the presentations: nonmodulating, modulating to the dominant, modulating to the subdominant, modulating to the supertonic, and modulating to the flattened seventh. Judgments of key distance in four-voice sequences were compared with judgments of key distance in the individual voices of those sequences. There were two main findings: first, both harmonic and single-voice presentations reliably conveyed a similar degree of key movement to listeners; second, for harmonic presentations, but not for single-voice presentations, greater distance was associated with modulations moving in the counterclockwise, rather than in the clockwise, direction. This second finding suggests that the key movement conveyed by harmonic sequences, but not by single voices, was asymmetric with respect to direction of modulation.

Together, the findings suggest that judgments of key distance in harmony and single voices are not adequately modeled by a strict hierarchical system. Within a strict hierarchical processing system, some information loss is expected between the levels of harmony and single voices. Therefore, judgments of single voices should be less reliable than judgments of

harmonic presentations. An exception to this latter outcome could occur only if listeners were able to abstract with complete accuracy the underlying harmonic progression from presentations of single voices: in that case, however, one would expect effects such as the directional asymmetry, mentioned earlier, to be evident for both judgments of harmonic sequences and judgments of single voices. Because our results were inconsistent with either possible outcome, we concluded that melody and harmony do not implicate key structure within a strict hierarchical system. Rather, the processes of abstracting key structure from melody may operate somewhat independently from the processes of abstracting key structure from harmony.

The present investigation was designed to replicate and elaborate on the earlier findings. For both harmonic and single-voice presentations, we compared judgments of key distance for three versions of the chorale sequences. The first version was the original form as notated by Leuchter (1968). The other versions were simplifications of the sequences [simplifications (1) and (2)]. Simplified versions were sequences of eight four-voice chords, that is, without passing notes or ornamentation.

Simplification (1) was provided by Professor Fred Lerdahl. It retains the overall key movement theoretically deemed present in the original chorale sequences but alters the harmonic progressions in order to equate the point of modulation across all sequences. Lerdahl (personal communication, 1986) commented that some of the modulations occurred either "too soon or too late," particularly those in the counterclockwise direction. This imbalance may have contributed to the directional asymmetry noted in Thompson and Cuddy (1989) for ratings of harmonic presentations. Simplification (2) was the version used in our earlier research: it closely preserved the harmonic progression of the original chorales.

Judgments of key distance in original sequences and Simplification (1) sequences were collected and compared with judgments previously collected for Simplification (2) sequences (Thompson & Cuddy, 1989). Since the three versions of each chorale sequence always maintained the same key structure, similarities among the results for the three versions should reveal the overall contribution of key structure to perceived key movement. Differences among the versions should reveal influences by local melodic and harmonic details.

Method

The method described refers to experimentation with original and Simplification (1) sequences. Procedures for Simplification (2) sequences were similar (Thompson & Cuddy, 1989).

LISTENERS

Four groups of listeners, each consisting of 20 undergraduate students from the University of Queensland, Australia, were tested. Listeners were selected from a first-year subject pool and were given course credit for participating. The participants had little or no formal training in traditional music theory, but all listened to classical music on a regular basis, or currently played a musical instrument. All subjects reported normal hearing.

APPARATUS AND STIMULI

Tones were triangular waveforms produced by a Yamaha DX-11 synthesizer, controlled by a MacIntosh SE-20 computer. The synthesizer was set to the system of equal temperament with A_4 equal to 440 Hz. Sequences were prepared with the music software package "Professional Composer" and presented under the control of the software package "Professional Performer." The tempo of each presentation was set to 120 quarter notes per minute.

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

Ten phrases were excerpted from the complete set of Bach chorales (Leuchter, 1968). The original sources are listed in Thompson and Cuddy (1989, appendix). The 10 excerpts provided two examples of each of five modulation conditions. The five conditions were as follows: nonmodulating [Condition NM], modulating to the key of the dominant [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 ended with a perfect cadence to the tonic chord of the final key. Two versions of each sequence were used in the investigation: the original excerpts and a simplified version of the excerpts [Simplification (1), prepared by Professor F. Lerdahl]. The simplified (1) version of each sequence consisted of eight chords with no ornamental or passing notes. For each sequence, the key structure, the root of the first chord, and the roots of the final two chords were always the same in the original and simplified versions. However, harmonic progressions were sometimes altered in the simplified (1) sequences in order to equate the point of modulation across all sequences.

