Developmental Psychology
1996, Vol. 32, No. 6, 1039-1050

0012-1649/96/$3.00

Children's Discrimination of Melodic Intervals

E. Glenn Schellenberg
University of Windsor

Sandra E. Trehub
University of Toronto

Adults and 6-year-old children were tested on their discrimination of pure-tone sequences as a function of the simplicity of the frequency ratios between tones in the sequences. Listeners were required to detect either changes from intervals (combinations of 2 tones) with simple frequency ratios to those with more complex ratios or changes from intervals with complex frequency ratios to those with simpler ratios. In Experiment 1, adults performed better on changes from simple ratios (2:1, 3:2, or 4:3) to more complex ratios (15:8, 32:15, or 45:32) than on the reverse changes. In Experiment 2, 6-year-olds who had never taken music lessons exhibited a similar pattern of performance. The observed asymmetries in performance imply that intervals with simple frequency ratios are naturally more coherent than are those with more complex ratios.

The diversity of musical styles across cultures and even within a culture implies that knowledge of particular styles of music is largely acquired through exposure. Indeed, music from foreign (non-Western) cultures often sounds strange and sometimes unpleasant to listeners who have only been exposed to Western musical structures. This situation does not preclude the possibility that some structural properties are shared by most if not all musical styles, or that some aspects of musical understanding are biologically based (Blacking, 1992). In the present article, we consider whether some aspects of Western music processing appear spontaneously and relatively early in development because they are based on inherent good form (Garner, 1974; Trehub & Unyk, 1991) or coherence (Bharucha & Pryor, 1986). Such processing strategies if evident would likely be reflected in structural regularities across musical cultures.

It is possible that some combinations of tones may simply be more coherent, perhaps even more pleasing (i.e., consonant), than others. We use *coherence* to refer to the ease with which a group of tones combine to form a single, potentially recognizable, percept (Bharucha & Pryor, 1986). Combinations of two tones (i.e., pairs of tones) are known as *intervals,* either *melodic,* consisting of two successive tones, or *harmonic,* consisting of two simultaneous tones. An interval is generally characterized by the pitch distance between its component tones (e.g., number of semitones) or by its *frequency ratio,* which relates the frequency of one component tone to that of the other. For example, tones of 200 Hz and 100 Hz have a frequency ratio of 2:1 (i.e., 12 semitones or an octave). Because musical pitch is perceived relationally (Attneave & Olson, 1971), the interval between tones of 300 Hz and 150 Hz is perceptually equivalent to that between tones of 200 and 100 Hz, both having a frequency ratio of 2:1. It follows that musical tunes maintain their invariance over changes in their initial tone provided the intervals (frequency ratios or numbers of semitones) between tones remain constant. When listening to music, then, each tone is perceived in relation to previously heard tones.

In comparison with speech, the relational and nonreferential nature of music perception generates greater demands on working memory. The limits of working memory likely account for the use of scales (a finite set of tones or pitches in music) and the occurrence of five to seven different tones per octave (Dowling & Harwood, 1986; Handel, 1989). The Western major scale, for example, comprises seven tones: *do, re, mi, fa, sol, la,* and *ti.* One consequence of the use of a scale is a small set of possible intervals among its component tones. Other biological influences on the structure of scales could favor some intervals over others, contributing to "a base of innate abilities and tendencies" (Sloboda, 1985, p. 194) from which music perception and performance abilities develop. Indeed, beginning with Pythagoras (Winnington-Ingram, 1980), numerous theorists have considered intervals with simple (i.e., small integer) ratios such as 2:1 and 3:2 to be more natural and consonant than other intervals (e.g., Bernstein, 1976; Kolinski, 1967; Roederer, 1979). These theorists have also considered scales whose intervals form simple frequency ratios to be more natural than other scales (see Burns & Ward, 1982).

Simple frequency ratios could be relatively coherent because of their presence in naturally occurring sounds (Terhardt, 1974, 1978, 1984). Most sounds in our environment, including those of speech and music, consist of several simultaneous pure tones (sine waves). For example, the sound produced by a single key on a piano is a multitone complex consisting of a number of simultaneous pure tones, the frequency of each being an integer multiple of the lowest component (or fundamental frequency). Thus, the lowest component of the note A (below middle C) is 220 Hz; successive components (harmonics or overtones) have frequencies of 440 Hz (two times 220 Hz), 660 Hz (three times 220 Hz), 880 Hz (four times 220 Hz), and so on. Accordingly, intervals between the simultaneous components of such complex tones have simple frequency ratios (2:1 between 440 Hz

---

This research was supported by the Natural Sciences and Engineering Research Council of Canada, and by a Grant-in-Aid of Research from Sigma Xi, The Scientific Research Society.

Correspondence concerning this article should be addressed to E. Glenn Schellenberg, Department of Psychology, University of Windsor, Windsor, Ontario, Canada N9B 3P4, or to Sandra E. Trehub, University of Toronto, Erindale Campus, Mississauga, Ontario, Canada L5L 1C6. Electronic mail may be sent to E. Glenn Schellenberg via Internet to schelle@uwindsor.ca.

and 220 Hz, 3:2 between 660 Hz and 440 Hz, 4:3 between 880 Hz and 660 Hz, etc.). A comparable situation prevails for speech sounds.

