Harmonic, melodic, and frequency height influences in the perception of multivoiced music

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Two experiments addressed the influences of harmonic relations, melody location, and relative frequency height on the perceptual organization of multivoiced music. In Experiment 1, listeners detected pitch changes in multivoiced piano music. Harmonically related pitch changes and those in the middle-frequency range were least noticeable. All pitch changes were noticeable in the high-frequency voice containing the melody (the most important voice), suggesting that melody can dominate harmonic relations. However, the presence of upper partials in the piano timbre used may have accounted for the harmonic effects. Experiment 2 employed pure sine tones, and replicated the effects of Experiment 1. In addition, the influence of the high-frequency melody on the noticeability of harmonically related pitches was lessened by the presence of a second melody. These findings suggest that harmonic, melodic, and relative frequency height relationships among voices interact in the perceptual organization of multivoiced music.

Many structural relationships mediate the perception of music in our culture. For instance, the roles of structural factors such as rhythm, pitch contour, and pitch intervals in how listeners perceive single-voiced music have been well-documented (e.g., Cuddy, Cohen, & Mewhort, 1981; Dowling, 1982; Kidd, Boltz, & Jones, 1984; Monahan, Kendall, & Carterette, 1987). Most Western tonal music, however, contains multiple parts or voices that are sounded simultaneously; the perception of musical structure is often more complex in this case, due to interactions that can form among the simultaneous voices. Relatively little work has addressed the structural relationships mediating the perception of multivoiced music. We describe two experiments that investigated the perception of multivoiced music with the goal of identifying important structural relationships among the simultaneous voices.

Recent attempts to study the perception of simultaneously sounded musical events have focused on the structural relationships among voices, including harmonic relationships that are explicit or implied among voices (Butler, 1992; Jones, Holleran, & Butler, 1991; Thompson, 1993). Harmony refers to the chordal or vertical structure of a musical piece formed by the interval relationships among pitches, as well as the structural principles

that govern their combination (Apel, 1972; Dahlhaus, 1980). Pitches bearing certain frequency ratio relationships are said to be of the same chord type and thus are harmonically related. Tests of explicit harmonic relationships demonstrate that harmonic contexts influence listeners' goodness-of-fit judgments for pitches following a chordal progression (Krumhansl & Kessler, 1982). Tests of implied harmony, in which listeners respond as if certain harmonic events were (simultaneously) present in a musical piece, reveal that listeners are best at detecting pitch changes that conflict with the implied harmonic relationships (Jones et al., 1991). Finally, performance of multivoiced music also reflects harmonic relationships among voices; pitch-substitution errors (in which unintended pitches replace intended ones) are often harmonically related to the intended pitches they replace (Palmer & van de Sande, 1993). These findings suggest that harmonic relationships influence listeners' perception of multivoiced music, with a perceptual advantage (increased sensitivity) for tones harmonically unrelated to the musical context.

Another influence on the perception of multivoiced music is that of the relative frequency heights of multiple voices, evidenced in tendencies to respond differentially to voices that occur in different relative frequency ranges (DeWitt & Samuel, 1990; Huron, 1989; Platt & Racine, 1990). Several sources of evidence suggest that listeners may have greater sensitivity for the highest-frequency tone among simultaneously presented tones. Experiments using a musical restoration paradigm, in which a single pitch from a chord is replaced with noise and the perception is that of hearing the original chord intact, suggested that listeners were more accurate at detecting changes that occurred in the highest-frequency voice (DeWitt & Samuel, 1990). Likewise, listeners' judgments of which chord component tone sounded most

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similar to that chord showed preferences for highest-frequency tones (Platt & Racine, 1990). Detection of voice entrances in multivoiced music also provided evidence that outer voices (those in highest- and lowest-frequency ranges) were detected best and that inner voices were detected worst (Huron, 1989); analyses of contrapuntal (multivoiced) musical pieces likewise suggested that composers avoid inner-voice entrances (Huron & Fantini, 1989). Study of pitch errors during piano performances indicated that fewer errors were produced in the highest-frequency voice than in other voices (Palmer & van de Sande, 1993). These findings suggest that the relative frequency heights of different simultaneous voices may influence listeners' perception of multivoiced music, with a perceptual advantage for the highest-frequency voice and a disadvantage for middle-frequency voices.

