Journal of Experimental Psychology:
Human Perception and Performance
1993, Vol. 19, No. 3, 615–626

0096-1523/93/$3.00

Musical Context Effects in Infants and Adults: Key Distance

Laurel J. Trainor and Sandra E. Trehub

Adults and 9- to 11-month-old infants listened to repeated transpositions of either a prototypical Western melody that was based on the major triad or a nonprototypical Western melody that was based on the augmented triad. In both cases, the transpositions were either to related keys (standing in a 2:3 frequency ratio) or to unrelated keys (more complex frequency ratios). For the prototypical melody, both infants and adults more readily discriminated a change to the melody in the context of related keys. For the nonprototypical melody, infant listeners performed better in the context of related keys, but adult listeners performed worse. The findings indicate that the global context of auditory patterns influences the processing of pattern details for infant and adult listeners.

A recurrent finding in pattern-perception research is the critical role of context. In speech perception, for example, cues for particular phonemes vary considerably when preceded or followed by different sounds (e.g., Cooper, Delattre, Liberman, Borst, & Gerstman, 1952; Delattre, Liberman, & Cooper, 1955; Dorman & Raphael, 1980) or when accompanied by different visual gestures (McGurk & MacDonald, 1976). Context effects are similarly prevalent in the visual domain (e.g., Enns & Prinzmetal, 1984; Hoffman, 1980; Kimchi, 1988; Lasaga & Hecht, 1991; Navon, 1977, 1983, 1991; Peretz, 1990; Pomerantz, 1981, 1983; Pomerantz & Sager, 1975; Pomerantz, Sager, & Stoever, 1977; Weisstein & Harris, 1974; Williams & Weisstein, 1978). For example, Pomerantz et al. (1977) created contexts that either aided adults' ability to detect elements (*configural superiority effects*) or impeded this ability.

Context effects are also evident in the perception of musical patterns. For example, Cuddy, Cohen, and Miller (1979) evaluated Western listeners' ability to discriminate 2 three-note patterns when surrounded by two sets of two notes (i.e., seven-note pattern: two-note context, three-note pattern, two-note context). Overall, performance was superior when the context conformed to Western music-theoretic conventions (e.g., diatonic notes, ending with a typical cadence) than when it did not.

Developmental studies of context effects have generated conflicting interpretations of the interaction of global and local levels of processing. According to Aslin and Smith (1988), infants begin as local processors of visual patterns and gradually become global processors. By contrast, Morrongiello (1984, 1986, 1988) argued that infants are initially sensitive to global aspects of auditory patterns, gradually becoming proficient with local features. Her position is consistent with Gibson's (1969) view of increasing perceptual differentiation with age. These contrasting views reflect the continuing controversy in the adult pattern-perception literature surrounding the processing priority of local over global forms (e.g., Treisman & Gelade, 1980; Treisman & Paterson, 1984) or the reverse (Navon, 1977, 1983, 1991).

In the present research, we focused on the interaction between global context and local processing in infants' and adults' perception of melodic patterns. Context effects in adults' perception of musical stimuli (Cuddy et al., 1979; Krumhansl, 1979, 1990; Krumhansl, Bharucha, & Kessler, 1982; Takeuchi & Hulse, in press) are generally considered to reflect experience with a particular musical system (see Dowling & Harwood, 1986; Jones, 1990; Krumhansl, 1990; Sloboda, 1985). It is possible, however, that certain global contextual relations confer local processing advantages that are independent of experience. In other words, some global contexts may facilitate local processing by infants despite their limited knowledge of Western musical structure.

The perception of musical structure presupposes basic grouping mechanisms for parsing the sequence of melody notes. In recent years, it has become clear that auditory perceptual grouping is characteristic of infants as well as adults. Like adults, infants group tones by their similarity in frequency, waveform, or intensity (Thorpe & Trehub, 1989; Thorpe, Trehub, Morrongiello, & Bull, 1988), and they also segregate auditory streams on such bases (Demany, 1982). Grouping processes are evident as well in infants' sensitivity to phrase boundaries in speech (Kemler Nelson, Hirsh-Pasek, Jusczyk, & Wright Cassidy, 1989) and music (Krumhansl & Jusczyk, 1990).

We examined the effect of one aspect of global context, that of the pitch relations between successive repetitions of a melody, on the processing of one aspect of local structure, that of specific intervals within the melody. A well-structured Western melody played at different pitch levels is said to be in different musical keys, and some keys are considered to be more closely related than others. To the extent that adults are sensitive to key relations, or *key distance*, this sensitivity is presumed to derive from their extensive music exposure.

In Western music, the octave is divided into 12 equally spaced notes (log frequency) that are separated by semitones,

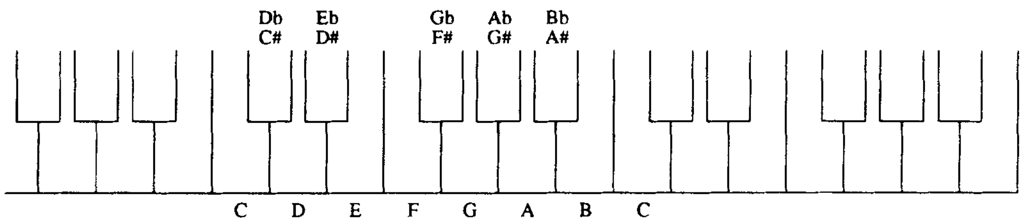
Laurel J. Trainor, Department of Psychology, University of Toronto, Mississauga, Ontario, Canada; Sandra E. Trehub, Centre for Research in Human Development, University of Toronto, Mississauga, Ontario, Canada.

This research was supported by grants to Sandra E. Trehub from the Natural Sciences and Engineering Research Council of Canada and the University of Toronto.

Correspondence concerning this article should be addressed to Laurel J. Trainor, who is now at the Department of Psychology, McMaster University, Hamilton, Ontario, Canada L8S 4K1.

forming the chromatic scale (see Figure 1). The same division is repeated in successive octaves such that notes an octave apart are considered functionally equivalent and given the same note name. Western compositions are typically based on unequal-interval subsets of these notes, the most common subset or scale being the major scale (see Figure 1). The intervals between successive notes of the major scale are 2, 2, 1, 2, 2, 2, and 1 semitones. A major scale can be formed by starting on any note of the chromatic scale as long as the succession of intervals is maintained. The resulting 12 scales are named by their initial note.

Different notes of the scale serve different functions in musical composition. The first note or *tonic* is the most important, with compositions usually ending on this note. Second in importance is the fifth note or *dominant*. The interval between the tonic and dominant (seven semitones), called a



chromatic scale:

	Db		Eb			Gb		Ab		Bb		
C	C#	D	D#	E	F	F#	G	G#	A	A#	B	C
0	1	2	3	4	5	6	7	8	9	10	11	0

major scale:

C	D	E	F	G	A	B	C	
0	2	4	5	7	9	11	0	
Eb	F	G	Ab	Bb	C	D	Eb	
3	5	7	8	10	0	2	3	

major triad:

C	E	G
0	4	7
Eb	G	Bb
3	7	10

augmented triad:

C	E	G#
0	4	8
Eb	G	B
3	7	11

Figure 1. Some basic aspects of Western musical structure: note names of the keys of the piano; note names and associated numbers of the chromatic scale; two major scales, C major and E♭ major; two major triads, beginning on C and E♭; and two augmented triads, beginning on C and E♭.

perfect fifth, is especially significant in Western music theory. Acoustically, the frequency ratio of the component notes of the perfect fifth approximates a simple and small integer relation, that of 2:3.