Figure 1 shows the original versions of the 10 chorale sequences in musical notation. Figure 2 shows the simplified (1) versions of the 10 sequences. The types of key movement displayed in Figures 1 and 2 are as follows: nonmodulating—Sequences 1 and 2, modulating one step on the cycle of fifths to the dominant or to the subdominant—Sequences 3, 4, 5, and 6, and modulating two steps on the cycle of fifths to the supertonic or to the flattened seventh—Sequences 7, 8, 9, and 10.[1]

PROCEDURE

Subjects were randomly assigned to one of four groups. Presentations for the four groups were as follows: Group 1—harmonic sequences excerpted from Leuchter (1968), Group 2—single voices of the latter sequences, Group 3—harmonic presentations of Sim-

1. Sequences 3 and 4 of Thompson and Cuddy (1989) were dropped for reasons explained in that paper, and the sequences of this paper have been renumbered accordingly.

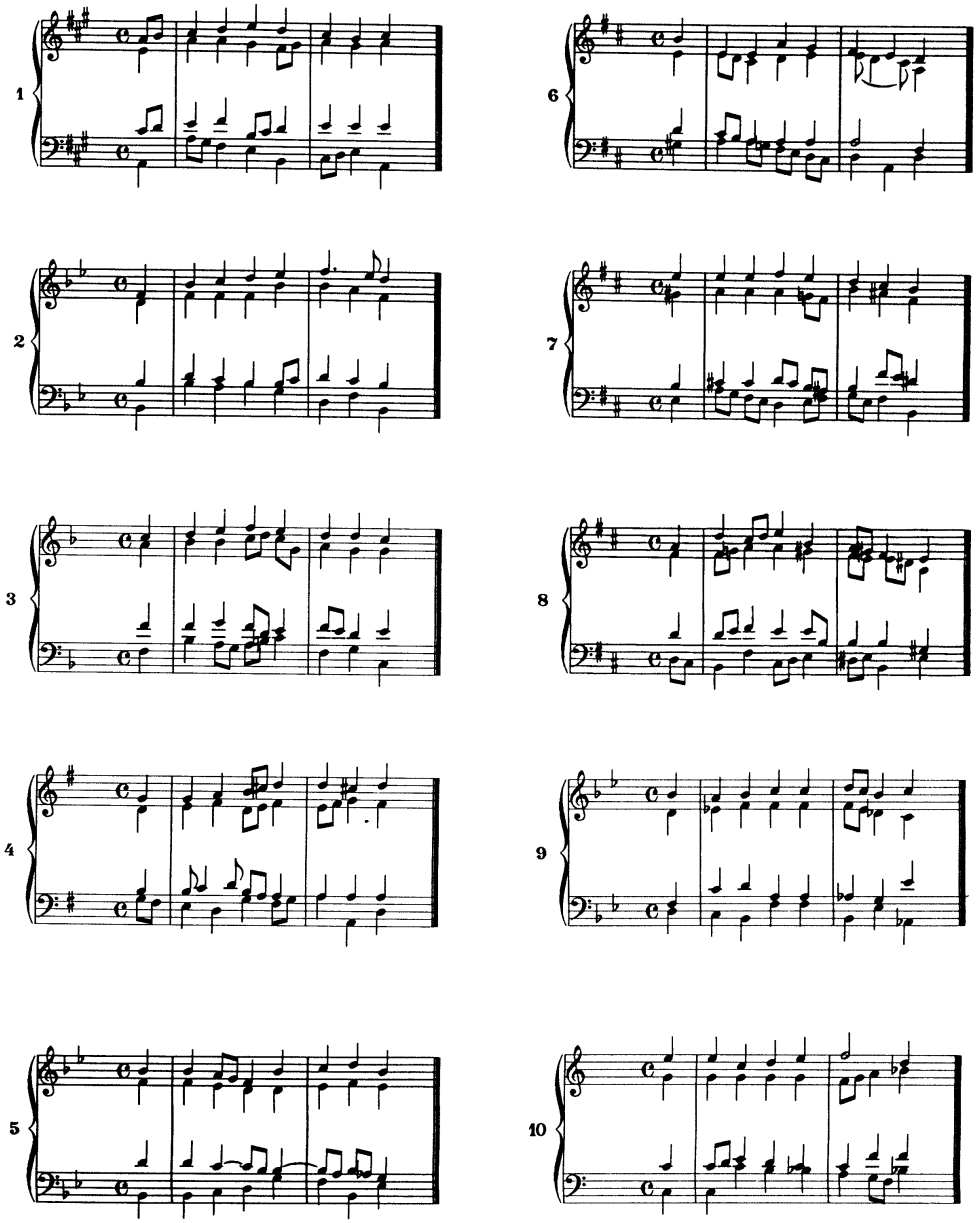

Fig. 1. The original versions of the 10 sequences, excerpted from Bach Chorales (Leuchter, 1968).

plification (1) sequences, Group 4—single voices of the latter sequences. Each trial consisted of an initial melodic pattern of five quarter notes, followed by a pause equal to two quarter notes, and then a harmonic or single-voice presentation. The initial melodic pattern outlined the tonic triad of the initial key of the sequence and was included to give the listener a strong sense for 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. For harmonic presentations, each harmonic sequence was