Relationships among simultaneous musical voices play an especially important role during music performance, in which the melody—the primary or most important voice—is often accentuated over others through use of expressive variations. For instance, the melody is often played louder and sooner than other voices notated as simultaneous (Palmer, 1989; Rasch, 1979). As expected, listeners' identification of the voice intended as melody by the performer is aided by these expressive variations (Palmer, 1988). Study of piano performances indicated that fewer errors were produced in the voice interpreted by performers as melody than in nonmelodic voices (Palmer & van de Sande, 1993). These findings suggest that melodic relationships influence the perception of multivoiced music, with a perceptual advantage for tones in the melodic voice over those in simultaneous voices.

Another aspect of multivoiced music that may influence its perception is the compositional structure, or the relationships specified among the various voices by the composer. Homophonic and polyphonic compositions offer one comparison: Homophonic music typically contains one melody, or primary voice, and additional voices with similar harmonic or rhythmic properties that provide accompaniment; polyphonic music tends to contain multiple melodies of varying importance with different rhythmic properties. In polyphonic music, the voices may be perceived in alternation, whereas in homophonic music, the melody may be perceived as figure and the harmonic accompaniment as background (Wolpert, 1990). Related evidence from the perception of voice entrances indicated that the more polyphonic voices that were present, the greater the difficulty listeners had in identifying voice entrances (Huron, 1989). Also, analyses of piano performances indicated that harmonically related substitution errors were more likely to occur in homophonic than in polyphonic performances, suggesting stronger harmonic relationships between voices in homophonic music (Palmer & van de Sande, 1993). Thus, the compositional structure may also influence the perception of relationships among multiple voices, with stronger harmonic relationships in the homophonic

structure and stronger melodic relationships in the polyphonic structure.

Some of the performance-based findings discussed above, such as the emphasis given to the melodic voice, may reflect constraints specific to the planning and execution of performance that may not apply to perception. For instance, melodic emphasis (such as temporal and intensity fluctuations) may be necessary in *performance* to indicate the relative importance of voices, which is often unspecified by the composer; the greater accuracy seen in pianists' reproduction of melodic events may result from such emphasis. However, the *perceptual* processes that apply to melodic and nonmelodic voices may not differ. Thus, the previous findings of melody and high-frequency advantages in music performance may be specific to performance goals or constraints, and may not pertain to perception.

Alternatively, music perception and performance may rely on the same organizational principles to communicate musical ideas among listeners and performers. According to a related view, music comprehension requires a correspondence between the composer's intentions and the perceiver's mental capabilities (Lerdahl, 1988). Similarly, influences seen in music performance may reflect or parallel constraints on perception of multivoiced music. For instance, performance findings such as higher accuracy for reproducing melodic events (Palmer & van de Sande, 1993) may have a perceptual analogue, such as higher accuracy in detecting changes in the melodic voice. The questions arise as to whether different influences interact and whether, when they conflict, one or the other dominates perceptually. Would melodic influences, for instance, dominate harmonic relatedness, such that harmonically related changes (which are less often detected) and unrelated changes (which are more often detected) are detected equally often when they occur in a melodic voice? We examine these questions by comparing listeners' sensitivity to harmonic, melodic, and frequency height relationships with findings reported in music performance.

We describe two experiments in which we manipulated each of these factors, namely, harmonic, melodic, and relative frequency height relationships among voices, in multivoiced music. Listeners were asked to detect pitch changes in three-voice musical pieces, which included homophonic and polyphonic compositions containing melodic and nonmelodic voices. In different compositions, the location of the melody occurred in the highest or lowest of the three voices. On some trials, a single pitch was altered in one of the three voices. The altered pitch was either harmonically related to the original pitch (from the same chord) or unrelated, and occurred in the voice at the highest-, the middle-, or the lowest-frequency height. The previous findings suggest that changes harmonically unrelated to the original pitch, changes occurring in the melody, and changes occurring in the highest-frequency voice should be detected most easily. We also investigated which influence dominates in cases of conflict—for example, whether a

harmonically related change (which may decrease chances of detection) is perceived more easily when it occurs in a high-frequency voice (which may increase chances of detection).

