

Modeling perceived relationships between melody, harmony, and key

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Perceptual relationships between four-voice harmonic sequences and single voices were examined in three experiments. In Experiment 1, listeners rated the extent to which single voices were musically consistent with harmonic sequences. When harmonic sequences did not change key, judgments were influenced by three sources of congruency: melody (whether the single voice was the same as the soprano voice of the harmonic sequence), chord progression (whether the single voice could be harmonized to give rise to the chord progression of the harmonic sequence), and key structure (whether or not the single voice implied modulation). When key changes occurred, sensitivity to sources of congruency was reduced. In Experiment 2, another interpretation of the results was examined: that consistency ratings were based on congruency in well-formedness. Listeners provided well-formedness ratings of the single voices and harmonic sequences. A multiple regression analysis suggested that consistency ratings were based not merely on well-formedness but on congruency in melody, chord progression, and key structure. In Experiment 3, listeners rated the extent of modulation in harmonic sequences and in each voice of the sequences. Discrimination between modulation conditions was greater for single voices than for harmonic sequences, suggesting that abstraction of key from melody may occur without reference to implied harmony. A partially hierarchical system for processing melody, harmony, and key is proposed.

The musical qualities of melody, harmony, and key have been widely discussed in music cognition. In this literature, there are abiding questions concerning the manner in which these qualities are perceived and remembered by listeners and concerning their perceptual and theoretical interrelationships (e.g., Butler, 1989; Cuddy, Cohen, & Mewhort, 1981; Dowling, 1978; Krumhansl, 1990; Krumhansl, Bharucha, & Kessler, 1982; Narmour, 1977, 1990; Schmuckler, 1989; Thompson & Cuddy, 1989, 1992). Such questions are often complicated by the fact that melody, harmony, and key are not easily understood in terms of simple defining features (Apel, 1972; Krumhansl, 1990b; Rosner & Meyer, 1986).

This paper examines perceived relationships between melody, harmony, and key. The psychological relationships between these aspects of music suggest that Western tonal music may be processed within a cognitive system involving three levels of musical description. From a logical perspective and by definition, this system may be considered to have a hierarchical organization, with melody represented at the lowest level, harmony at an intermediate level, and key at the highest level. In particular, a hierarchical conception of melody, harmony, and key reflects

the fact that these aspects of music constrain each other in an asymmetric manner. This asymmetry is illustrated by the following two points. First, two four-voice sequences may have the same chord progression but different pitches in the individual voices. However, it is not logically possible for two sequences to have the same pitches in the individual voices but different chord progressions. Second, two four-voice sequences may have the same key structure but have different chord progressions. However, it is not possible for two sequences to have the same chord progression but different key structures.

Empirical evidence suggests that listeners have internalized these asymmetric constraints, resulting in a hierarchically organized cognitive system of perceiving and remembering melody, harmony, and key. First, it has been demonstrated that judgments of melodies reflect a sensitivity to possible harmonic accompaniments (Cuddy et al., 1981; Cuddy & Lyons, 1981). Second, key context has been shown to influence judgments of both melodies (Cuddy et al., 1981; Cuddy, Cohen, & Miller, 1979; Dowling, 1978; Krumhansl, 1979) and harmonic materials (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982).

These effects support the notion that Western tonal music is processed within a cognitive system involving three interdependent levels of musical description: melody, harmony, and key. Although the precise organization of this cognitive system cannot be derived from empirical results to date, the system is assumed to have a hierarchical organization (Krumhansl, Bharucha, &

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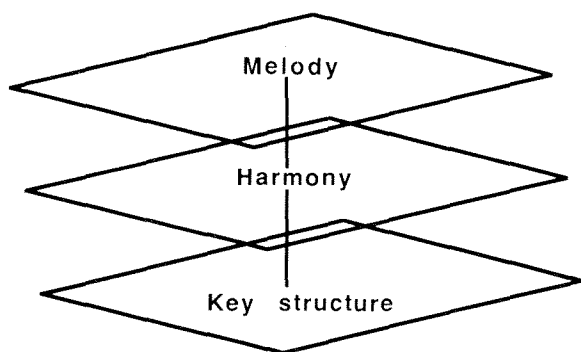


Figure 1. A strict hierarchical model of perceived relationships between melody, harmony, and key.

Kessler, 1982, p. 34; see also, Bharucha, 1987; Lerdahl, 1988). A simple version of this system is shown in Figure 1.

In two studies, Thompson and Cuddy (1989, 1992) investigated this cognitive system by evaluating the implications of a strict hierarchical model of melody, harmony, and key. Judgments of key movement (modulation) in four-voice sequences were compared with judgments of key movement in the individual voices of those sequences. Within a strict hierarchical system, an individual voice implicates key structure by first implicating an underlying chord progression. Because there are several plausible chord progressions for a given voice, discrimination among types of key movement should in general be poorer for single voices than for harmonic sequences. In both reports, however, the degree of key movement was perceived within harmonic sequences and single-voice presentations with approximately equal ease. These findings are not well modeled by a strict hierarchical system, in which a single voice implicates key structure only by first implicating an underlying chord progression.

As an alternative to a strict hierarchical system, Thompson and Cuddy (1989, 1992) suggested that melody, harmony, and key may be processed within a partially hierarchical system. A partial hierarchy may be defined in this context as a system of increasingly abstract levels of description in which processing at a given level is partially independent of processing at other levels.¹ A partially hierarchical model of melody, harmony, and key suggests that the perception of key movement in a single voice is partially independent from the perception of key movement in a harmonic sequence. That is, although listeners may abstract key movement from a melodic line with reference to an implied chord progression, other properties of a melodic line that are independent of its implied chord progression also may influence the perception of key movement. Partial independence of levels also allows for the possibility that interlevel effects, such as perceiving an individual note with respect to the current harmony, may be more or less evident depending on such factors as how the listener attends to the music, compositional structure, and performance expression.

The aim of this investigation was to examine the extent to which melodic and harmonic materials are perceived to be interrelated. As in previous reports (Thompson & Cuddy, 1989, 1992), the research evaluates predictions of a strict hierarchical model in which processing occurs at three interdependent levels of musical description. Within a strict hierarchical model, the three levels of musical description are assumed to be connected to each other in a functional sense. That is, the encoding of information at one level will lead to or influence the perception and encoding of other levels of musical description.

In Experiment 1, listeners judged how musically “consistent” single (soprano) voices were with four-voice harmonic sequences. If processing involves a hierarchical system with functional connections between levels, both single voices and harmonic sequences should be perceived with reference to all three levels of musical description—that is, with reference to melody, harmony, and key. Therefore, a strict hierarchical model predicts that judgments of consistency between single voices and harmonic sequences should be influenced by congruency at all three levels in the system. If the system allows for partial independence of levels, however, single voices and harmonic sequences may not always be perceived with reference to all three levels.