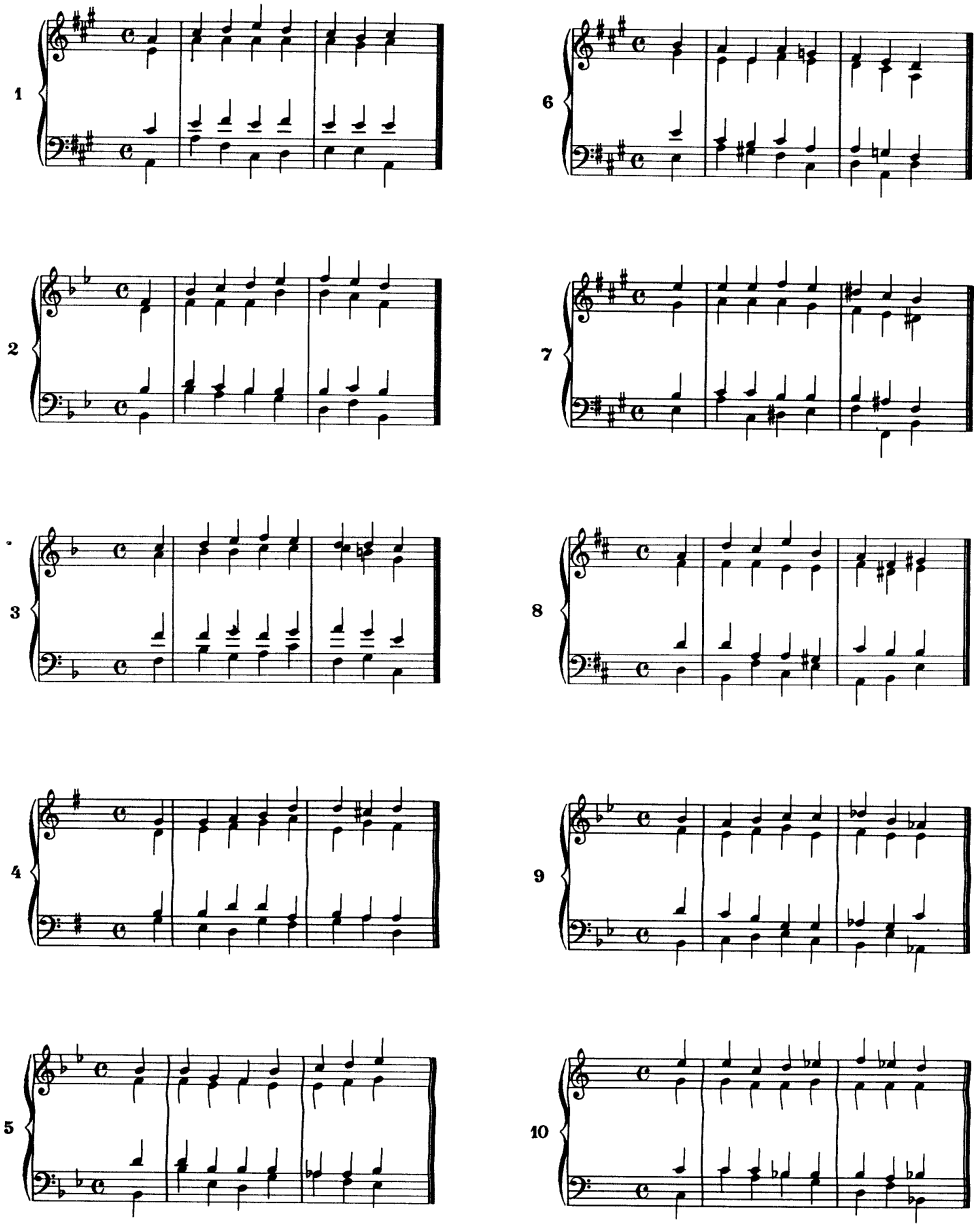

Fig. 2. The simplified (1) versions of the 10 sequences.

presented once. For single-voice presentations, each voice from each harmonic sequence was presented once. The order of presentation was randomly and independently determined for each listener.

Listeners were informed that they should rate the distance between the first and final key of each presentation on a scale of one to seven. For listeners not familiar with a formal definition of key, an 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

Table 1 displays mean ratings of perceived key distance for three types of key structure and three versions of the sequences. The three types of key structure in the table are nonmodulating (Nonmod), modulating one step on the cycle of fifths (Mod 1 step), and modulating two steps on the cycle of fifths (Mod 2 steps). The upper part of the table shows mean ratings for four-voice harmonic presentations; the lower part shows mean ratings for single voices averaged across voices (soprano, alto, tenor, bass).

Table 1 reveals similar patterns of results for each of the three versions. Single voices, on the average, conveyed as much information about key change as four-voice harmonic presentations. As the theoretical distance on the cycle of fifths increased, ratings of perceived distance increased by about the same amount for four-voice harmony and for single voices. Analysis of variance yielded strong effects of modulation distance and no interactions between modulation distance and version of the sequences. For four-voice harmonic presentations, nonmodulating sequences were rated lower than modulating sequences [$F(1, 57) = 57.19$, $p < .01$], and key changes of one step on the cycle of fifths were associated with lower ratings than key changes of two steps [$F(1, 57) = 97.18$, $p < .01$]. Similarly, for single-voice presentations, nonmodulating sequences were rated lower than modulating sequences [$F(1, 61) = 190.93$, $p < .01$], and key changes of one step were associated with lower ratings than key changes