The use of a pitch-change-detection task resembles an error-detection task often used with proofreading. A familiar paradigm in psychology (Sloboda, 1976; Wolf, 1976), the task reflects a tendency for incorrect items to be overlooked when the errors "fit" well in the context. In a study of music reading, Sloboda (1976) presented pianists with an unfamiliar musical score that contained alterations of certain pitches in the original score. Because the alterations were "implausible alternatives," pianists tended to misplay the alterations as they were originally notated in the score. Although this study may have reflected extraperceptual processes (input processes from sight-reading musical text, as well as output processes from performing two-handed music), the findings suggest that performers relied on knowledge of musical structure to predict what pitches were likely in certain musical contexts. We follow the same logic here, using a pitch-change-detection task to infer what knowledge of musical structure listeners apply to predict what pitch relationships are likely in multivoiced music.

EXPERIMENT 1

Pitch-Change Detection With Acoustic Piano Tones

Method

Subjects. Twelve listeners with moderate musical training were recruited from the Ohio State University community (mean age = 24.3 years). They had a mean of 8.8 years of private instruction on their primary instrument (range = 3–17 years) and all passed a short test that demonstrated their knowledge of musical notation, major and minor chord components, and time and key signatures. Some received course credit in an introductory psychology course for their participation.

Stimulus materials. Four musical pieces were composed for the experiment, and were based on harmonies and rhythms common in simple keyboard music of the Western common practice era. Each piece contained three voices and approximately the same number of chords (9–10) and individual note events (33–36), and each piece was five measures long and in 2/4 time. Two of the pieces were of homophonic compositional structure, while the other two were polyphonic. They were designed to be similar to those used in the piano performance study described earlier (Palmer & van de Sande, 1993). The pieces generally followed traditional common practice period principles of part-writing (Piston, 1978), including patterns of chordal progression and movement among individual voices. The musical pieces were constructed as follows: Two melodies of the same length were composed, one in the highest-frequency range and one in the lowest-frequency range. These melodies will be referred to as "primary" melodies. A two-voice homophonic and a two-voice polyphonic accompaniment were then created for each primary melody (in the lowest- and middle-frequency ranges for the high-frequency melody and in the highest- and middle-frequency ranges for the low-frequency melody). The homophonic accompaniments consisted of two nonmelodic voices, providing chordal accompaniment. The polyphonic accompaniments consisted of one nonmelodic voice (in the middle-frequency range) and a second melodic voice, which is referred to as a "secondary" melody. The secondary melody was constructed to have approximately the same number of note events as the pri-

mary melody it accompanied, as well as the same amount of variation in pitch and note durations. This yielded a total of four stimulus pieces in which melody location was varied so that one of the pieces in each compositional structure contained the primary melody in the highest-frequency voice, while the other contained it in the lowest-frequency voice. Figure 1 displays one of the homophonic and one of the polyphonic pieces based on the same primary melody.

Three types of pitch-change variation were created for each of the four original pieces: no change, harmonically related, and harmonically unrelated. The no-change variations had no pitch changes (they were identical to the originals), and formed one-third of the variations. The harmonically related variations contained a single pitch change harmonically related to the chord occurring at that serial position (i.e., from the root, third, or fifth scale steps in the chord), and formed one-third of the variations. The harmonically unrelated variations contained a single pitch change that was not the root, third, or fifth of the chord at that serial position; all harmonically unrelated changes were chosen from the diatonic key of the piece, in order to produce a natural-sounding alternative. The following constraints were placed on all pitch changes: (1) as much as possible, they retained the duration, pitch contour, and interval size of the context of the original pitch (when this was not possible, the size of the change was larger in the harmonically related condition than in the unrelated condition); (2) they occurred on chords whose harmonic content was unambiguous in the original pieces (those containing the root, third, and fifth scale steps) and approximately equally often on chords that contained the root, third (first inversion), or fifth (second inversion) in the lowest-frequency voice; (3) they occurred in the same position within a measure (the second beat); and (4) they did not create repeating pitches, or minor second, augmented fourth, or seventh intervals (which can yield a dissonant sound).¹

The pitch changes occurred equally often at each of the three frequency heights represented by the three voices (highest, middle, and lowest frequency) and were placed in one of three randomly chosen serial positions throughout the piece (in the second, third, or fourth measures of each piece). Thus, nine variations were created for each of the harmonically related and unrelated pitch changes, and the chord context surrounding the pitch changes was identical in homophonic and polyphonic pieces. Nine no-change variations were also included, yielding a total of 27 stimuli for each of the four original pieces. Examples of harmonically related and unrelated pitch changes in each of the three voices are shown in Figure 1.