Experiment 1 also examined the possibility that key changes may reduce the ability of listeners to perceive sources of congruency between harmonic and melodic materials. This prediction is based on findings by Thompson and Cuddy (1989, 1992) that suggest that the implication of key change in single voices is partially independent of the implication of key change in the harmonic sequences from which those voices were taken. The latter findings generally conflict with a strict hierarchical model and also raise the possibility that key movement itself may promote perceptual independence between melody and harmony. This perceptual independence, in turn, may make it difficult for listeners to perceive sources of congruency between harmonic and melodic materials.

Three possible effects of key change are considered. First, key change may reduce the sensitivity of listeners to congruency in key structure only. That is, it may become difficult for listeners to relate the key structure conveyed by a single voice to the key structure conveyed by a harmonic sequence. Second, key changes may reduce the sensitivity of listeners to congruency in key structure and chord progression. That is, in addition to a reduced sensitivity to congruency in key structure, it may become difficult for listeners to relate the implied chord progression of a single voice to the chord progression of a harmonic sequence. Third, key movement may reduce the sensitivity of listeners to all three sources of congruency. That is, in addition to a reduced sensitivity to congruency in key movement and chord progression, the perception of melodic characteristics in a single voice may become partially independent of how that same melody is perceived when it is embedded in a harmonic progression.

In Experiment 2, listeners provided “well-formedness” ratings for the single voices and harmonic sequences. The

experiment was done because the single voices and harmonic sequences used in Experiment 1 may have conveyed different degrees of overall coherence or form. It was therefore necessary to evaluate the influence of this factor on the consistency ratings obtained in Experiment 1.

In Experiment 3, listeners judged key movement in four-voice harmonic sequences and in the individual voices (i.e., soprano, alto, tenor, and bass) of those harmonic sequences. The experiment was a replication of investigations reported by Thompson and Cuddy (1989, 1992), except that it involved musical materials not previously tested. Within a strict hierarchical system, discrimination among different types of key movement should be poorer in general for single voices than for harmonic sequences. If the system is but a partial hierarchy, however, implications of key structure in a single voice may derive, in part, from factors that are independent of harmony. In that case, key structure may be conveyed as well in single voices as in harmonic sequences (Thompson & Cuddy, 1989, 1992).

EXPERIMENT 1

In Experiment 1, listeners rated the extent to which single voices were musically consistent with harmonic sequences. The conditions under which judgments were made allowed an assessment of influences by three sources of congruency: melody, chord progression, and key structure. Within a strict hierarchical system, all three levels are represented and connected in a functional sense. Thus, all three levels are predicted to influence the perceived degree of congruency between single voices and harmonic sequences.

Based on previous findings by Thompson and Cuddy (1989, 1992), it was predicted that key movement may reduce the sensitivity of listeners to sources of congruency between single voices and harmonic sequences. Thus, in addition to the above prediction, Experiment 1 assessed the influence of key movement on consistency ratings.

Key movement was examined with respect to the circle of fifths model of keys (Apel, 1972). In this model, each key is labeled by the first note of the scale (*do*). Keys separated by an interval of a perfect fifth (the distance between *do* and *sol*) are adjacent on the circle. Adjacent keys are musically related—for example, they share all but one scale note. Adjacent keys also may be described as one step removed from each other on the circle of fifths. When a key change occurs, the number of steps between the initial key and the new key is closely related to the perceived degree of key change (Thompson & Cuddy, 1989, 1992).

Method

Subjects. Twenty-four adult listeners participated in the experiment. The listeners were at least moderately trained in music, having had a minimum of 5 years of formal training on a musical instrument. All of the listeners reported having normal hearing.

Stimulus materials. Musical sequences were generated by a Roland U-20 sound module under the control of a Macintosh SE-

30 computer. Tones used for the sequences were taken from the sampled piano sound of the Roland U-20. The tempo of the music was 120 quarter-tone beats/min, or 0.5 sec/beat. All pitches were based on equal-tempered tuning.

Each trial consisted of a four-voice sequence followed by a pause of 1 sec and then by a single voice. A response cue was displayed on the computer monitor, and responses were entered into the computer. There were eight four-voice sequences, and four single (soprano) voices following each four-voice sequence, giving a total of 32 experimental trials. The order in which trials were presented was random.

Harmonic sequences. The eight harmonic sequences are displayed in Figure 2. The sequences were based on harmonization exercises from Hindemith (1968, pp. 105, 109). The harmonizations were done by a highly trained musician and checked by the author and another trained musician.

From Figure 2, it may be noted that the eight sequences can be classified into two sets of four sequences. Within each set of four sequences, the first two measures of each sequence are identical. In the third and fourth measures, the four sequences are identical in rhythm, and similar in the contour of the soprano voice, but they differ in chord progression and key structure. The four sequences of each set represent four types of key structure, as follows: (1) absence of modulation (Nonmodulation), (2) modulating two steps on the circle of fifths to the key of the supertonic (Modulation to II), (3) modulating four steps on the circle of fifths to the key of the mediant (Modulation to III), and (4) modulating six steps on the circle of fifths to the key of the raised subdominant (Modulation to #IV). An independent assessment of the sequences by a music theorist substantiated this classification of sequences.

Single voices. Each harmonic sequence was paired with four single voices. As an example, the four single voices paired with one of the harmonic sequences modulating four steps on the circle of fifths are displayed in Figure 3.²

For each harmonic sequence, four types of single voices were constructed. Voices labeled Type 1 were identical to the soprano voice of the preceding harmonic sequence. Thus, these voices were congruent with harmonic sequences on three levels of musical description: melody, harmony, and key. Voices labeled Type 2 were different from the soprano voice of the harmonic sequence but congruent with (i.e., could be harmonized with) the chord progression of the sequence. Thus, these voices were congruent with harmonic sequences on two levels: chord progression and key structure. Voices labeled Type 3 were incongruent with the chord progression of the harmonic sequence but congruent with the key movement of the sequence. Thus, these voices were congruent with harmonic sequences on only one level—key structure. Voices labeled Type 4 were incongruent with the key movement of the harmonic sequence and were thus not congruent with harmonic sequences on any of the three levels.

For Type 2, single voices were constructed such that notes occurring on the four beats within each measure were congruent with chords at the same temporal positions in the preceding harmonic sequence. For Type 3, single voices were constructed such that a number of notes were harmonically incongruent with (i.e., could not be harmonized with) chords at the same temporal positions in the preceding harmonic sequences. For Type 4, single voices were constructed such that they were incongruent with the key structure of the preceding harmonic sequences, as follows: nonmodulating harmonic sequences (Nonmodulation) were paired with single voices implying key movement to the supertonic (II), harmonic sequences involving key movement to the supertonic were paired with single voices implying no key movement (Nonmodulation), harmonic sequences involving key movement to the mediant (III) were paired with single voices implying key movement to the raised subdominant (#IV), and harmonic sequences involving key movement to the raised subdominant (#IV) were paired with single voices implying key movement to the mediant (III).

Nonmodulation: Example 1



Modulation to II: Example 1



Modulation to III: Example 1



Modulation to #IV: Example 1



Nonmodulation: Example 2



Modulation to II: Example 2



Modulation to III: Example 2



Modulation to #IV: Example 2



Figure 2. Harmonic sequences used as stimuli in the experiments. The type of key movement conveyed is listed above each sequence.