TABLE 1
Mean Ratings of Key Distance for Four-Voice Harmony and Single Voices

	Version		
	Original	Simplified (1)	Simplified (2)
Four-voice harmony			
Nonmod	2.58	2.45	2.54
Mod 1 step	3.03	3.58	3.32
Mod 2 steps	4.46	4.50	4.45
Mean of four single voices			
Nonmod	2.65	2.49	2.64
Mod 1 step	3.38	3.60	3.23
Mod 2 steps	4.38	4.50	4.16

of two steps [$F(1, 61) = 154.20$, $p < .01$]. Thus, ratings of key distance were as reliable for single voices as they were for full harmonic sequences.

ASYMMETRY OF MODULATION DIRECTION

The asymmetry of modulation direction reported for Simplification (2) by Thompson and Cuddy (1989) was replicated for the original sequences but was much less evident in the simplified (1) sequences provided by Lerdahl. For four-voice harmonic presentations of the original sequences, key changes involving clockwise movement on the cycle of fifths were associated with lower ratings (mean, 3.1) than key changes involving counterclockwise movement on the cycle of fifths (mean, 4.4). For the simplified (1) harmonic sequences, however, mean ratings were 3.9 and 4.2 for clockwise and counterclockwise movement, respectively. Thus, original and simplified (1) harmonic sequences differed significantly with respect to the presence of an asymmetry of modulation direction [$F(1, 38) = 4.43$, $p < .05$]. This finding suggests that directional asymmetry is related to the specific characteristics of the harmonic progressions—the means by which modulation is effected. It is not necessarily a property of the psychological representation of key relationships.