Apparatus. All musical stimuli were sounded on an acoustic Yamaha Disklavier piano controlled by a personal computer, and the hammer velocities (controlling amplitudes) and interonset durations (set to 700 msec per quarter-note) of all note events were set equal. An acoustic piano timbre was employed in the first experiment in order to compare findings with the predictions of the piano performance studies that implicated the same variables under study. The subjects' (listeners') view of the piano keyboard was blocked to prevent perception of the depressed keys during playback.

Procedure. Each subject was run individually and was seated next to the piano in front of a computer keyboard, which recorded the subject's responses. The design of the experiment included a learning phase and a testing phase, adapted from previous studies using pitch-detection paradigms (Edworthy, 1985; Smith & Cuddy, 1989). Learning and testing trials were blocked by each of the four original pieces.

In each learning phase, the subjects (listeners) learned a single musical piece during repeated exposure to it. Each learning phase contained six standard-comparison trials, in which one of the four original stimuli was used as the standard and some of its 27 pitch-change variations were the comparisons. The listeners were instructed to learn to recognize the standard. On each trial, a stan-

Homophonic

primary melody →

Polyphonic

secondary melody →

primary melody →

Type of pitch change:

Location of pitch change:	Harmonically related change	Harmonically unrelated change
Highest frequency voice
Middle frequency voice
Lowest frequency voice

Figure 1. Experiment 1: Musical notation of homophonic and polyphonic stimuli, with harmonically related and unrelated pitch changes.

dard was preceded by a 500-msec high-pitched warning tone and was followed by a 3000-msec pause before the comparison sounded. The listeners were asked to respond in terms of how sure they were that the comparison was the same as or different from the standard, on a scale of 1 to 9, where 1 = very sure same and 9 = very sure different. The next trial began 2 sec after the response (or after 12 sec had elapsed, whichever came first). There was a total of six learning trials, which contained at least one instance of each type of pitch change (no change, harmonically related, and unrelated) and of each frequency height of pitch change (highest-, middle-, and lowest-frequency voice). Trials were randomly ordered in each learning phase.

In each testing phase, the listeners were presented with comparisons only (those corresponding to the standard presented in the previous learning phase). The listeners indicated whether or not each comparison was the same as or different from the standard they had just learned.² During testing, the listeners heard the stan-

dard, signaled by a repeated warning tone, on the first trial and following every seventh trial thereafter, to prevent forgetting or confusion across the trials. They were instructed to respond only to the comparisons and not to the repetitions of the standard, using the same 1–9 scale as for the learning trials. The next trial began 2 sec after they had responded (or after 6 sec had elapsed, whichever came first). This procedure of a learning phase (standard-comparison pairs) followed by a testing phase (comparisons interspersed with repetitions of the standard) was used in order to prevent overlearning or boredom with the musical pieces, which were short and memorized quickly by the listeners.

The subjects were randomly assigned to one of four block orders of the original stimuli. The four orders were determined such that the two homophonic and two polyphonic stimuli were always successively ordered (half of the time the homophonic stimuli were first, and half of the time the polyphonic stimuli were first). Trials in the learning phase were presented in the same order for

all of the subjects; trials in the testing phase were presented in a different random order for each subject. The entire session lasted approximately 1 h and 15 min, and the subjects completed a questionnaire on their musical background and a brief music-notation test during a break halfway through the experiment.