Attempts were made to balance the four types of single voices in all respects except for the levels of congruency described above. First, Types 2, 3, and 4 were equivalent with respect to the average number of notes in single voices that were different from notes in the soprano voice of the preceding harmonic sequence—for each type of voice, the average was 7.0 notes. Second, single voices and soprano voices of preceding harmonic sequences always had the same rhythmic structure. Third, single voices and soprano voices

of preceding harmonic sequences had nearly identical melodic contours. (In no case was a rising contour changed to a falling contour, or vice versa. In some cases, a rising or falling contour was changed to a repeated note.)

Procedure. The listeners were instructed to rate on a scale from 1 (inconsistent) to 7 (consistent) the extent to which single voices and harmonic sequences were consistent with each other in a musical sense. The term “consistent” was defined operationally to be synonymous with the following terms: congruent, similar, and fits. The listeners were free to set their own criteria but were encouraged to use the full range of the rating scale. Practice trials, selected randomly from the set of experimental trials, were provided to acquaint the listeners with the task. The listeners were allowed to quit the practice trials and begin the experimental trials at any time.

Results and Discussion

Results were subjected to an analysis of variance (ANOVA) with repeated measures on three factors. The first factor corresponded to the type of key movement conveyed by the harmonic sequence. The second factor corresponded to the two examples of each type of key movement. The third factor corresponded to the type of single voice that followed each harmonic sequence. Mean ratings for the four types of single voices, for each of the four conditions of modulation, are displayed in Figure 4.

There were four types of key movement conveyed by harmonic sequences: nonmodulation (Nonmod); modulation to the key of the supertonic (Mod II); modulation to the key of the mediant (Mod III); and modulation to the key of the raised subdominant (Mod #IV). There was a significant main effect of the type of key structure [$F(3,69) = 7.19, p < .001$]. Overall, there was a tendency for mean ratings to be inversely proportional to the extent of key movement in harmonic sequences. Across

Modulation to III: Example 1

Type 1



Type 2



Type 3



Type 4



Figure 3. An example of single voices paired with harmonic sequences. The four single voices displayed were paired with Example 1 of the harmonic sequence involving a modulation to the mediant (III), displayed in Figure 2.

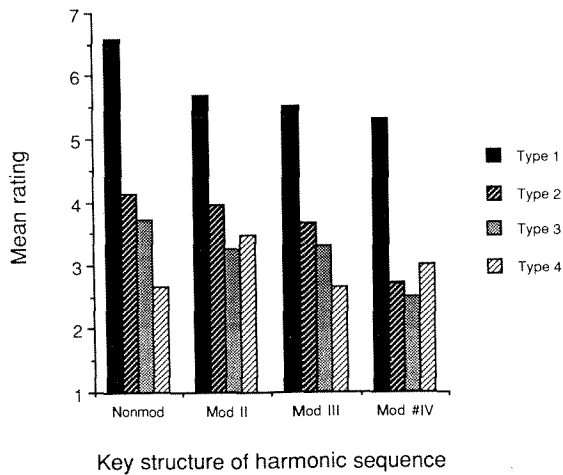


Figure 4. Mean ratings of the consistency between single voices and harmonic sequences for the four types of single voices and the four types of key structure.

the four types of single voices, and across examples, mean ratings for the conditions of Nonmod, Mod II, Mod III, and Mod #IV were 4.28, 4.10, 3.79, and 3.40, respectively. This finding is generally consistent with the prediction that sources of congruency between single voices and harmonic sequences are less likely to be perceived when key movement is involved. There was no significant effect of example.

Sensitivity to levels of congruency. Four types of single voices were paired with each harmonic sequence. The four types, as outlined above, differ in the extent to which they are congruent with harmonic sequences, as follows:

1. 3-L: three levels of congruence (identical to soprano voice).
2. 2-L: two levels of congruence (chord progression and key movement).
3. 1-L: one level of congruence (key movement).
4. 0-L: zero levels of congruence.

Types 2-L, 1-L, and 0-L were equivalent with respect to the average number of notes in single voices that were different from notes in the soprano voice of the preceding harmonic sequences. Therefore, differences in mean ratings between these conditions cannot be attributable merely to the average number of note differences between single voices and the soprano voice of harmonic sequences. Rather, differences in mean ratings reflect the extent to which listeners were sensitive to each of three levels of congruency between single voices and harmonic sequences: melody, chord progression, and key structure.

Sensitivity to levels of congruency across types of key structure. Across sequences, there was an overall effect of the type of single voice presented after harmonic sequences [$F(3,69) = 95.78, p < .0001$]. Three planned orthogonal comparisons revealed an overall sensitivity to two levels of congruency between single voices and harmonic sequences: melody and chord progression.

First, voices that were identical to the soprano voice of harmonic sequences (3-L) were assigned significantly higher ratings than were other voices [$F(1,23) = 194.70, p < .0001$]. This effect suggests that listeners were sensitive, at a minimum, to melodic similarity between single voices and harmonic sequences. Second, voices that were congruent only in chord progression and key structure (2-L) were assigned significantly higher ratings than were voices that were not congruent in chord progression [1-L or 0-L; $F(1,23) = 10.78, p < .005$]. This effect suggests that the listeners were sensitive to congruency in chord progression between single voices and harmonic sequences. Finally, voices that were congruent only in key structure (1-L) were not assigned significantly higher ratings than were voices that were not congruent in key structure (0-L). This finding suggests that, across all sequences, the listeners were not sensitive to congruency in key structure between single voices and harmonic sequences.

The influence of key movement on sensitivity to levels of congruency. There was a significant interaction between the key structure of harmonic sequences and the type of single voice paired with harmonic sequences [$F(9,207) = 3.58, p < .001$]. Multiple comparisons revealed that sensitivity to the three levels of congruency depended on the key movement of harmonic sequences.

When harmonic sequences did not involve key movement, the listeners were sensitive to all three levels of congruency between single voices and harmonic sequences. First, voices that were identical to the soprano voice of harmonic sequences (3-L) were assigned significantly higher ratings than were other voices [$F(1,23) = 170.98, p < .0001$]. Second, voices that were congruent only in chord progression and key structure (2-L) were assigned significantly higher ratings than were voices that were not congruent in chord progression [1-L or 0-L; $F(1,23) = 14.68, p < .001$]. Finally, voices that were congruent only in key (1-L) were assigned significantly higher ratings than voices that were not congruent in key structure [0-L; $F(1,23) = 9.64, p < .01$]. The above findings suggest that, for nonmodulating harmonic sequences, the listeners were sensitive to three levels of congruency between single voices and harmonic sequences: melody, chord progression, and key structure.