As noted, a unique major scale can begin on each note of the chromatic scale. The relatedness of two major scales can be considered to be a function of the number of their notes in common (e.g., see Krumhansl, 1990, p. 32). For instance, the major scales with tonics of C and E have three notes in common, differing in the remaining four notes. Every scale or key is most closely related to two others, differing from them in only one note. Thus the 12 major scales can be arranged in a circle (the *cycle of fifths*) such that adjacent scales differ in only one note (see Figure 2). The distance between two major keys is defined as the number of keys that separate them in the circle, which corresponds to the number of notes by which they differ. The tonics of scales that are most closely related (i.e., adjacent on the cycle of fifths) are separated by seven semitones or the interval of the perfect fifth. (If played in descending rather than ascending order, the tonics are separated by five semitones or a *perfect fourth*. With octave equivalence, these intervals are the same and in this context will be designated perfect fifths.) In other words, the tonic of one scale is the dominant of the other. In Western musical structure, then, the perfect fifth interval is important both within the major scale (i.e., relating the most important notes) and across scales (i.e., defining the most closely related keys).

The notion of key distance is central to Western music. Compositions often begin in one key and then modulate to

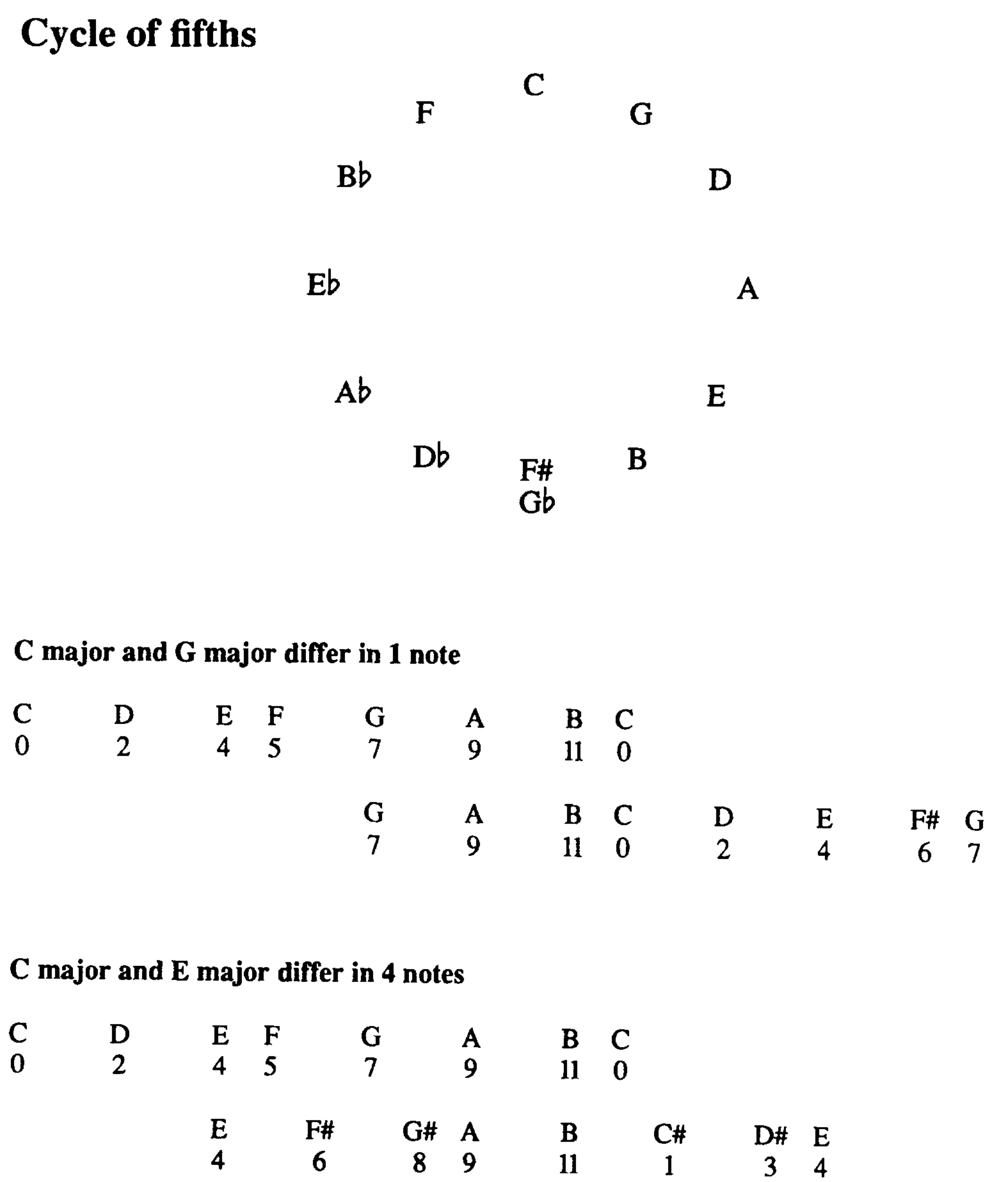


Figure 2. The cycle of fifths. (C major and G major are closely related, but C major and E major are not.)

another key, with modulations to related keys being especially common because they preserve the coherence of the music (Sloboda, 1985). A few studies have revealed perceptual effects of key distance (Bartlett & Dowling, 1980; Cuddy, Cohen, & Mewhort, 1981; Cuddy et al., 1979; Krumhansl, Bharucha, & Castellano, 1982; Sloboda & Edworthy, 1981; Takeuchi & Hulse, 1992; Thompson & Cuddy, 1989), although such effects are not always robust (Takeuchi & Hulse, 1992) or evident with longer melodies (Pick et al., 1988). Bartlett and Dowling (1980) found that pairs of brief conventionally structured Western melodies were perceived as more similar when they were in related than in unrelated keys. Sloboda and Edworthy (1981) found that listeners could more readily detect a pitch error in one of two melodies played together if the melodies were a perfect fifth apart than if they were an augmented fourth apart. Similarly, Cuddy et al. (1979) and Cuddy et al. (1981) demonstrated that adults were better at detecting a semitone change to a well-structured Western melody when the comparison was presented in a related key (differing in one scale note) than in an unrelated key (differing in six scale notes). Specifically, performance was most accurate when the comparison sequence was separated from the standard sequence by a perfect fifth interval (i.e., with the tonic seven semitones above that of the standard melody). For poorly structured Western melodies, key relatedness had the opposite effect (Cuddy et al., 1981) or no effect at all (Cuddy et al., 1979). Cohen (1982) and Cuddy et al. (1981) claimed that what appears to be an effect of unrelated keys on poorly structured melodies may be attributable to the shared pitch information between original and transposed sequences. Key distance and overlapping pitches, however, were confounded in Cohen (1982) and Cuddy et al. (1981). In the case of their poorly structured melodies, the transpositions to unrelated keys had more notes in common with the original melody than did the transpositions to related keys.