Results and Discussion

Analyses of variance (ANOVAs) were conducted on the listeners' ratings by type of pitch change (no change, harmonically related, or harmonically unrelated), frequency height of pitch change (highest-, middle-, or lowest-frequency voice), melody location (highest- or lowest-frequency voice), and compositional structure (homophonic or polyphonic). Analyses were conducted on ratings combined across serial positions of pitch changes. None of the effects in Experiment 1 differed between homophonic and polyphonic pieces, and this variable was therefore removed from further analyses. There was a significant main effect of type of pitch change [$F(2,22) = 203.0$, $MS_e = 6.28$, $p < .01$]. As expected, the listeners rated the no-change condition as significantly closer to "very sure same" (mean = 2.4) than they rated all other conditions (Tukey *HSD* post hoc comparisons, $p < .01$). In addition, harmonically related pitch changes received a significantly lower rating (mean = 6.8) than did unrelated changes (mean = 8.1), indicating that harmonically related changes were less noticeable than were unrelated changes (Tukey *HSD*, $p < .01$).

There was also a significant main effect of frequency height of pitch change [$F(2,22) = 31.0$, $MS_e = 2.51$, $p < .01$]. Pitch changes in the middle-frequency voice were significantly less noticeable than were those in all other conditions (mean = 4.9, Tukey *HSD*, $p < .01$), agreeing with the perceptual findings of lower accuracy in detecting inner-voice (mid-range voice) entrances (Huron, 1989). This could also be due to effects of melody location, since the melody occurred half of the time in the highest-frequency voice and half of the time in the lowest-frequency voice (i.e., never in the middle-frequency voice). Additionally, pitch changes in the highest-frequency voice were most noticeable (mean = 6.4), followed by those in the lowest-frequency voice (mean = 6.0). Although a nonsignificant difference, this ordering matches the earlier predictions that the listeners may be most accurate in perceiving pitch changes in the highest-frequency voice.

There was also a significant interaction of type of pitch change and frequency height of pitch change [$F(4,44) = 20.9$, $MS_e = 2.16$, $p < .01$]. As shown in Figure 2, no-change trials received a lower rating than harmonically related or unrelated changes at each frequency height (Tukey *HSD* post hoc comparisons, $p < .01$). In addition, harmonic-relatedness effects—defined here as the difference between ratings for harmonically related and unrelated pitch changes—were greater for the middle-frequency voice than they were for the other frequency heights combined [orthogonal contrasts, $t(44) = 3.5$, $p < .01$]. Thus, the listeners were least accurate at detecting harmonically related pitch changes in the middle-frequency range.

Figure 2. Experiment 1: Listeners' mean ratings by type of pitch change (no change, harmonically related, or harmonically unrelated) and frequency height (highest, middle, lowest).

Finally, there was a significant interaction of type of pitch change, frequency height of pitch change, and melody location [$F(4,44) = 2.7$, $MS_e = 1.24$, $p < .05$]. As shown in Figure 3 (and also in Figure 2), the difference in ratings for harmonically related and unrelated pitch changes was largest for pitch changes in the middle-frequency height, the location that never contained the melody. In addition, the difference between harmonically related and unrelated changes was smaller when the changes occurred in the highest-frequency voice and melody location than it was for all other frequency height and melody location combinations [orthogonal contrast, $t(44) = 9.2$, $p < .01$]. All means shown in Figure 3 differed significantly from the rating-scale endpoint (t tests with Dunn-Bonferroni adjustment, $p < .05$), indicating that this was not a ceiling effect. Thus, the effects of harmonic relatedness were surprisingly reduced (i.e., the listeners detected any type of change) in the location of highest-frequency voice and the highest-frequency melody. This effect suggests that interpretation of a high-frequency voice as melody aids pitch discrimination relative to high-frequency nonmelodic voices, and the combination overrides the harmonic-relatedness effects on pitch-change detection.

There is a possible confounding factor in these results, however. The effects of both frequency height and type of pitch change may be due to the presence of overlapping upper harmonics in the piano timbre used in this experiment. The presence of upper harmonics that are

Figure 3. Experiment 1: Listeners' mean ratings by type of pitch change, frequency height, and melody location (highest or lowest).

shared between pitches can create more overlap (and thus less noticeability) for harmonically related pitch changes than for unrelated changes, especially those occurring in the middle-frequency range (middle voice) whose upper harmonic energy may overlap more with that of simultaneously sounded higher and lower pitches. We addressed this problem in a second experiment.