Across conditions in which harmonic sequences involved key movement, listeners were sensitive to congruency in melody and chord progression, but not to congruency in key structure, between single voices and harmonic sequences. First, voices that were identical to the soprano voice of harmonic sequences (3-L) were assigned significantly higher ratings than were other voices [$F(1,23) = 148.90, p < .0001$]. Second, voices that were congruent only in chord progression and key structure (2-L) were assigned significantly higher ratings than voices that were not congruent in chord progression [1-L or 0-L; $F(1,23) = 5.86, p < .05$]. However, there was no significant difference between ratings of voices that were congruent only in key structure (1-L) and voices that

were not congruent in key structure (0-L). This finding suggests that when harmonic sequences involved key movement, the listeners were not able to use congruency in key structure as a basis for comparing single voices and harmonic sequences.

When harmonic sequences involved the greatest possible key movement, that is, a key movement to the raised subdominant, the perceived relationship between single voices and harmonic sequences was based only on congruency in melody. For these sequences, voices that were identical to the soprano voice of harmonic sequences (3-L) were assigned significantly higher ratings than were other voices [$F(1,23) = 82.34, p < .0001$]. However, voices that were congruent in chord progression and key structure (2-L) were not assigned significantly higher ratings than were voices that were not congruent in chord progression (1-L and 0-L), and voices that were congruent only in key structure (1-L) were not assigned significantly higher ratings than were voices that were not congruent in key structure (0-L). This finding suggests that for large key changes, the listeners were sensitive to congruency in melody but were not sensitive to congruency in chord progression or key structure.

These findings generally suggest that key movement—particularly large key movement—reduced the sensitivity of the listeners to sources of congruency between single voices and harmonic sequences. When key structure was stable, the perceived relationship between single voices and harmonic sequences was influenced by congruency in melody, chord progression, and key structure, suggesting that the listeners were able to encode the single voices and harmonic sequences on all three levels. When sequences involved key movement, however, the listeners were not sensitive to congruency in key structure. When large key changes were involved, the listeners were not even sensitive to congruency in chord progression.

The influence of key movement on sensitivity to levels of congruency: A comparison of models. To further evaluate the effect of key movement on sensitivity to sources of congruency, four sets of predicted ratings were constructed and compared with actual ratings by using a correlation analysis. Predicted ratings were calculated on the basis of two principles. First, ratings were predicted to correspond to the levels of congruency to which the listeners were thought to be sensitive. If the model predicted sensitivity to all three levels of congruency, predicted ratings for voice types 3L, 2L, 1L, and 0L were assigned the values 3.0, 2.0, 1.0, and 0.0, respectively. If the model predicted that the listeners were not sensitive to sources of congruency associated with a given type of voice, the predicted rating for that condition was assigned a value of 0.0. Second, for models assuming an influence of key movement on sensitivity to sources of congruency, sensitivity was assumed to decrease in proportion to the number of steps involved in the key movement, with the furthest modulation associated with zero sensitivity.

For conditions in which harmonic sequences did not involve a key change, all four models predicted that the listeners were sensitive to all three sources of congruency between single voices and harmonic sequences. Model 1 predicted key movement had no influence on that sensitivity. Thus, predicted ratings were 3.0, 2.0, 1.0, and 0.0 for all four types of key movement. Model 2 predicted that sensitivity to congruency in key structure decreased in proportion to the extent of key movement. Model 3 predicted that sensitivity to congruency in both key structure and chord progression decreased in proportion to the extent of key movement. Model 4 predicted that sensitivity to congruency in key structure, chord progression, and melody decreased in proportion to the extent of key movement. Each set of predicted ratings was a matrix of 16 values: 1 value for each condition of key movement and single voice.

A correlation analysis suggested that Model 3 provided the best predictor of ratings ($r = .954, p < .001$). The correlation values associated with Models 1, 2, and 4 were .824, .848, and .751, respectively. The high correlation between consistency ratings and ratings predicted by Model 3 suggests that sensitivity to congruency in key structure and chord progression decreased in proportion to the extent of key movement.

In general, the results support the predictions. For conditions in which harmonic sequences did not involve a key change, the listeners perceived three levels of congruency between single voices and harmonic sequences: melody, chord progression, and key structure. For sequences involving a key change, sensitivity to sources of congruency was reduced.

Inspection of Figure 4, however, suggests that additional factors may have influenced judgments of consistency. As an example, it may be noted that for single voices that were incongruent with harmonic sequences in key structure (0-L), consistency ratings were lower if they involved greater key movement than harmonic sequences (mean = 2.67) than if they involved less key movement than harmonic sequences [mean = 3.25; $F(1,23) = 4.20, p = .052$]. This marginal effect cannot be explained in terms of the three levels of congruency or in terms of the effect of key movement discussed above. The purpose of Experiment 2 was to examine another possible influence on judgments.

EXPERIMENT 2

The four types of single voices used in Experiment 1 were designed to manipulate three levels of congruency: melody, chord progression, and key structure. Attempts were made to equate the voices in other respects. For example, the four types of voices had identical rhythmic structure and nearly identical contours. Voices that were incongruent with harmonic sequences on one or more levels were also equated with each other with respect to the number of notes that differed from the soprano voice of the preceding harmonic sequence.

In spite of the attempts to control for confounding factors, construction of these voices may have introduced differences among the four types of voices. Most importantly, introducing changes to the soprano voice of harmonic sequences may have produced a voice that sounded less well-formed overall than did the original soprano voice. For example, changing a note but maintaining congruency with the chord progression of the harmonic sequence sometimes resulted in an awkward melodic leap. Thus, many voices that were incongruent with harmonic sequences in melody, chord progression, or key structure also differed from the soprano voice of harmonic sequences in terms of how well-formed they were. It is possible that differences in well-formedness, in addition to differences in the number of levels of congruency, influenced ratings of consistency.

To examine this possibility, well-formedness ratings in Experiment 2 were obtained for each single voice and harmonic sequence used in Experiment 1. These ratings were then compared with the results of Experiment 1.

Method

Subjects. Nine adult listeners participated in the experiment. Listeners were at a level of musical training comparable to those tested in Experiment 1. All listeners reported having normal hearing.

Stimulus materials. Musical sequences were generated by a Roland U-20 sound module under the control of a Macintosh SE-30 computer. Tones used for the sequences were taken from the sampled piano sound of the Roland U-20. The tempo of the music was 120 quarter-tone beats/min, or 0.5 sec/beat. All notes were based on equal-tempered tuning.

Each trial consisted of a four-voice harmonic sequence or a single voice, followed by a response cue displayed on the computer screen. The 8 harmonic sequences and 32 single-voice sequences used in Experiment 1 were presented to the listeners in an order that was randomized independently for each listener.

Procedure. The listeners were instructed to rate on a scale from 1 (poorly formed) to 7 (well-formed) the extent to which single voices and harmonic sequences were musically well-formed. A well-formed sequence was described as one that was perceived to have good overall structure, closure, or coherence. A poorly formed sequence was defined as one that was perceived to have poor structure or closure, or to contain unexpected or jarring notes. The listeners were encouraged to use the full range of the rating scale. Practice trials, selected randomly from the set of experimental trials, were provided to acquaint the listeners with the task. The listeners were allowed to quit the practice trials and begin the experimental trials at any time.