Cohen, Thorpe, and Trehub (1987) first suggested that related keys might facilitate infants' comparison of melodies. Infants appear to process music independently of any particular musical system such as Western tonality (Lynch, Eilers, Oller, & Urbano, 1990; Trainor, 1991; Trehub & Trainor, 1993), and they appear to lack knowledge of Western major scale structure (Trainor & Trehub, 1992). Consequently, if global key relations affected their processing of local melodic features, this finding would be attributable to inherent perceptual properties of global pitch relations rather than infants' sensitivity to key distance per se. Thus, comparisons of infants and adults have the potential to distinguish inherent from acquired effects of global context on melodic processing.

At the same time that infants show culture-independent musical processing, they find it easier to detect subtle changes to some melodies than to others (Cohen et al., 1987; Trainor, 1991; Trehub, Thorpe, & Trainor, 1990). Trehub and Trainor (1993) have suggested that some melodies may be intrinsically well structured or good in the sense that they promote more detailed processing. Similarly, some global contexts might be intrinsically well structured, leading to enhanced local processing for infant listeners. Indeed, the basis of key-distance effects in Western adults is unknown: To what extent do they reflect extensive experience with Western music, and to what extent do they reflect general pattern-processing dispositions?

To separate the effects of experience and of inherent processing predispositions, we compared infants' and adults' ability to detect interval changes in a melody that repeated in transposition to related (i.e., near) or unrelated (i.e., far) keys. Because some researchers have suggested that the perfect fifth interval may be inherently easy to process (Cohen et al., 1987; Trainor, 1991; Trehub & Trainor, 1990, 1993) and because the most closely related keys in Western music stand in a perfect fifth relation, we predicted that infants would show enhanced performance in that context. Following earlier studies in this domain (Cohen et al., 1987; Trehub, Cohen, Thorpe, & Morrongiello, 1986), we selected two melodies (Figure 1), one based on the major triad, a prototypical form in Western music, and the other based on the augmented triad, an uncommon form. The major triad consists of three notes separated by successive intervals of four and three semitones, for example, the first, third, and fifth notes of the major scale form. The augmented triad is superficially similar to the major triad, consisting of three notes separated by four and four semitones. Musically, however, the augmented triad is very different from the major triad because it cannot be formed from any three-note subset of the major scale. As a result, it is relatively rare in Western music (see Cohen et al., 1987, p. 35; Roberts, 1982). The two triads also differ acoustically. The frequencies of the outer notes of the major triad form a perfect fifth, standing approximately in a 2:3 ratio. By contrast, the augmented triad is considered to be more dissonant, with its outer notes approximating the more complex ratio of 16:25.

We used melodies that were based on the major and augmented triads for two principal reasons. First, these melodies permitted comparisons of infants and adults across prototypical and nonprototypical Western forms. Second, this selection allowed us to capitalize on previous research with these melodic structures. For example, Cohen et al. (1987) and Trainor (1991) found that infants were better able to detect an upward semitone change to the top note of the major triad than a downward semitone change to the top note of the augmented triad when presented in transposition. Cohen et al. (1987) concluded that infants process the major triad more readily than the augmented triad. In other studies (Trainor, 1991; Trehub et al., 1986), however, infants detected upward changes to the top note of both the major and augmented triads equally well, raising the possibility that infants have difficulty with downward changes to the augmented triad only. In the present study, we used upward changes to the top notes of these triads to ensure that infants would be able to perform the task.

We examined infants' discrimination of melody changes with a conditioned head-turn procedure (see Eilers, Wilson, & Moore, 1977; Kuhl, 1985; Trehub, Bull, & Thorpe, 1984). Specifically, infants were trained to turn to the sound source (leftward) in response to a melody change and were rewarded for doing so with animated toys. We used two standard five-note melodies that were based on either the major triad or the augmented triad. The comparison melody incorporated an upward semitone change to the middle note of each melody. The standard and comparison melodies were presented in transposition to related or to unrelated keys, precluding the use of absolute pitch cues. If the global context (i.e., key relations between melodies) exerted an effect on infants' processing of local information (i.e., interval information within melodies), then infants would perform better with patterns transposed to related than to unrelated keys. Such an outcome would imply that the perfect fifth interval relation between melodies was responsible for this processing advantage.

Experiment 1

Method

Subjects. There were 44 healthy, full-term infants between 9 and 11 months of age who participated in one of four conditions. Mean ages in each condition (N = 11) were 9 months, 27 days (major–related), 9 months, 20 days (major–unrelated), 10 months, 1 day (augmented–related), and 10 months, 9 days (augmented–unrelated), and the distributions of men and women were 7 and 4, 7 and 4, 6 and 5, and 5 and 6, respectively. A further 21 infants were

Table 1
Complete List of Melodies and Changed Notes for All Conditions

Triad	Standard background melodies					Changed notes	Triad	Standard background melodies					Changed notes
						Related keys condition							
Major	B♭	D	F	D	B♭	F#	Augmented	B♭	D	F#	D	B♭	G
	10	2	5	2	10	6		10	2	6	2	10	7
	F	A	C	A	F	C#		F	A	C#	A	F	D
	5	9	0	9	5	1		5	9	1	9	5	2
	C	E	G	E	C	G#		C	E	G#	E	C	A
	0	4	7	4	0	8		0	4	8	4	0	9
	G	B	D	B	G	D#		G	B	D#	B	G	E
	7	11	2	11	7	3		7	11	3	11	7	4
	D	F#	A	F#	D	B♭		D	F#	A#	F#	D	B
	2	6	9	6	2	10		2	6	10	6	2	11
						Unrelated keys condition							
Major	C	E	G	E	C	G#	Augmented	C	E	G#	E	C	A
	0	4	7	4	0	8		0	4	8	4	0	9
	E	G#	B	G#	E	C		E	G#	C	G#	E	C#
	4	8	11	8	4	0		4	8	0	8	4	1
	A♭	C	E♭	C	A♭	E		A♭	C	E	C	A♭	F
	8	0	3	0	8	4		8	0	4	0	8	5
						Unrelated keys II condition							
Major	C	E	G	E	C	G#	Augmented	C	E	G#	E	C	A
	0	4	7	4	0	8		0	4	8	4	0	9
	E♭	G	B♭	G	E♭	B		E♭	G	B	G	E♭	C
	3	7	10	7	3	11		3	7	11	7	3	0
	G♭	B♭	D♭	B♭	G♭	D		G♭	B♭	D	B♭	G♭	D#
	6	10	1	10	6	2		6	10	2	10	6	3
	A	C#	E	C#	A	F		A	C#	F	C#	A	F#
	9	1	4	1	9	5		9	1	5	1	9	6

Note. The following data are for the major triad. Related keys condition: background note set, 0, 2, 4, 5, 6, 7, 9, 10, 11; changed note set, 1, 3, 6, 8, 10; notes in common, 6, 10. Unrelated keys condition: background note set, 0, 3, 4, 7, 8, 11; changed note set, 0, 4, 8; notes in common, 0, 4, 8. Unrelated keys II condition: background note set, 0, 1, 3, 4, 6, 7, 9, 10; changed note set, 2, 5, 8, 11; notes in common, none. The following data are for the augmented triad. Related keys condition: background note set, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11; changed note set, 2, 4, 7, 9, 11; notes in common, 2, 4, 7, 9, 11. Unrelated keys condition: background note set, 0, 4, 8; changed note set, 1, 5, 9; notes in common, none. Unrelated keys II condition: background note set, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11; changed note set, 0, 3, 6, 9; notes in common, 0, 3, 6, 9.