EXPERIMENT 2

Pitch-Change Detection With Sine-Wave Tones

On the basis of findings of the first experiment, we predicted that if overlapping upper harmonics in the piano timbre accounted for the listeners' inability to detect harmonically related changes in the middle-frequency voice as accurately as other pitch changes, the effects of harmony and frequency height might disappear in the absence of upper harmonics. Alternatively, if these effects arose from the perceptual organization of intervoice relationships beyond the sensory cues available, the findings of the earlier study should be replicable in the absence of upper harmonics. Therefore, we repeated the first experiment, using the same musical pieces but a different timbre, one generated from pure sine tones that contained no upper harmonics.

Method

Subjects. Twelve listeners with moderate musical training were recruited from the Ohio State University community (mean age = 21 years). None of the listeners had participated in the first experiment. They had an average of 7.9 years of private instruction on their primary instrument (range = 5–14 years) and all passed

the same music test used in the first experiment. Some received credit in an introductory psychology course for their participation.

Stimulus materials and Apparatus. The stimulus materials were the same as those used in Experiment 1, except that sine-wave tones rather than acoustic piano tones were used to create the musical pieces played to the listeners. Musical stimuli were produced by a Yamaha TX81Z FM tone generator set to a sine-wave timbre with an attack time of 10 msec and decay of 10 msec, ending 30 msec before the onset of the next tone. The sine tones were sounded through an EV BK-832 mixer and QSC 1200 amplifier on a JBL 4410 speaker positioned in front of the computer keyboard on which the subjects made their responses.

Procedure. The procedure and design were identical to those of Experiment 1.

Results and Discussion

The same ANOVA was conducted on the listeners' ratings (by type of pitch change, frequency height of pitch change, melody location, and compositional structure). There was a significant main effect of type of pitch change [$F(2,22) = 154.2$, $MS_e = 5.78$, $p < .01$]. As before, the listeners rated the no-change condition as significantly closer to "very sure same" than they rated all other conditions (mean = 3.1; Tukey *HSD* post hoc comparisons, $p < .01$). In addition, harmonically related pitch changes (mean = 6.9) received a significantly lower rating than did unrelated changes (mean = 7.9; Tukey *HSD*, $p < .01$). Thus, harmonically related changes were again less noticeable than were unrelated changes, even in the absence of upper harmonic cues.

There was also a significant main effect of frequency height of pitch change [$F(2,22) = 24.2$, $MS_e = 3.83$, $p < .01$]. Changes in the middle-frequency voice were again least noticeable (mean = 5.15), and changes in the highest-frequency voice were most noticeable (mean = 6.8); in addition, all three means differed significantly (lowest-frequency voice mean = 6.0; Tukey *HSD*, $p < .01$). These findings suggest that the listeners' differential responses to pitch changes in certain frequency ranges are not due to the presence or absence of upper harmonics.

Again, there was a significant interaction of type of pitch change and frequency height of pitch change [$F(4,44) = 20.2$, $MS_e = 2.32$, $p < .01$]. As shown in Figure 4, no-change trials received a lower rating than harmonically related or unrelated changes at each frequency height (Tukey *HSD* post hoc comparisons, $p < .01$). As seen before, the difference between ratings for harmonically related and unrelated pitch changes was greater for the middle-frequency voice than it was for the other frequency heights combined [orthogonal contrasts, $t(44) = 2.7$, $p < .01$]. Thus, the absence of upper harmonics did not reduce the effects of harmonic relatedness and frequency height.

There was also a significant interaction of type of pitch change, frequency height of pitch change, and melody location [$F(4,44) = 3.3$, $MS_e = 1.08$, $p < .05$]. As shown in Figure 5 (and also in Figure 4), the difference in ratings for harmonically related and unrelated pitch changes was largest in the middle-frequency voice. Again, the difference between harmonically related and

Figure 4. Experiment 2: Listeners' mean ratings by type of pitch change and frequency height.

Figure 5. Experiment 2: Listeners' mean ratings by type of pitch change, frequency height, and melody location.

Figure 6. Experiment 2: Listeners' mean ratings by type of pitch change, frequency height, melody location, and compositional structure (homophonic or polyphonic).

unrelated conditions was smaller for changes occurring in the highest-frequency voice and the high-frequency melody location than it was for all other frequency height and melody location combinations [orthogonal contrast, $t(44) = 2.55, p < .05$]. This was not due to ceiling effects; all means differed significantly from 9 (the rating-scale endpoint; $p < .05$). All pitch changes were noticeable when they occurred in both the highest-frequency voice and the high-frequency melody location, demonstrating again the dominance of melody and frequency height over harmonic relationships.