Results and Discussion

ANOVAs were first conducted for single voices and harmonic sequences separately. Following these analyses, ratings were combined to derive a single set of ratings representing the congruency in well-formedness between each pair of sequences (i.e., single voice and harmonic sequence) presented in Experiment 1. An ANOVA was then conducted on this set of ratings and compared with the results of Experiment 1.

Single voices. In the analysis of single voices, each voice was classified as conveying one of four types of key movement, as described in Experiment 1. It may be noted that for 3-L, 2-L, and 1-L voices, but not for 0-L voices,

classification of key movement corresponded to the key movement of the harmonic sequence with which they were paired in Experiment 1.

An ANOVA indicated that well-formedness ratings for single voices were significantly influenced by the type of key movement conveyed [$F(3,24) = 22.26, p < .001$]. Across voices, the mean rating for single voices that did not suggest a key change was 5.19. Mean ratings for single voices suggesting a modulation to the key of the supertonic (II), the mediant (III), and the raised subdominant (#IV) were 3.96, 3.81, and 2.83, respectively.

Multiple comparisons showed a reliable tendency for well-formedness ratings to decrease as the extent of key change on the circle of fifths increased. First, voices that did not suggest a key change were given significantly higher ratings than were voices that suggested a key change [$F(1,8) = 29.11, p < .001$]. Second, voices that suggested a modulation to the key of the supertonic (II) were given significantly higher well-formedness ratings than were voices that suggested a modulation to the key of the mediant (III) or raised subdominant [#IV; $F(1,8) = 8.08, p < .05$]. Finally, voices that suggested a modulation to the key of the mediant (III) were given significantly higher well-formedness ratings than were voices that suggested a modulation to the key of the raised subdominant [#IV; $F(1,8) = 21.83, p < .01$].

The effect of key movement suggests that listeners associate well-formedness with tonal stability. However, it is difficult to assess whether key movement influenced well-formedness directly or whether voices involving key movement also tended to involve other factors, such as awkward melodic movement, that led to a reduction in well-formedness.

Harmonic sequences. For judgments of harmonic sequences, an ANOVA indicated that well-formedness ratings were significantly influenced by the type of key movement conveyed [$F(3,24) = 15.91, p < .001$]. The mean rating of well-formedness for harmonic sequences that did not change key was 6.67. Mean ratings for harmonic sequences that modulated to the key of the supertonic (II), the mediant (III), and the raised subdominant (#IV) were 5.39, 5.17, and 4.28, respectively.

Multiple comparisons again showed a reliable tendency for well-formedness ratings to decrease as the extent of key change on the circle of fifths increased. First, harmonic sequences that did not change key were given significantly higher ratings than were sequences that changed key [$F(1,8) = 34.95, p < .001$]. Second, sequences modulating to the key of the supertonic (II) were given significantly higher well-formedness ratings than were sequences modulating to the key of the mediant (III) or raised subdominant [#IV; $F(1,8) = 5.82, p < .05$]. Finally, sequences modulating to the key of the mediant (III) were given significantly higher well-formedness ratings than were sequences modulating to the key of the raised subdominant [#IV; $F(1,8) = 5.75, p < .05$].

The effect of key movement again suggests that listeners associate well-formedness with tonal stability. It may also be noted that ratings of well-formedness were higher for

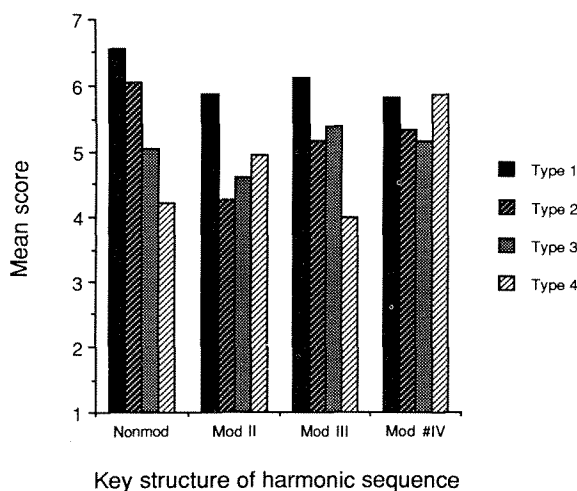


Figure 5. Mean scores of congruency in well-formedness between single voices and harmonic sequences paired with those voices in Experiment 1, for the four types of single voices and the four types of key structure.

harmonic sequences (mean = 5.38) than for single voices (mean = 3.95), which suggests that harmonic accompaniment enhances the sense that a musical sequence is well-formed.

A comparison of well-formedness in single voices and harmonic sequences. A third ANOVA examined the difference in ratings of well-formedness between single voices and harmonic sequences. For each listener, the absolute difference was calculated between ratings of each single voice and ratings of each harmonic sequence that was paired with that voice in Experiment 1. For ease of comparison to the results of Experiment 1, this difference score was then subtracted from the maximum rating of 7.0. Each final score thus represented the extent to which each single voice was *congruent* with harmonic sequences in well-formedness, on a scale from 1 (incongruent in well-formedness) to 7 (congruent in well-formedness). An ANOVA was then performed on the resultant scores.

Figure 5 shows the mean scores for each type of key movement conveyed by harmonic sequences and for each type of voice paired with harmonic sequences. If consistency ratings in Experiment 1 were based on congruency in well-formedness, Figures 4 and 5 should reveal a similar pattern of means.

Across the four voice types, there was a significant overall effect of the key movement of harmonic sequences on congruency in well-formedness [$F(3,24) = 3.92$, $p < .05$]. These differences do not correspond with the effect of key movement on consistency ratings that was found in Experiment 1. In Experiment 1, increases in key movement were associated with decreases in consistency ratings. However, increases in key movement were not associated with decreased congruency in well-formedness.

Across the four types of key movement, the type of voice had a significant overall effect on congruency in well-formedness [$F(3,24) = 14.16$, $p < .001$]. The mean scores for 3-L, 2-L, 1-L, and 0-L voices were 6.10, 5.21, 5.06, and 4.76, respectively. These means are comparable to the mean consistency ratings for the four types of voices that were reported in Experiment 1. As in Experiment 1, the effect of the type of voice differed depending on the key movement of harmonic sequences [$F(3,24) = 6.30$, $p < .001$].

Overall, the pattern of means in Figure 5 is similar to the pattern of mean consistency ratings displayed in Figure 4. The correlation between the 16 mean values displayed in the two figures is .70 ($p < .01$). This similarity in mean values for Experiments 1 and 2 raises the possibility that consistency ratings were not based entirely on congruency in melody, chord progression, and key structure, as was suggested in Experiment 1, but were based, in part, on congruency in the more general quality of well-formedness. This possibility was further examined by using multiple regression.

In Experiment 1, consistency ratings were correlated with four models of the ratings. For nonmodulating harmonic sequences, all four models predicted that ratings would reflect a sensitivity to three sources of congruency between harmonic and single-voice sequences: melody, chord progression, and key structure. In the most successful model, sensitivity to congruency in chord progression and key structure was predicted to decrease in proportion to the extent of key movement ($r = .954$).