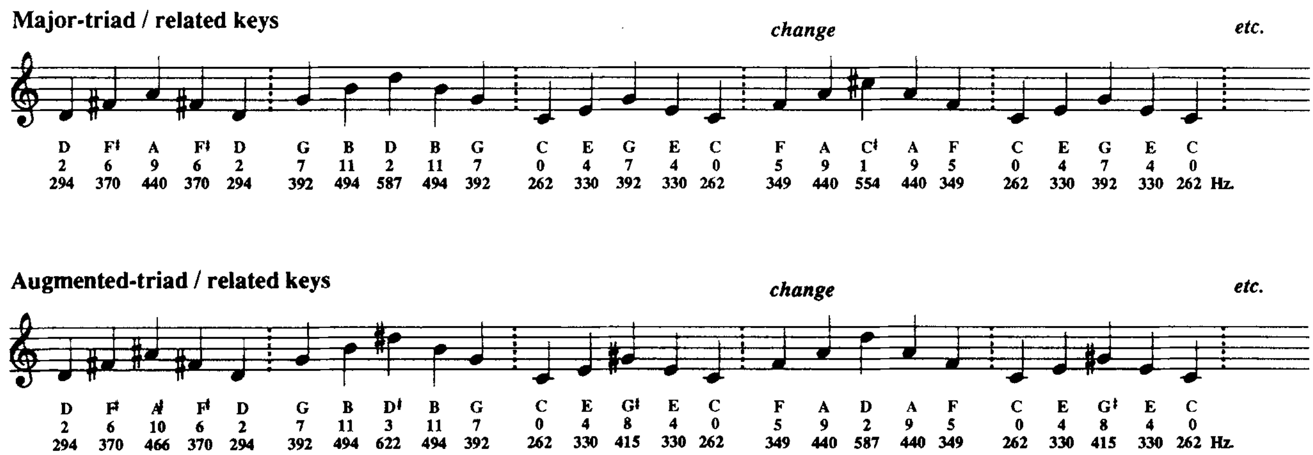


Figure 3. Sample excerpts from test sessions of the two conditions. (The standard melody is repeated three times followed by a change in the third note of the melody [fourth repetition] and a subsequent return to the standard [fifth repetition].)

excluded for not meeting the training criterion (7) or for not completing the test session because of fussing (14).

Apparatus. Infants were tested individually in a double-walled, sound-attenuating booth (Industrial Acoustics Co.). The infant sat on their parent's lap in one corner of the booth facing the experimenter, who sat in the opposite corner. A loudspeaker and toy box were located 45° to the infant's left. The experiments were controlled by an ECS microcomputer, which regulated the audio equipment and mechanical toys through a custom-built interface. The experimenter signaled to the computer by way of touch-sensitive buttons when the infant was ready for a trial (i.e., quiet and looking directly ahead) and when the infant made a head turn to the loudspeaker (45° or greater). The toy box contained four chambers, each housing a mechanical toy and light. The front of the toy box was smoked Plexiglas so that infants could not see into any chamber unless a light was on. The toys and lights were controlled by the computer. Two Hewlett-Packard 3325A synthesizer–function generators produced the sine-wave tones. The signals were subsequently attenuated by two attenuators (Med Associates) and switched on and off by two rise–fall switches (Med Associates). The signals were then fed through a stereo amplifier (Marantz 1070) to the single loudspeaker (Avant 2AX) in the booth.

Stimuli. Two five-note standard background melodies were used, one based on the major triad (e.g., Notes C4, E4, G4, E4, C4; 261, 329, 391, 329, 261 Hz) and the other on the augmented triad (e.g., C4, E4, G♯4, E4, C4; 261, 329, 415, 329, 261 Hz). Successive melodies were presented in transposition, that is, at different pitch levels but with the same intervals (log frequency ratios) between successive notes of the melody. Two different transpositions were used. In the related-keys condition, each standard background melody was in one of the following keys: B♭, F, C, G, or D, which are adjacent on the cycle of fifths (see Figure 2). Successive melodies were always in different keys and were always in most closely related keys, that is, adjacent on this list. In the unrelated-keys condition, each standard background melody was in the key of C, E, or A♭, such that adjacent melodies were in different keys. These three keys are maximally distant on the cycle of fifths, any two of them differing in four notes, with tonics related by a major third. Table 1 contains a complete list of the melodies used in each condition. Infants were randomly assigned to one of the four conditions created by crossing the two triad melodies (major, augmented) with the two key relations (related, unrelated).

Infants' task for both the major and augmented melodies was to detect an upward semitone change to the middle note of the melody (see Table 1). During the training phase, the task was easier. In the first three training trials, infants were required to detect an upward change of six semitones to the middle note; the change was reduced to three semitones in subsequent training trials. The tones of each melody were contiguous sine waves 400 ms in duration. Each had 10-ms linear rise and decay ramps. Repetitions of the melody were separated by 1,200 ms.

Procedure. Infants were randomly assigned to one of the four conditions created by crossing the two triad melodies (major, augmented) with the two key relations (related, unrelated; see *Stimuli*). In each case, the procedure was identical. Infants were tested with a go–no-go conditioned head-turn procedure (see Trehub, Thorpe, & Morrongiello, 1987). The standard background melody repeated continuously in transposition (see *Stimuli*) throughout the entire test session. The experimenter encouraged the infant to look directly ahead by means of hand-held toys. When the infant was quiet and facing straight ahead, the experimenter signaled to the computer (by using one button) that the infant was ready for a trial. Half of the 30 trials were control trials consisting of a further repetition of the standard background melody and were therefore indistinguishable from the repeating background. The other 15 trials were change trials in which the middle note of the melody was raised by a semitone (see *Stimuli*). Because of fluctuating infant attentiveness, there were variable numbers of repetitions (in transposition, of course) of the standard background melody between trials, with the minimum number being fixed at two. Sample excerpts from test sessions are shown in Figure 3. The experimenter signaled to the computer (by using another button) whenever the infant turned 45° or more to the left. If on change trials the infant turned to the loudspeaker during the response interval, the computer automatically activated the light and animated toy in one chamber of the toy box for 4 s. The response interval began with the onset of the middle (third) note of the triad melody and ended 3 s later. The computer recorded head turns during the response intervals of control and change trials. The parent and experimenter listened to masking music on headphones to keep them unaware of the type of trial being presented. Additionally, the parent and experimenter were unaware of the research hypotheses.

The test phase was preceded by a training phase designed to illustrate the contingency between head turning to a change and reinforcement with animated toys. During training, there were no

Table 2
Nine- to 11-Month-Olds' d' Scores on Related and Unrelated Keys

Triad	Key relation	
	Related	Unrelated
Major		
M	0.53	−0.03
SD	0.23	0.63
Augmented		
M	0.53	0.13
SD	0.53	0.39

control trials, and the to-be-detected change was much larger (see *Stimuli*). The first two change trials in the training phase were presented 5 dB above the standard background melody. Subsequent change trials were presented at the intensity of the background unless the infant failed to respond on two successive change trials. In this case, the level of the change trials was increased by 5 dB. Correct responding resulted in lowered intensity of the change trials until the background level was reached. Infants were required to achieve four correct responses in a row at equivalent background and change intensity before proceeding to the test phase.