Finally, there was a significant interaction of type of pitch change, frequency height of pitch change, melody location, and compositional structure [$F(4,44) = 2.6, MS_e = 1.10, p < .05$]. As shown in Figure 6, the effects of frequency height and melody location on the noticeability of harmonically related pitches for homophonic compositions differed from those for polyphonic compositions. The main difference between homophonic and polyphonic conditions was the presence of a second melody in one of the polyphonic voices; the interaction was thus examined in terms of this difference.

Ratings for harmonically related pitch changes in the highest-frequency range when the melody was in the lowest-frequency location (i.e., ratings for the location of the polyphonic secondary melody) were significantly smaller in the homophonic condition (Figure 6a; mean = 8.0) than they were in the polyphonic condition (Figure 6b; mean = 8.89) [orthogonal contrast, $t(44) = -2.08, p < .05$]. One explanation is that the polyphonic condition's secondary melody in the highest-frequency location increased the listeners' sensitivity to harmonically related pitch changes occurring there. Thus, harmonically related pitch changes were more easily detected in the presence of a high-frequency secondary melody (polyphonic condition) than they were in its absence (homophonic condition). The same comparison between ratings for harmonically related pitch changes in the lowest-frequency range when the melody was in the highest-frequency location (ratings for the location of the polyphonic secondary melody) did not differ significantly between homophonic conditions (Figure 6e; mean = 7.17) and polyphonic conditions (Figure 6f; mean = 6.78) [orthogonal contrast, $t(44) = 0.91, p > .10$].

Thus, only the polyphonic secondary melody in the highest-frequency range aided the detection of harmonically related pitch changes. These contrasts indicate that the effects of frequency height and melody location are mediated by compositional structure. Polyphonic compositions that contained additional melodies in the highest-frequency range enhanced the noticeability of harmonically related pitch changes occurring there.

The results of Experiment 2, using sine tones, replicated the previous findings of harmonic, melodic, and frequency height influences on the perception of pitch changes in music based on piano tones. This suggests that harmonically related pitch changes are less noticeable to listeners not because of overlapping upper har-

monics with other voices, but instead because of influences of intervoice relationships in the perceptual organization of multivoiced music. In addition, compositional structure mediated melodic and frequency-height effects when additional (secondary) melodies were introduced in polyphonic compositions. This effect was found for sine tones but not for piano tones (of Experiment 1), possibly due to the overlapping harmonics in piano tones creating greater fusion of voices in both compositional structures. The voices may sound more distinct in the absence of overlapping harmonics (sine tones), making all intervoice relationships perceptually clearer, a possibility to be addressed in further research.

GENERAL DISCUSSION

We have identified three intervoice relationships that influence listeners' perception of multivoiced music: harmonic, melodic, and frequency height relationships. First, harmonic relationships among voices affected the detection of pitch changes, with harmonically related changes (those bearing the same chordal relationships as the original) being more difficult to detect than unrelated changes. The influence of harmonic relationships was mediated by the associations among voices specified by the compositional structure; the presence of multiple melodies in polyphonic compositions increased the detection of harmonically related changes in Experiment 2 (using sine tones). Harmonic expectations may be formed more easily for voices that have strong associations with other simultaneous voices (as in homophonic compositions), making pitch changes that fit those expectations more difficult to detect. These results are thus congruent with findings of implied harmony and perceptual restoration of harmonically related tones (Butler, 1992; DeWitt & Samuel, 1990; Jones et al., 1991).

Second, frequency height influenced the detectability of pitch changes. The worst detection of pitch changes (especially of harmonically related changes) occurred in the middle-frequency voice, and the best detection (of both harmonically related and unrelated changes) occurred in the highest-frequency voice. This fits well with findings that suggest a perceptual advantage for tones that occur in the highest-frequency voice (DeWitt & Samuel, 1990) and a perceptual disadvantage for voices entering in the middle-frequency range (Huron, 1989). These perceptual findings also agree with work in music performance that indicates that performers are most accurate at producing the highest-frequency voice and least accurate at producing the middle-frequency voice (Palmer & van de Sande, 1993). The question arises as to whether the melody and frequency height effects stem from the same source (Platt & Racine, 1990). The highest-frequency voice is often the location of the optimal vocal range in song and of melodies in multivoiced music. For instance, an analysis of a corpus of Western tonal piano music indicated that the melody typically occurs in the highest-

frequency voice (Palmer & van de Sande, 1993). In the current experiment, frequency height effects were separated from those of melody location; the detection of pitch changes was best in the highest-frequency voice, whether or not the melody was located there.