Although the models predicted consistency ratings well, interpretation of these models relies on the assumption that the four types of voices are balanced in all respects except the extent to which they are congruent with harmonic sequences in melody, chord progression, and key structure. Figure 5, however, suggests that these voices also differed in the extent to which they were congruent with harmonic sequences in well-formedness. Multiple regression was done to evaluate the predictive power of the models once differences in well-formedness are taken into account.

The use of multiple regression to evaluate correlated predictor variables in similar contexts has been discussed by Cuddy and Thompson (1992), Krumhansl (1990, pp. 75-76, 232-234), and Thompson and Mor (1992). In each of these discussions, two theoretically distinct, though statistically related, factors could account for mean ratings collected for musical stimuli. Each factor was represented by a set of predicted ratings, and multiple regression was done to assess the predictive power of each factor once the other factor had been taken into account.

Multiple regression was done separately for each of the four models. In each analysis, predicted ratings based on the model and predicted ratings based on congruency in well-formedness were entered as predictors of the mean consistency ratings collected in Experiment 1. Each vari-

Table 1
Normalized Regression Coefficients (Beta Weights)
for Predictors of Mean Consistency Ratings

Analysis	Predictor	Beta Weight	<i>r</i>
1	Model 1	.637†	.854†
	Well-formedness	.292	
2	Model 2	.671†	.878†
	Well-formedness	.289	
3	Model 3	.874†	.959†
	Well-formedness	.122	
4	Model 4	.530*	.834†
	Well-formedness	.424*	

Note—Model 1 predicts that listeners are always sensitive to congruency between single voices and harmonic sequences in melody, chord progression, and key structure. Model 2 predicts that key change reduces the sensitivity of listeners to congruency in key structure. Model 3 predicts that key change reduces the sensitivity of listeners to congruency in key structure and chord progression. Model 4 predicts that key change reduces the sensitivity of listeners to all three sources of congruency. * $p < .05$ † $p < .01$.

able was entered as a matrix of 16 values corresponding to the four types of key movement in harmonic sequences and to the four types of single voices. Beta weights and multiple correlation coefficients for each of the four analyses are shown in Table 1.

The beta weights were statistically significant for all four models tested in Experiment 1. This finding indicates that each of the four models had predictive power beyond that which could be accounted for by predictions based on well-formedness alone. Consistent with the results of Experiment 1, the regression equation with the greatest predictive power included Model 3 as a predictor variable. When ratings were analyzed for each participant individually, the beta weight for Model 3 was significant for 19 of the 24 participants, with a mean value of .64 ($t = 18.71$, $p < .001$). These findings suggest that listeners are sensitive to congruency in melody, chord progression, and key structure and that sensitivity to congruency in chord progression and key structure is reduced by key changes.

Beta weights for the predictor based on well-formedness were not statistically significant in three of the four analyses of mean consistency ratings. These beta weights, however, are difficult to interpret because differences in well-formedness are already partially embedded within each of the four models. For example, for harmonic sequences that did not change key, all four models predicted that mean ratings should show a decreasing trend across the 3-L, 2-L, 1-L, and 0-L voice types, and this prediction is consistent with differences in well-formedness. Thus, to the extent that predictions based on well-formedness were significantly correlated with consistency ratings ($r = .70$), it is likely that this factor did have an important influence on consistency ratings. The critical finding of the multiple regression analyses, however, is that all four models have predictive power significantly beyond what can be explained by well-formedness alone. Thus, considerations of well-formedness by no means in-

validate the interpretation of consistency ratings provided in Experiment 1.

EXPERIMENT 3

Experiment 1 demonstrated that for sequences involving key movement, perceived relationships between single voices and harmonic sequences were not influenced by congruency in key structure. This finding suggests that, under these conditions, the implications of key movement from single voices either were unclear or were in some manner incomparable to the implications of key movement in harmonic sequences. Experiment 3 addressed this issue by directly comparing the implications of key structure in harmonic sequences with the implications of key structure in the individual voices of those sequences.

There were two goals in Experiment 3. The first goal was to evaluate a basic prediction of a strict hierarchical model of melody, harmony, and key structure, and in doing so, to replicate earlier investigations (Thompson & Cuddy, 1989, 1992). Within a strict hierarchical system, a melodic line implicates key structure by first implicating a chord progression. Thus, key structure should in general be conveyed more clearly by a harmonic sequence than by an individual voice or melody.

The second goal was to clarify the finding that sensitivity to congruency in key structure between single voices and harmonic sequences was reduced in proportion to the extent of key movement involved. Experiment 3 examined the consequences of this reduced sensitivity with regard to the ability of listeners to abstract key movement from single voices and harmonic sequences. If listeners continue to rely on a strict hierarchical processing strategy in spite of a reduced sensitivity to sources of congruency, their ability to abstract key structure from single voices should be quite poor when key movement is involved. It is also possible, however, that a reduced sensitivity to sources of congruency between single voices and harmonic sequences encourages listeners to employ nonhierarchical, independently driven strategies of abstracting key movement from single voices and harmonic sequences. In the latter case, their ability to abstract key movement may be just as good for single voices as it is for harmonic sequences.

Method

Experiment 3 was conducted in two separate parts. In Part 1, the listeners judged key movement in four-voice harmonic sequences. In Part 2, the listeners judged key movement in single voices.

Subjects. Twenty-two adult listeners participated in Part 1 of the experiment. Nineteen different adult listeners participated in Part 2 of the experiment. The level of musical training of the listeners was comparable to that of the listeners used in Experiment 1, that is, all had at least 5 years of formal instruction on a musical instrument. All of the listeners reported having normal hearing.

Stimulus materials. Musical sequences were generated by a Roland U-20 sound module under the control of a MacIntosh SE-30 computer. Tones used for the sequences were taken from the sampled piano sound of the Roland U-20. The tempo of the music

was 120 quarter-tone beats/min, or 0.5 sec/beat. All pitches were based on equal-tempered tuning.

Each trial consisted of a musical sequence followed by the response cue. In Part 1, the listeners provided judgments of the eight four-voice sequences used in Experiment 1. In Part 2, the listeners provided judgments of each of the individual voices (i.e., soprano, alto, tenor, and bass) of the eight harmonic sequences. The order in which listeners completed the two parts was counterbalanced. The order of trials within each part was randomized independently for each listener.

Procedure. In Part 1, the listeners were presented each of the eight harmonic sequences. In Part 2, the listeners were presented each of the 32 individual voices of the eight harmonic sequences. Following each presentation, the listeners were asked to judge the psychological distance between the first and final keys of the sequence on a scale from 1 (the first and final keys are the same) to 7 (the first and final keys are very different). The listeners were informed that they should use the entire range of the response scale.

Results and Discussion

Figure 6 displays, both for single voices and harmonic sequences, mean ratings of key distance for each type of key structure. For single voices, each measure represents the mean rating across all four voices and the two examples of each type of key structure. For harmonic sequences, each measure represents the mean rating across the two examples of each type of key structure.