Results

We transformed the proportion of correct head turns (hits) and the proportion of incorrect turns (false alarms) to d' scores for each infant according to yes–no signal detection tables (Swets, 1964). This transformation serves the dual purpose of controlling for response bias and normalizing the distributions (Thorpe et al., 1988). Because each infant completes only a relatively small number of trials, occasional proportions of 0 or 1 can occur, posing a potential problem (i.e., infinite d' values). Under such conditions, infinite d' values are considered to reflect sampling error rather than statistically infinite d' values (Macmillan & Kaplan, 1985). To circumvent this potential problem, we calculated all proportions by adding ½ to the actual number of turns and dividing by the number of trials plus 1 (i.e., 16). This has little effect on the proportions and maintains the relative ranking of d' scores (see Thorpe et al., 1988). With the d' transformation, chance performance (50% correct) would lead to an expected d' of 0; maximal performance with 30 trials would generate a d' value of 3.76. Infant responding was typically noisy, however, which resulted in d' values considerably below the maximum (e.g., Thorpe & Trehub, 1989; Thorpe et al., 1988; Trainor & Trehub, 1992).

An analysis of variance with triad type (major, augmented) and key relation (related, unrelated) as independent variables revealed a significant main effect of key relation, $F(1, 40) = 11.71, p < .002$ (see Table 2), but no other significant effects or interactions. Percentage correct scores that are based on all 30 trials are plotted in Figure 4.

With related keys, changes to both the major and augmented triads were detected significantly above chance levels, $t(10) = 7.64, p < .0001$, and $t(10) = 3.38, p < .005$, respectively. With unrelated keys, however, changes to the major and augmented triads were detected at chance levels, $t(10) = -0.15$, and $t(10) = 1.10$, respectively. Moreover, 15 of the 21 infants who failed to meet the training criterion or who failed to complete the test session (because of fussing) were in the unrelated-keys condition. Such high attrition rates have been associated with difficult conditions in other infant research (e.g., Trehub et al., 1990). Finally, approximately equal numbers of infants failed the training phase or did not complete the testing phase in the major- and augmented-triad conditions (10 and 11, respectively).

Discussion

Infants' ability to detect subtle changes to transposed melodies was enhanced when the transpositions of these melodies were related by the interval of a perfect fifth. Furthermore, this enhancement occurred for both major and augmented triads. Can we then conclude that the perfect fifth relation conferred processing advantages for infants? An alternative explanation is that infants considered all notes of all transpositions as members of one large set and simply responded to notes outside of this set.

Table 1 shows the overall pitch set of the major triad under transposition to related and unrelated keys. In the case of related keys, three of the five changed notes went outside the set. For unrelated keys, however, none of the three changed notes went outside of this set. Thus, responding on this basis could account for performance with the major-triad melody. By contrast, all of the changed notes of the augmented-triad melody went outside the overall pitch set in the unrelated-keys condition, but none did so in the related-keys condition (see Table 1). As a result, reliance on overall pitch-set cues should have led to superior performance for augmented-triad melodies transposed to unrelated keys, especially because the overall pitch set had only three notes. Nevertheless, in-

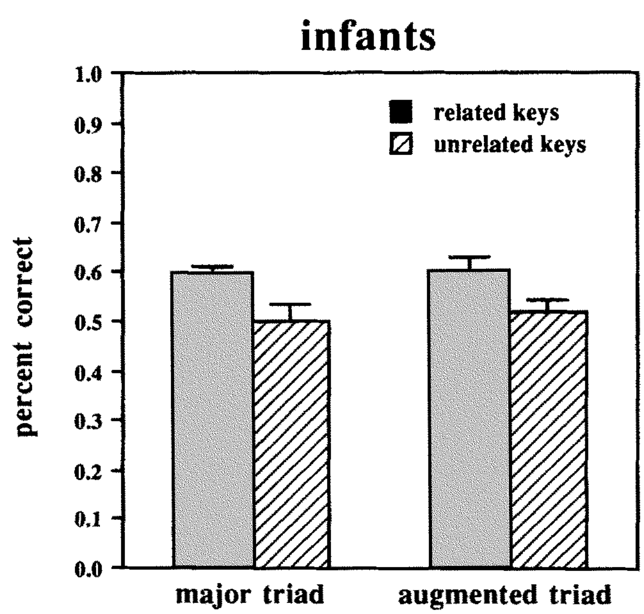


Figure 4. Percentage correct performance for infants. (Error bars indicate the standard error of the mean.)

fants performed better with augmented triads transposed to related keys than to unrelated keys, indicating that they did not capitalize on set membership cues. Rather, they seemed to compare successive presentations of the melody with an internalized standard.

Experiment 2

Although infants seemed to be influenced by key relations between melodies in a manner that was consistent with knowledge of Western musical structure, there was no information about adult performance with the identical stimuli. Accordingly, we evaluated adult nonmusicians for key-distance effects with the same melodies. Other researchers have suggested that adults, unlike the infants of Experiment 1, might be sensitive to pitch-set membership, particularly in the case of unconventionally structured or atypical melodies (Cohen, 1982; Cuddy et al., 1981). To examine this possibility, we added a second condition with unrelated keys to the conditions with related (B♭, F, C, G, D) and unrelated keys (C, E, A♭) from Experiment 1. This second condition consisted of the keys C, E♭, G♭, and A, whose tonics are separated by minor thirds (three semitones). Scales adjacent on this list differ by three scale notes. To make these key relations operate as similarly as possible to the related-keys condition, movement occurred only between keys adjacent on the list (in either direction). In this additional condition, all 12 chromatic pitches were represented in the collection of background melodies, with the result that all changed notes were within the background set (see Table 1). If adults capitalized on pitch-set membership cues, then they would perform better on the augmented-triad melody when the unrelated keys offered pitch-set cues (C, E, A♭) than when the keys offered no such cues.

Method

Subjects. The subjects were 84 university students 18–24 years of age ($M = 19$ years) who were tested individually in one of six conditions (14 in each condition). In each condition, there was no professional musician, and the number of years of formal music lessons varied (overall, 28 had none; 27 had 1–4 years; 22 had 5–10 years; 7 had 10 or more years).

Stimuli. Four of the six conditions were identical to those of Experiment 1: major triad–related keys, major triad–unrelated keys, augmented triad–related keys, and augmented triad–unrelated keys. An additional key relation, unrelated keys II, was included with both the major and augmented triads. Thus there were six conditions: two triad types × three key relations (see Table 1). In unrelated keys II, the melodies were transposed to four different keys, C, E♭, G♭, and A. As before, successive melodies were always in different keys. To make this condition as similar as possible to the related-keys condition, successive melodies were adjacent (in either direction) on the aforementioned list. Thus, successive melodies were always related by a minor third (up or down). As in Experiment 1, listeners had to detect an upward semitone change to the third note of the melodies. In training, the change was much larger, six semitones for the first three training trials and three semitones thereafter.

Apparatus. The apparatus was identical to that of Experiment 1.