Finally, the presence of a melody interacted with frequency height to dominate the harmonic-relatedness effects on pitch-change detection. Both melody location and frequency height aided detection of pitch changes; detection improved for changes occurring in the highest-frequency voice or the melody, and was further facilitated by the presence of both melody and highest-frequency voice. This finding suggests that listeners may attend more readily to the melodic voice, especially when it occurs in the high-frequency range. The melody frequently contains interesting changes in harmony, contour, and rhythm, factors that have well-documented effects on listeners' attending to musical structure (Edworthy, 1985; Kidd et al., 1984; Monahan et al., 1987). When melody location and frequency height conflicted with harmonic relatedness in the current study, they tended to override the perceptual disadvantage that harmonically related changes usually afforded; all pitch changes (harmonically related and unrelated) were equally noticeable in the presence of high-frequency melodies.

Researchers have long been interested in the ability to detect pitch errors as an indicator of musical skill (Hansen, 1955; Larson, 1977; Ramsey, 1979). For example, sight-reading (performing unfamiliar music from notation), a valuable musical skill, is often regarded as dependent on the ability to evaluate one's own performance by detecting (and correcting) errors (Sloboda, 1976). Performance on pitch-error-detection tasks is sometimes correlated with performance of other musical skills, such as musical dictation (Larson, 1977), theory training, and aural (ear-training) tasks (Hansen, 1955). Pianists' detection of pitch errors in multivoiced choral music was better than that of other instrumentalists (Hansen, 1955), suggesting that experience on an instrument capable of producing multivoiced music may also influence pitch-error detection. However, these studies employed "real" music performances as stimuli (rather than computer-generated stimuli), which usually contain multiple cues, such as timing and intensity variations, as well as occasional real (uncontrolled) pitch errors, making the results of such error-detection tasks difficult to evaluate. Despite these problems, these studies suggest, as do the current findings, that pitch-change-detection tasks reflect listeners' knowledge of structural relationships among multiple voices. Error-detection tasks may also provide a naturalistic link for study of the cognitive processes underlying perception and performance.

Finally, perception of multivoiced music reflected the same intervoice relationships found in performance, despite the different perceptual/motor demands on the two behaviors. That is, melodic and high-frequency voices afforded increased pitch detection during perception and

decreased error rates during performance (Palmer & van de Sande, 1993). This finding supports the view that musical comprehension occurs when the perceiver is able to assign a mental representation that fits that of the performer, as well as that of the composer. Most theories of Western tonal music assume a degree of correspondence between compositional and listening goals and that the interpretation of important pitches and harmonies follows perceptual principles (Huron, 1989; Lerdahl, 1988; Narmour, 1990). Assuming that musical behavior reflects a communication of structure among composers, performers, and listeners, similarities in the intervoice relationships that influence perception and performance may ensure that encoding of musical structure matches its retrieval during performance, making communication possible.

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NOTES

1. In accordance with traditional voice-leading principles (see Piston, 1978), the pitch changes were designed to avoid unisons, perfect fifths, octaves, and parallel intervals, as well as part-crossing and large leaps in pitch. However, it was impossible to substitute pitches in intact chords that did not result in unbalanced chords (those doubling or missing the root, third, or fifth scale tones), which may influence their prominence. The unbalanced chords were distributed approximately equally across all conditions; analyses conducted on the bases of chord inversion (reflecting the chord position relative to frequency height) and chord imbalance (root, third, or fifth scale tone missing) indicated that these factors did not interact with the variables under study (although there were too few instances in some stimuli to test their effects adequately).

2. Stimulus familiarity gained during the learning phase was evidenced by the high accuracy and confidence of ratings given to trials in the testing phase, during which no standard was present.

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