The data for single voices and harmonic sequences were subjected to separate ANOVAs.

Single voices. Results were subjected to an ANOVA with repeated measures on three factors: type of key movement, example, and voice. There were four types of key movement, two examples of each sequence, and four voices for each sequence (soprano, alto, tenor, and bass).

The main effect of type of key movement was highly significant [$F(3,54) = 54.93, p < .001$]. It may be noted from Figure 6 that, across voices, mean ratings of perceived distance between the first and final keys increased

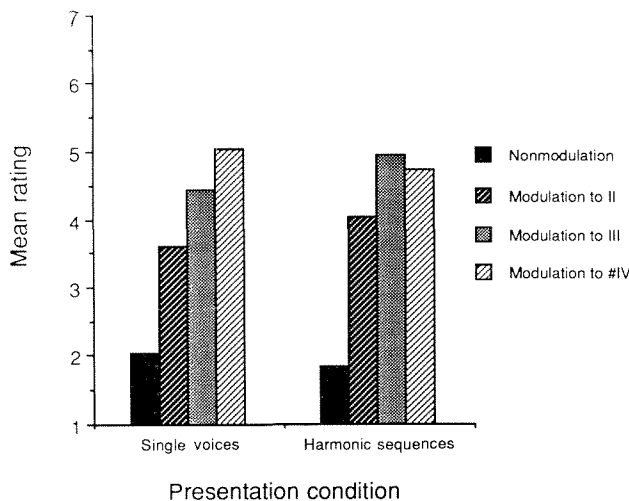


Figure 6. Mean ratings of key distance for each type of key structure, for single voices, and for harmonic sequences.

as distance on the circle of fifths increased. Three planned orthogonal contrasts confirmed the reliability of this trend. First, single voices taken from nonmodulating sequences were assigned significantly lower ratings than were voices from modulating sequences [$F(1,18) = 71.34, p < .001$]. Second, single voices taken from sequences modulating two steps on the circle of fifths were assigned significantly lower ratings than were voices taken from sequences modulating four or six steps on the circle of fifths [$F(1,18) = 59.99, p < .001$]. Finally, single voices taken from sequences modulating four steps on the circle of fifths were assigned significantly lower ratings than were voices taken from sequences modulating six steps on the circle of fifths [$F(1,18) = 8.06, p < .02$].

There was a significant overall effect of voice on ratings [$F(3,54) = 3.81, p < .05$]. Across conditions of key movement, mean ratings for soprano, alto, tenor, and bass voices were 3.88, 4.15, 3.68, and 3.41, respectively. These differences contrast with findings reported in Thompson and Cuddy (1992), in which key movement in Bach chorale excerpts was conveyed more strongly by outer voices (soprano and bass) than by inner voices (alto and tenor). There was no significant interaction between type of key movement and voice, or between type of key movement and example.

Harmonic sequences. Results were subjected to an ANOVA with repeated measures on two factors: type of key movement and example. The main effect of key movement was highly significant [$F(3,63) = 40.60, p < .001$]. There was no significant interaction between type of key movement and example.

As seen in Figure 6, mean ratings of perceived distance between the first and final keys increased as distance on the circle of fifths increased but reached a maximum for sequences modulating four steps on the circle of fifths. The reliability of this trend was assessed by three planned orthogonal contrasts. First, nonmodulating sequences were assigned significantly lower ratings than were modulating sequences [$F(1,21) = 102.53, p < .001$]. Second, sequences modulating two steps on the circle of fifths were assigned significantly lower ratings than were sequences modulating four or six steps on the circle of fifths [$F(1,21) = 9.52, p < .01$]. Ratings of sequences modulating four steps on the circle of fifths, however, were not significantly lower than were ratings of sequences modulating six steps on the circle of fifths.

The above results indicate that when the listeners were presented harmonic sequences, they were not able to discriminate between key movement of four steps on the circle of fifths and key movement of six steps on the circle of fifths. When the listeners were presented single voices, however, they reliably assigned lower ratings to sequences involving key movement of four steps on the circle of fifths than they did to sequences involving key movement of six steps on the circle of fifths. Taken together, the findings suggest that large key changes are more clearly conveyed by single voices than by harmonic sequences.

GENERAL DISCUSSION

Experiments 1 and 3 were designed to evaluate a hierarchical model of perceiving Western tonal music. The results of Experiment 2 highlight the inherent difficulties in attempting to manipulate the stimulus attributes relevant to this hierarchical model while controlling for all other musical qualities. In spite of these difficulties, the results of the investigations converge with previous investigations by Thompson and Cuddy (1989, 1992) toward the concept of a partially hierarchical system.

Within a hierarchical system, both single voices and harmonic sequences are perceived with respect to all three levels of musical description: melody, harmony, and key. Therefore, a hierarchical model predicts that all three levels should be relevant to the perceived relationship between single voices and harmonic sequences. Experiment 1 revealed that when there was no key movement, the listeners judged the relationship between single voices and harmonic sequences with reference to congruency in melody, chord progression, and key structure. This finding suggests that under conditions of tonal stability, single voices and harmonic sequences are indeed processed within a hierarchical processing system that involves functional connections between the three levels of musical description.

Other results of the investigation, however, suggest that this system is most accurately conceived as a partial hierarchy. A partially hierarchical model suggests that sensitivity to sources of congruency between structural levels may be more or less evident depending on the musical context, and processes may exist at each level that are not influenced by processes at other levels in the system. The results of Experiment 1 suggest that when key movement was implicated, single voices and harmonic sequences were not associated with each other with respect to all three levels of musical description. In Experiment 3, differentiation between key movement of four and six steps on the circle of fifths was actually superior when single voices were presented than when harmonic sequences were presented, in contrast to a basic prediction of a strict hierarchical model.

A partially hierarchical model accounts for the experience that the musical implications of melodic and

harmonic materials may be more or less interrelated, depending on factors such as how one is attending to the music, performance factors, or compositional factors. For example, a performer may choose to implement expression either in a way that emphasizes hierarchical relationships between melody and harmony or in a way that dissociates melodic implications from the harmonic materials. The present results suggest that a composer, in emphasizing key movement, may enhance independence of melodic and harmonic implications.

Influences of Key Movement on Perceived Congruency Between Single Voices and Harmonic Sequences

Experiment 1 demonstrated that when key movement was large, the perceived relationship between single voices and harmonic sequences was not influenced by congruency in chord progression. One explanation of this result is that, under these conditions, the listeners were unable to infer a chord progression (correctly or at all) from the single voices. Listeners may infer a chord progression from a melody most readily if the key structure is stable—if a large key change is implicated in a melody, listeners may focus on the nature of the key movement at the expense of harmonic implications.

The results of Experiment 3 indicate that, although the listeners could discriminate key movement reliably in single voices, discrimination of key movement in harmonic sequences was less reliable. This finding helps to explain why the listeners in Experiment 1 were unable to use key structure as a basis for comparing single voices and harmonic sequences involving key movement.