Procedure. The procedure was as similar as possible to that of Experiment 1, except for changes to accommodate differences between infants and adults. Thus, adults were told that they were to listen for changes. As in the infant procedure, adults sat in the chair across from the experimenter, who called for trials and recorded responses with the button box connected to the computer. Although adults were instructed to raise a hand rather than turn to indicate that they had heard a change, they were nevertheless rewarded with the animated toys for correct responses.

Results

The preliminary transformation of hits and false alarms to d' scores was performed as in Experiment 1. An analysis of variance with triad type (major, augmented) and key relation (related, unrelated, unrelated II) as independent variables revealed a significant main effect of triad type, $F(1, 78) = 21.56$, $p < .0001$, with major triads easier than augmented triads overall. There was no main effect of key relation, but the interaction between triad type and key relation was significant, $F(2, 78) = 19.93$, $p < .0001$ (see Table 3). We performed separated analyses for each triad type. For the major triad, the effect of key relation was significant, $F(2, 39) = 9.80$, $p < .0004$, and the Student Newman-Keuls test revealed that performance was significantly better in the related-keys condition than in the two unrelated-keys conditions, which did not differ. For the augmented triad, key relation was also significant, $F(2, 78) = 10.56$, $p < .0002$, but in this case the Student Newman-Keuls test revealed performance to be significantly worse for related keys than for the two unrelated keys, which did not differ. Performance significantly exceeded chance levels (d' of 0) in all six conditions. See Figure 5 for percentage correct scores.

We calculated correlations between performance and musical training (number of years of music lessons) for each of

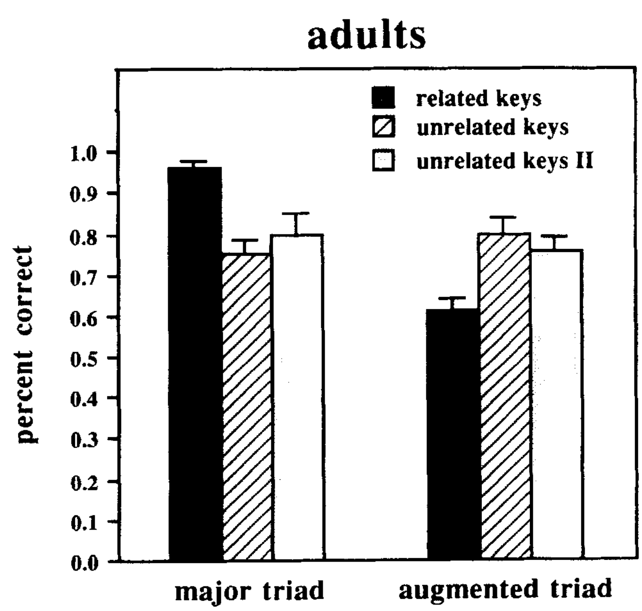


Figure 5. Percentage correct performance for adults. (Error bars indicate the standard error of the mean.)

the six conditions. For the major triad, correlations were significantly above chance for unrelated keys (unrelated keys, $r = .66, p < .02$; unrelated keys II, $r = .56, p < .04$) but not for related keys. None of the correlations was significant for the augmented triad. Thus, performance was high and unaffected by musical training when the major triad was transposed to related keys. In all conditions involving the augmented triad, performance was low and unaffected by musical training. Such training proved helpful only when the major triad was transposed to unrelated keys. In this case, musically trained listeners may have engaged analytical skills specialized for Western musical structures such as the major triad. Such skills may have been unnecessary when the major triad was transposed to related keys (i.e., even untrained listeners performed well) and ineffective with the augmented triad (an unconventional Western structure). It is possible, however, that highly trained musicians would show a pattern of performance different from that of the moderately trained listeners of the present study (see Cohen, Trehub, & Thorpe, 1989).

Discussion

In Experiment 1, key relations had similar effects on major- and augmented-triad melodies, with related keys enhancing infant performance in both cases. For adults, however, related keys enhanced performance on the major triad but impeded performance on the augmented triad. How can this be interpreted?

One possibility is that adults were aware of the overall set of notes from all transpositions of the background or standard melody (see Table 1). As a result, changed notes that went outside the set would be more noticeable than those within the set. This explanation is consistent with the findings for related keys and for the first set of unrelated keys but inconsistent with the findings for the additional set of unrelated keys (unrelated keys II condition; see Table 3). First, consider the findings for related keys and the original set of unrelated keys. For the augmented-triad melody, performance was better in the context of transpositions to unrelated than to related keys. Moreover, all changed notes went outside the global note set for unrelated keys, but none did so for related keys. With the major-triad melody, performance was better in the context of related keys than in the original unrelated keys. Three of the five changed notes went outside the background note set for related keys, but none did so for unrelated keys. Results such as these are consistent with the hypothesized sensitivity to background note set.

Table 3
Adults' d' Scores on Related and Unrelated Keys

Triad	Key relation: Related	Unrelated	Unrelated II
Major			
M	3.34	1.64	2.13
SD	0.72	0.83	1.44
Augmented			
M	0.63	1.97	1.67
SD	0.58	1.08	0.69

Consider, however, the additional condition with unrelated keys (unrelated keys II). For the augmented-triad melody, all changed notes were in the overall background set, but performance was significantly better for unrelated keys than for related keys and not significantly worse than for the original unrelated keys. For the major-triad melody, all changed notes in the unrelated keys II went outside the background note set, but performance was significantly worse for these keys than for the related keys. Moreover, performance on these additional unrelated keys was not significantly better than for the original unrelated keys. The background note set may have had a minor effect in the unrelated-keys conditions (well beyond the detection power of the statistical tests), as reflected in the ordering of performance across conditions (unrelated < unrelated keys II for the major triad; unrelated > unrelated keys II for the augmented triad). Nevertheless, sensitivity to the background note set can be ruled out as the primary explanation of the interaction between triad type and key relation.

With the major-triad melody, adults' performance was consistent with the previously reported finding that brief well-structured melodies are easier to compare in the context of related than in unrelated keys (Cuddy et al., 1979). It is interesting, however, that transpositions to unrelated keys (major triad–unrelated keys, major triad–unrelated keys II, augmented triad–unrelated keys, augmented triad–unrelated keys II) resulted in equivalent performance for melodies that were based on major and augmented triads. Consistent with a previous study (Cuddy et al., 1981), transpositions to related keys resulted in significantly poorer performance on the nonprototypical augmented triad. As noted, however, overlapping pitch information (Cohen, 1982; Cuddy et al., 1981) cannot account for the present findings. One possibility is that the presentation of successive melodies in related keys activated schemata for Western music in Western adult listeners. Such schemata would facilitate performance on the major triad but degrade performance on the augmented triad. By contrast, the presentation of successive melodies in unrelated keys would not prime schemata for Western music, leaving listeners to rely on more basic pattern-processing skills. Following from this speculative interpretation, global context (i.e., key relations) would exert a more powerful effect than local context (i.e., major or augmented triad) in eliciting schemata specialized for the processing of Western music.

Although there is evidence of infants' enhanced processing for some Western musical forms in particular circumstances (Cohen et al., 1987; Trainor, 1991; Trehub et al., 1990), there are indications that infants have not yet developed schemata specialized for the processing of Western music (Lynch et al., 1990; Trainor & Trehub, 1992). The absence of such schemata implies that infants in Experiment 1 would have been unaffected by the degree of conformance of the transposition in question to Western musical structure. Instead, the presence or absence of the perfect fifth relation between successive melodies may have influenced infants' ease of comparing successive melodies.