There was no asymmetry of modulation direction for judgments of single voices, for either version tested in this investigation. This finding is consistent with the results reported in Thompson and Cuddy (1989): In both investigations, asymmetry of modulation direction, when it emerged for four-voice harmonic sequences, was not evident in judgments of single voices. This difference between judgments of harmonic presentations and judgments of single-voice presentations occurred in spite of the fact that ratings of key distance were equally reliable for single-voice and harmonic presentations. Evidently, processes underlying the asymmetry effect reported for judgments of harmonic presentations were not operating for judgments of single voices. More generally, harmony and single voices may be partially independent in the implication of key structure.

JUDGMENTS OF SINGLE VOICES

Table 2 displays mean ratings assigned to soprano, alto, tenor, and bass voices, for each of the three versions, averaged across modulating sequences only. For single-voice presentations, the three versions differed with respect to the amount of key change conveyed by the four voices contained in modulating sequences. For the original versions, ratings of key distance were lower for soprano voices than for other voices. For the two simplified versions, ratings of key distance for the soprano voice of

TABLE 2
Mean Ratings of Key Distance in Soprano, Alto, Tenor, and Bass Voices, Averaged across Modulating Sequences

	Voice			
	Soprano	Alto	Tenor	Bass
Original	2.78	3.88	4.50	4.38
Simplified (1)	3.57	3.44	4.59	4.59
Simplified (2)	3.87	3.34	3.70	3.87

most sequences were similar to ratings of key distance for other voices. In other words, the degree of key change conveyed by single voices was less balanced across voices in the original versions than in the simplified versions. These differences were supported by an overall interaction between Voice × Sequence-type × Version [$F(24, 732) = 5.42$, $p < .01$].

Not surprisingly, voices that introduced the new note or notes involved in a key change were most informative that a key change had occurred. For example, ratings of the soprano voice of Sequence 9 were much lower for the original version (mean, 2.45) than for the simplified (1) version (mean, 5.15) [$t(19) = 5.88$, $p < .001$]. This difference appears to be related to the presence of accidentals in the voice: the original soprano voice involves no accidentals, but the simplified (1) soprano voice involves two accidentals (i.e., notes from the new key) in the last bar. For the alto of the same sequence, mean ratings for the original and simplified (1) version were 5.55 and 3.25, respectively [$t(19) = 4.67$, $p < .001$]. Again, the difference appears to be related to the presence of an accidental. In the original alto voice, an accidental is introduced by the new key at the penultimate note. In the simplified (1) alto voice, there are no accidentals.

COMPARISON OF HARMONY AND SINGLE VOICES

As noted in Table 1, mean ratings of key distance for four-voice harmony and for single voices increased by similar amounts as theoretical distance on the cycle of fifths increased. However, examination of ratings for the individual sequences within a given modulation distance revealed that judgments of harmonic presentations and judgments of single-voice presentations did not always correspond. The musical changes made to the original sequences to create simplified (1) sequences did not always have the same effect on judgments of harmonic presentations as they did on judgments of single-voice presentations. As noted earlier, for example, ratings of original harmonic sequences contained a directional asymmetry that was significantly reduced in ratings of simplified (1) harmonic se-

quences. However, no corresponding influence of the musical changes was found for the comparison of ratings of original single voices and simplified (1) single voices.

For each sequence, we examined the effect of the changes in musical detail introduced by Simplification (1) on both judgments of harmonic presentations and judgments of single voices. Differences in ratings between original and simplified (1) versions of each harmonic sequence were calculated and compared with differences in ratings between original and simplified (1) versions of the single voices contained in each harmonic sequence. The changes introduced by Simplification (1) sometimes increased and sometimes decreased ratings both for single-voice presentations and for harmonic presentations. However, differences for judgments of harmonic presentations were uncorrelated with differences for judgments of single voices [$r(8) = -.324$, n.s.].[2]

In a few cases, the direction of the difference between original and simplified (1) versions for judgments of harmonic sequences was opposite to the direction of the difference between these two versions for judgments of single voices. This interaction between Version and Condition of Presentation was most evident for Sequence 10. Figure 3 shows mean ratings for original and simplified (1) versions of Sequence 10, for harmonic and single-voice presentations.