It is surprising that key movement was conveyed less well by harmonic sequences than by single voices—not only because the finding is inconsistent with a strict hierarchical conception of melody, harmony, and key, but because harmonic sequences themselves contained individual voices. It should be noted, however, that harmonic sequences were played precisely as notated, with no phrasing of individual voices, and sounded mostly like a series of block chords. That is, harmonic presentations emphasized chord progression, making it difficult for the listeners to abstract and benefit from the musical implications of individual voices. In a more realistic context,

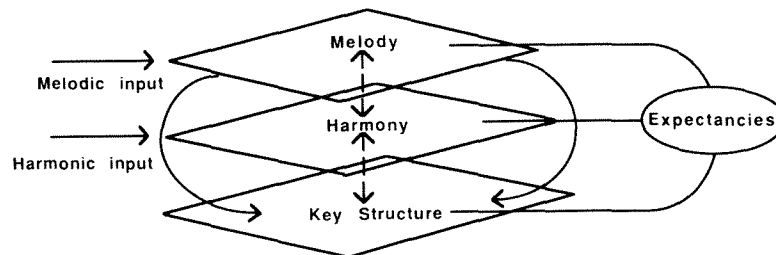


Figure 7. A model of perceived relationships between melody, harmony, and key. The model incorporates the principles of partially hierarchical structure (dotted connections), direct links between melody and key structure, and the generation of expectancies from each of the three levels.

a performer may implement expressive actions to enhance the independence of voices and thereby convey harmony and melody in a more balanced way.

Conclusion

The cognitive system of processing melody, harmony, and key may be described as partially hierarchical. When key structure is stable, a chord progression implicates key structure, and a melody is perceived, at least in part, in relation to the chord progression. In addition to such interlevel encoding strategies, it is presumed that there are encoding strategies at each level that are somewhat independent of the properties of other levels. These intralevel encoding strategies may include pattern-induction rules, as discussed by Deutsch and Feroe (1981), and melodic principles governing musical expectancies, as outlined by Narmour (1990, 1991). Both interlevel and intralevel strategies of encoding music may contribute to the development of expectations for successive events (see Schmuckler, 1989). A schematic outline of these principles is displayed in Figure 7.

Key movement appears to weaken interlevel encoding strategies within the system. This effect may reflect the fact that functional connections between levels develop as part of the process of establishing a key. When a key change occurs, the established interlevel relationships dissolve, and new relationships must be established. For moderate key changes, in which keys are highly overlapping in structure, relationships between levels may be quickly reestablished. For large key changes, interlevel relationships may be slower to develop, thereby encouraging listeners to process melodic and harmonic materials through independent strategies.

REFERENCES

- APEL, W. (Ed.) (1972). *Harvard dictionary of music*. Cambridge, MA: Harvard University Press.
- BHARUCHA, J. J. (1987). Music cognition and perceptual facilitation: A connectionist framework. *Music Perception*, *5*, 1-30.
- BHARUCHA, J. J., & KRUMHANSL, C. L. (1983). The representation of harmonic structure in music: Hierarchies of stability as a function of context. *Cognition*, *13*, 63-102.
- BUTLER, D. (1989). Describing the perception of tonality in music: A critique of the tonal hierarchy theory and a proposal for a theory of intervallic rivalry. *Music Perception*, *6*, 219-242.
- CUDDY, L. L., COHEN, A. J., & MEWHORT, D. J. K. (1981). Perception of structure in short melodic sequences. *Journal of Experimental Psychology: Human Perception & Performance*, *7*, 869-883.
- CUDDY, L. L., COHEN, A. J., & MILLER, J. (1979). Melody recognition: The experimental application of rules. *Canadian Journal of Psychology*, *33*, 148-157.
- CUDDY, L. L., & LYONS, H. I. (1981). Musical pattern recognition: A comparison of listening to and studying tonal structures and tonal ambiguities. *Psychomusicology*, *1*, 15-33.
- CUDDY, L. L., & THOMPSON, W. F. (1992). Asymmetry of perceived key movement in chorale sequences: Converging evidence from a probe-tone analysis. *Psychological Research*, *54*, 51-59.
- DEUTSCH, D., & FEROE, J. (1981). The internal representation of pitch sequences in tonal music. *Psychological Review*, *88*, 503-522.
- DOWLING, W. J. (1978). Scale and contour: Two components of a theory of memory for melodies. *Psychological Review*, *85*, 341-354.
- HINDEMITH, P. (1968). *A concentrated course in traditional harmony: Book 1* (rev. ed.). New York: Schott.
- KRUMHANSL, C. L. (1979). The psychological representation of musical pitch in a tonal context. *Cognitive Psychology*, *11*, 346-374.
- KRUMHANSL, C. L. (1990a). *The cognitive foundations of musical pitch*. New York: Academic Press.
- KRUMHANSL, C. L. (1990b). Tonal hierarchies and rare intervals in music cognition. *Music Perception*, *7*, 309-324.
- KRUMHANSL, C. L., BHARUCHA, J. J., & CASTELLANO, M. A. (1982). Key distance effects on perceived harmonic structure in music. *Perception & Psychophysics*, *32*, 96-108.
- KRUMHANSL, C. L., BHARUCHA, J. J., & KESSLER, E. J. (1982). Perceived harmonic structure of chords in three related musical keys. *Journal of Experimental Psychology: Human Perception & Performance*, *8*, 24-36.
- LERDAHL, F. (1988). Tonal pitch space. *Music Perception*, *5*, 315-349.
- MCNAMARA, T. P. (1986). Mental representations of spatial relations. *Cognitive Psychology*, *18*, 87-121.
- NARMOUR, E. (1977). *Beyond Schenkerism: The need for alternatives in music analysis*. Chicago: University of Chicago Press.
- NARMOUR, E. (1990). *The analysis and cognition of basic melodic structures: The implication-realization model*. Chicago: University of Chicago Press.
- NARMOUR, E. (1991). The top-down and bottom-up systems of musical implication: Building on Meyer's theory of emotional syntax. *Music Perception*, *9*, 1-26.
- ROSNER, B. S., & MEYER, L. B. (1986). The perceptual roles of melodic process, contour, and form. *Music Perception*, *4*, 1-39.
- SCHMUCKLER, M. A. (1989). Expectation in music: Investigation of melodic and harmonic processes. *Music Perception*, *7*, 109-150.
- THOMPSON, W. F., & CUDDY, L. L. (1989). Sensitivity to key change in Chorale sequences: A comparison of single voices and four-voice harmony. *Music Perception*, *7*, 151-168.
- THOMPSON, W. F., & CUDDY, L. L. (1992). Perceived key movement in four-voice harmony and single voices. *Music Perception*, *9*, 427-438.
- THOMPSON, W. F., & MOR, S. (1992). A perceptual investigation of polytonality. *Psychological Research*, *54*, 60-71.

NOTES

1. Defined similarly, the concept of a partial hierarchy has been used to account for findings on spatial memory for maps (McNamara, 1986).
2. The complete set of single voices is available from the author.

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