General Discussion

The experiments in this report provide evidence of global context effects in infant auditory pattern perception. In particular, infants found melodies transposed to related keys (i.e., a perfect fifth apart) easier to compare than the same melodies transposed to unrelated keys (i.e., a major third apart). Furthermore, the global context of musical structure affected local processing in both infants and adults. Listeners' relative ease of detecting a single note change to a major or augmented triad depended on the context in which it was embedded. Different global musical contexts aided or impeded the processing of local interval structure in the same way that different global visual contexts aid or impede the processing of local elements (Pomerantz, 1981; Pomerantz et al., 1977).

Previous research on melodic processing has revealed that infants show superior processing for the perfect fifth interval in comparison to the augmented fifth interval (Cohen et al., 1987; Trainor, 1991). Specifically, infants detect both upward (Cohen et al., 1987; Trainor, 1991) and downward (Trainor, 1991; Trehub et al., 1986) semitone changes to the top note of the major triad. In the case of the augmented triad, however, infants detect upward changes to the top note (Trehub et al., 1986; Trainor, 1991) but not downward changes (Cohen et al., 1987; Trainor, 1991). A downward change to the top note of an augmented triad results in a major triad, whereas an upward change results in a triad clearly different from the major triad. The findings to date are consistent with the notion of privileged perceptual status for the perfect fifth interval. Perhaps small-integer frequency ratios (e.g., 2:3 for the perfect fifth) in auditory patterns function as prototypes, assimilating near instances (e.g., the augmented fifth). In the case of speech, prototypical vowel sounds are known to affect the perception of neighboring sounds both for adult (Samuel, 1982) and for infant (Grieser & Kuhl, 1989; Kuhl, 1991) listeners. Such processes of assimilation, if operative, would facilitate certain discriminations (e.g. upward changes to the augmented triad) and impede others (e.g., downward changes). Unique perceptual features have been documented for the octave interval (Demany & Armand, 1984), which also embodies a small-integer frequency ratio, 1:2.

On the whole, infants and adults exhibited a similar pattern of performance on the major triad. Adults' performance can be interpreted in terms of acquired sensitivity to Western musical structure arising from the frequent occurrence of the major-triad and near-key relations compared with the rarity of the augmented-triad and far-key relations. In the case of infants, however, the inherent good form of the perfect fifth interval may be a more parsimonious interpretation than is the internalization of regularities in Western music.

There were some notable differences between infants and adults. Specifically, adults performed better on the major triad transposed to related than to unrelated keys but worse on the augmented triad transposed to related than to unrelated keys. By contrast, infants performed better on both types of triads in the context of related compared with unrelated keys. These findings are consistent with adults' use of culture-specific schemata when the global context indicates Western music, as is the case with transpositions to related keys. With related keys, one would expect enhanced performance on the major triad, a prototypical form, and degraded performance on the augmented triad, a nonprototypical form. When the global context was unconventional such that transpositions were to unrelated keys, adults performed equally well on the major and augmented triads. Infants' performance, however, was enhanced for both the major and augmented triads when the transpositions of the melodies were related by the perfect fifth. These findings are consistent with an interpretation of natural processing proclivities or biases (i.e., special status for the perfect fifth) that become modified or fine-tuned as knowledge of Western musical structure is acquired.

In our previous work (Trainor & Trehub, 1992), we reported some musical processing differences between infants and adults. We evaluated infants' and adults' ability to detect two types of changes to a conventionally structured Western melody (i.e., one that was based on the major scale). One change violated Western musical rules by going outside the key of the melody. The other conformed to such rules by remaining within the key. Although adults found the out-of-key change highly salient compared with the within-key change, infants performed equivalently on both. Infants' non-differential performance on such structure-conserving and structure-violating changes underlines their lack of knowledge of major scale structure. Further evidence relevant to the issue of culture-specific musical knowledge derives from research on the perception of foreign melodies. Lynch et al. (1990) found that in contrast to Western adults (nonmusicians), who detected mistunings (i.e., subtle pitch changes) to Western melodies more readily than to Javanese melodies, 6-month-old Western infants performed equivalently on both melody types.

The present investigation provides additional evidence that fundamental aspects of human auditory processing underlie some of the prominent features of Western musical structure. Specifically, the centrality of the perfect fifth interval may derive from processing predispositions of the human auditory system. Even if some experience is necessary for consolidating the special status of the perfect fifth interval, this experience appears to be minimal compared with that required for major scale structure (Trainor, 1991) and other culture-specific musical schemata (Lynch et al., 1990). At the very least, then, the perfect fifth interval assumes a central role in musical pattern perception on the basis of very early and effortless learning.

References

Aslin, R. N., & Smith, L. B. (1988). Perceptual development. *Annual Review of Psychology, 39,* 435–473.

Bartlett, J. C., & Dowling, W. J. (1980). Recognition of transposed melodies: A key-distance effect in developmental perspective. *Journal of Experimental Psychology: Human Perception and Performance, 6,* 501–515.

Cohen, A. J. (1982). Exploring the sensitivity to structure in music. *Canadian University Music Review, 3,* 15–30.

Cohen, A. J., Thorpe, L. A., & Trehub, S. E. (1987). Infants' perception of musical relations in short transposed tone sequences. *Canadian Journal of Psychology, 41,* 33–47.

Cohen, A. J., Trehub, S. E., & Thorpe, L. A. (1989). Effects of uncertainty on melodic information processing. *Perception & Psychophysics, 46,* 18–28.

Cooper, F. S., Delattre, P. C., Liberman, A. M., Borst, J. M., & Gerstman, L. J. (1952). Some experiments on the perception of synthetic speech sounds. *Journal of the Acoustical Society of America, 24,* 597–606.

Cuddy, L. L., Cohen, A. J., & Mewhort, D. J. K. (1981). Perception of structure in short melodic sequences. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 869–883.

Cuddy, L. L., Cohen, A. J., & Miller, J. (1979). Melody recognition: The experimental application of musical rules. *Canadian Journal of Psychology, 33,* 148–156.

Delattre, P. C., Liberman, A. M., & Cooper, F. S. (1955). Acoustic loci and transitional cues for consonants. *Journal of the Acoustical Society of America, 27,* 769–773.

Demany, L. (1982). Auditory stream segregation in infancy. *Infant Behavior and Development, 5,* 261–276.

Demany, L., & Armand, F. (1984). The perceptual reality of tone chroma in early infancy. *Journal of the Acoustical Society of America, 76,* 57–66.

Dorman, M. F., & Raphael, L. J. (1980). Distribution of acoustic cues for stop consonant place of articulation in VCV syllables. *Journal of the Acoustical Society of America, 67,* 1333–1335.

Dowling, W. J., & Harwood, D. L. (1986). *Music cognition.* Orlando, FL: Academic Press.

Eilers, R. E., Wilson, W. R., & Moore, J. M. (1977). Developmental changes in speech discrimination in infants. *Journal of Speech and Hearing Research, 20,* 766–780.

Enns, J. T., & Prinzmetal, W. (1984). The role of redundancy in the object-line effect. *Perception & Psychophysics, 35,* 22–32.

Gibson, E. J. (1969). *Principles of perceptual learning and development.* New York: Appleton-Century-Crofts.