Sequence 10 involves a key change from C major to B♭ major. In comparison to the original version of Sequence 10, the simplified (1) version involves earlier introduction of chords from the final key. For judgments of harmonic presentations, the mean ratings displayed in Figure 3 suggest that the changes introduced by Simplification (1) reduced the perceived degree of key movement. For single voices, however, the opposite effect was found. Changes introduced by Simplification (1) appeared to enhance or emphasize the sense of key change.

The reliability of this interaction was established by comparing ratings of single voices of Sequence 10 (averaged across voices) with ratings of the full harmonic presentations of Sequence 10. Analysis of variance revealed a significant interaction of Version [original vs. simplified (1)] × Condition of Presentation (single voice vs. full harmony) [$F(1, 76) = 8.15$, $p < .01$]. The effect is consistent with the notion that there are different processes by which key structure is abstracted from single

2. Analysis of variance conducted for judgments of original and simplified (1) harmonic presentations indicated a significant contrast within the triple interaction of Modulation Condition × Example × Version [$F(1, 38) = 4.35$, $p < .05$]. In addition, judgments of original and simplified (1) harmonic sequences were significantly different with respect to the presence of an asymmetry of modulation direction. Thus, the lack of correlation between differences for harmonic presentations and single-voice presentations was not merely the result of correlating two random distributions.

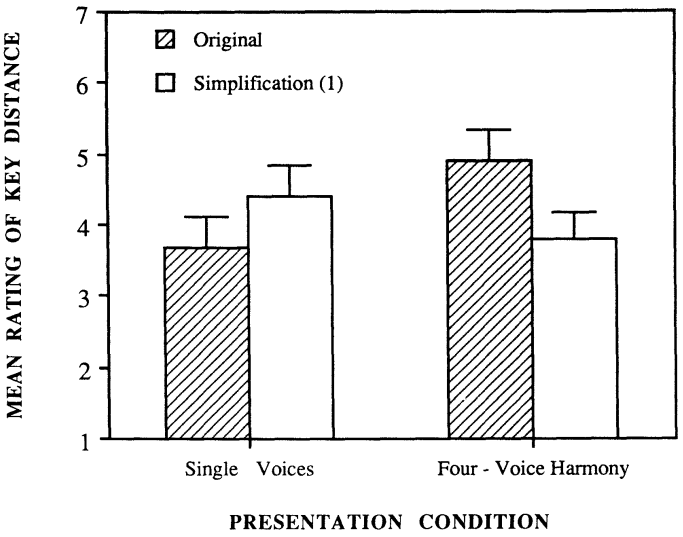

Fig. 3. Mean ratings of key distance for original and simplified (1) versions of Sequence 10, for harmonic and single-voice presentations.

voices and full harmony: musical details that may reduce key movement in a harmonic context may actually enhance key movement in single voices.

Conclusions

Judgments of key movement in original and simplified (1) sequences confirm earlier findings concerning the sensitivity of listeners to key change in short chorale excerpts. Results obtained with simplified (2) sequences (Thompson & Cuddy, 1989) may be generalized to their original sources. Moreover, further evidence is provided that melody and harmony may follow different principles in the process of identifying key change. Asymmetry of modulation direction, when it occurs, emerges for four-voice harmonic presentations only, and not for single voices. Moreover, effects of local musical changes on judgments of harmonic sequences were not similar, and in some cases were in an opposite direction, to the effects of those changes on judgments of single voices.

Comparison of judgments for four-voice harmony and single voices suggest that melody and harmony are partially independent in the implication of key. [In a somewhat different context, Schmuckler (1989) found that melody and harmony contributed independently and additively to expectancy generation.] This partial independence is not well modeled

by a strict hierarchical system, in which a melodic line implicates a key by first implicating an underlying harmonic progression. The results are consistent with a partially hierarchical system, however, in which musical relations at each level can be evaluated with or without reference to other levels in the hierarchy. Although listeners can evaluate key relationships in a melodic line with reference to an implied harmonic progression, other aspects of melodic structure are available, and they may provide listeners with an important source of information about key and key movement.[3,4]

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