Grieser, D. L., & Kuhl, P. K. (1989). Categorization of speech by infants: Support for speech–sound prototypes. *Developmental Psychology, 25,* 577–588.

Hoffman, J. E. (1980). Interaction between global and local levels of a form. *Journal of Experimental Psychology: Human Perception and Performance, 6,* 222–234.

Jones, M. R. (1990). Learning and the development of expectancies: An interactionist approach. *Psychomusicology, 9,* 193–228.

Kemler Nelson, D. G., Hirsh-Pasek, K., Jusczyk, P. W., & Wright Cassidy, K. (1989). How the prosodic cues in motherese might assist language learning. *Journal of Child Language, 16,* 66–68.

Kimchi, R. (1988). Selective attention to global and local levels in the comparison of hierarchical patterns. *Perception & Psychophysics, 43,* 189–198.

Krumhansl, C. L. (1979). The psychological representation of musical pitch in a tonal context. *Cognitive Psychology, 11,* 346–374.

Krumhansl, C. L. (1990). *Cognitive foundations of musical pitch.* New York: Oxford University Press.

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 keys. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 24–36.

Krumhansl, C. L., & Jusczyk, P. W. (1990). Infants' perception of phrase structure in music. *Psychological Science, 1,* 70–73.

Kuhl, P. K. (1985). Methods in the study of infant speech perception. In G. Gottlieb & N. A. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life: A methodological overview* (pp. 223–251). Norwood, NJ: Ablex.

Kuhl, P. K. (1991). Human adults and human infants show a "perceptual magnet effect" for the prototypes of speech categories, monkeys do not. *Perception & Psychophysics, 50,* 93–107.

Lasaga, M. I., & Hecht, H. (1991). Integration of local features as a function of global goodness and spacing. *Perception & Psychophysics, 49,* 201–211.

Lynch, M. P., Eilers, R. E., Oller, D. K., & Urbano, R. C. (1990). Innateness, experience, and music perception. *Psychological Science, 1,* 272–276.

Macmillan, N. A., & Kaplan, H. L. (1985). Detection theory analysis of group data: Estimating sensitivity from average hit and false-alarm rates. *Psychological Bulletin, 98,* 185–199.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature, 264,* 746–748.

Morrongiello, B. A. (1984). Auditory temporal pattern perception in 6– and 12–month-old infants. *Developmental Psychology, 20,* 441–448.

Morrongiello, B. A. (1986). Infants' perception of multiple-group auditory patterns. *Infant Behavior and Development, 9,* 307–319.

Morrongiello, B. A. (1988). The development of auditory pattern perception skills. In C. Rovee-Collier (Ed.), *Advances in infancy research* (Vol. 5, pp. 135–172). Norwood, NJ: Ablex.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9,* 353–383.

Navon, D. (1983). How many trees does it take to make a forest? *Perception, 12,* 239–254.

Navon, D. (1991). Testing a queue hypothesis for the processing of global and local information. *Journal of Experimental Psychology: General, 120,* 173–189.

Peretz, I. (1990). Processing of local and global musical information by unilateral brain-damaged patients. *Brain, 113,* 1185–1205.

Pick, A. D., Palmer, C. F., Hennessy, B. L., Unze, M. G., Jones, R. K., & Richardson, R. M. (1988). Children's perception of certain musical properties: Scale and contour. *Journal of Experimental Child Psychology, 45,* 28–51.

Pomerantz, J. R. (1981). Perceptual organization in information processing. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 141–180). Hillsdale, NJ: Erlbaum.

Pomerantz, J. R. (1983). Global and local precedence: Selective attention in form and motion perception. *Journal of Experimental Psychology: General, 112,* 516–540.

Pomerantz, J. R., & Sager, L. C. (1975). Asymmetric integrality with dimensions of visual pattern. *Perception & Psychophysics, 18,* 460–466.

Pomerantz, J. R., Sager, L. C., & Stoever, R. J. (1977). Perception of wholes and of their component parts: Some configural superiority effects. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 422–435.

Roberts, L. A. (1982). *Perceived structure of four elementary chords: The effects of musical training, key, and inversions.* Unpublished master's thesis, Rutgers University, New Brunswick, NJ.

Samuel, A. G. (1982). Phonetic prototypes. *Perception & Psychophysics, 31,* 307–314.

Sloboda, J. A. (1985). *The musical mind: The cognitive psychology of music.* Oxford: Clarendon Press.

Sloboda, J. A., & Edworthy, J. (1981). Attending to two melodies at once: The effect of key relatedness. *Psychology of Music, 9,* 39–43.

Swets, J. A. (1964). *Signal detection and recognition by human observers.* New York: Wiley.

Takeuchi, A. H., & Hulse, S. H. (1992). Key-distance effects in melody recognition re-examined. *Music Perception, 10,* 1–24.

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.

Thorpe, L. A., & Trehub, S. E. (1989). Duration illusion and auditory grouping in infancy. *Developmental Psychology, 25,* 122–127.

Thorpe, L. A., Trehub, S. E., Morrongiello, B. A., & Bull, D. (1988). Perceptual grouping by infants and preschool children. *Developmental Psychology, 24,* 484–491.

Trainor, L. J. (1991). *The origins of musical pattern perception: A comparison of infants' and adults' processing of melody.* Unpublished doctoral dissertation, University of Toronto, Toronto, Ontario, Canada.

Trainor, L. J., & Trehub, S. E. (1992). A comparison of infants' and adults' sensitivity to Western musical structure. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 394–402.

Trehub, S. E., Bull, D., & Thorpe, L. A. (1984). Infants' perception of melodies: The role of melodic contour. *Child Development, 55,* 821–830.

Trehub, S. E., Cohen, A. J., Thorpe, L. A., & Morrongiello, B. A. (1986). Development of the perception of musical relations: Semitone and diatonic structure. *Journal of Experimental Psychology: Human Perception and Performance, 12,* 295–301.

Trehub, S. E., Thorpe, L. A., & Morrongiello, B. A. (1987). Organizational processes in infants' perception of auditory patterns. *Child Development, 8,* 213–223.

Trehub, S. E., Thorpe, L. A., & Trainor, L. J. (1990). Infants' perception of good and bad melodies. *Psychomusicology, 9,* 5–15.

Trehub, S. E., & Trainor, L. J. (1990). Rules for listening in infancy. In J. Enns (Ed.), *The development of attention: Research and theory* (pp. 87–119). Amsterdam: Elsevier.

Trehub, S. E., & Trainor, L. J. (1993). Listening strategies in infancy: The roots of language and musical development. In S. McAdams & E. Bigand (Eds.), *Thinking in sound: The cognitive psychology of human audition* (pp. 278–327). London: Oxford University Press.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97–136.

Treisman, A. M., & Paterson, R. (1984). Emergent features, attention, and object perception. *Journal of Experimental Psychology: Human Perception and Performance, 10,* 12–31.

Weisstein, N., & Harris, C. S. (1974). Visual detection of line segments: An object-superiority effect. *Science, 186,* 752–754.

Williams, A., & Weisstein, N. (1978). Line segments are perceived better in a coherent context than alone: An object-line effect in visual perception. *Memory & Cognition, 6,* 85–90.

Received December 19, 1991
Revision received August 27, 1992
Accepted August 27, 1992 ■