Until recently, the notion that intervals with simple frequency ratios have special perceptual status (e.g., Jones, 1990) has received little empirical support. When adult listeners make aesthetic judgments about simultaneous tones (harmonic intervals), they give more favorable ratings to intervals with simple frequency ratios than to those with complex ratios, provided the tones of the intervals in question are natural-sounding complexes (i.e., each with multiple components), such as those produced by musical instruments (J. W. Butler & Daston, 1968; Malmberg, 1918; Vos, 1986). These effects are negligible with pure tones, or tones with a single component frequency. Instead, ratings of harmonic pure-tone intervals vary primarily as a function of the frequency distance (rather than frequency ratio) between component tones (Kameoka & Kuriyagawa, 1969; Plomp & Levelt, 1965). Studies of melodic intervals (sequential tones) have generally failed to reveal effects of frequency ratios (Burns & Ward, 1978; Houtsma, 1968; Kallman, 1982), leading contemporary psychologists (Burns & Ward, 1982; Dowling & Harwood, 1986; Serafine, 1983) to dispute earlier claims that musical intervals with simple ratios are perceptually privileged.

Nevertheless, Schellenberg and Trehub (1994a) had adults listen to a standard tone sequence presented repeatedly in transposition (different absolute frequencies but same frequency ratios between tones) and asked them to indicate when the pattern changed (different absolute frequencies and different frequency ratios). Performance improved with increasing ratio simplicity of the standard pattern and with decreasing ratio simplicity of the comparison pattern. The investigators argued that sequential pure-tone intervals with simple as opposed to complex frequency ratios are more readily processed by listeners and, consequently, more likely to result in a stable perceptual representation. This situation could generate performance asymmetries such that alterations to simple-ratio intervals would be more noticeable than comparable alterations to complex-ratio intervals. Moreover, a reanalysis of interval perception data from several laboratories (Schellenberg & Trehub, 1994b) led the authors to conclude that the relative simplicity of frequency ratios provided the most parsimonious account of the available data.

Because adults are the usual participants in studies of interval perception, their performance may reflect their many years of informal exposure to Western scale structure and harmony in which simple frequency ratios predominate. Thus, these findings are essentially irrelevant to the issue of natural intervals. Adult listeners may simply generalize implicit knowledge gained from musical contexts (with multitone complexes) to nonmusical contexts such as those with pure tones. Accordingly, less experienced listeners, notably children, could potentially shed more light on the question of whether simple-ratio intervals are inherently good or special.

First-grade children are known to perform well below adult levels on musical processing tasks, which suggests that they have not internalized all of the musical conventions of our culture (see Hargreaves, 1986; Morrongiello, 1992). Research on children's aesthetic judgments of simultaneous piano tones has indicated that only by 12 or 13 years of age do children show adultlike judgments of intervals—essentially favorable for intervals with relatively simple frequency ratios and unfavorable for intervals with more complex ratios (Valentine, 1913). Children with musical training show comparable response patterns a few years earlier. Other research with children has focused on knowledge of Western scales, in which simple-ratio intervals are structurally significant. When children are required to judge whether tone sequences are correct or not, the performance of 9- and 11-year-olds (but not 5-year-olds) is affected by whether the tone sequences conform to Western scale structure, but to a lesser extent than is the case for adults (Sloboda, 1985).

Although perceptual processing in adults is clearly more efficient for tone sequences that conform to Western scale structure than for those that deviate from such structure (e.g., Cuddy, Cohen, & Miller, 1979; Dowling, 1991; Dowling, Kwak, & Andrews, 1995), these factors seem to be of little relevance until listeners are well beyond 6 years of age. For example, Morrongiello and Roes (1990) asked musically trained and untrained 5- and 9-year-olds to match line drawings to the pitch movement (upward and downward) of tone sequences. Whether or not the sequences adhered to Western scale structure was irrelevant to the performance of all children except the musically trained 9-year-olds. Lynch and Eilers (1991) evaluated 10- to 13-year-old children on their ability to detect subtle pitch changes in melodies (tone sequences) derived from structurally familiar (Western) or unfamiliar (Javanese) scales. Familiarity was irrelevant to the performance of musically untrained children. Only the trained children showed an advantage for Western sequences, as did adult nonmusicians (Lynch, Eilers, Oller, & Urbano, 1990). In short, the aforementioned studies indicate that 6-year-old children would be unlikely to show processing advantages for some tone sequences solely on the basis of the cultural familiarity of such sequences (see also Andrews & Dowling, 1991; Krumhansl & Keil, 1982).

Aside from the abilities that show substantial age-related changes, other skills may appear early in ontogeny and remain relatively invariant; the latter would be likely candidates for natural contributions to Western scales. In the present investigation, we evaluated young children's ability to discriminate pure-tone sequences as a function of the simplicity of their frequency ratios. If musically untrained 6-year-old children exhibit performance asymmetries based on ratio simplicity as adults do (Schellenberg & Trehub, 1994a), then extended exposure to Western music is unlikely to be the principal explanatory factor. The age of 6 years ensured that, compared with adults, children were considerably less exposed to Western music but had sufficient cognitive skill for an adultlike task. On the one hand, differences in performance if evident would not be unequivocally attributable to natural as opposed to cultural factors. On the other hand, simple frequency ratios such as 2:1 (octave), 3:2 (perfect fifth), and 4:3 (perfect fourth) seem to be prevalent cross-culturally (e.g., Meyer, 1956; Trehub, Schellenberg, & Hill, in press), raising the possibility that humans have a predisposition for perceptual processing of such ratios. In any case, we attempted to minimize potential influences of implicit musical knowledge (i.e., culture) by assessing discrimination in relatively nonmusical contexts. Specifically, each sequence contained only two different tones and therefore a single interval (i.e., single frequency ratio). Moreover, the sequences

Table 1
Interval Size (Semitones), Interval Name, and Justly Tuned Frequency Ratio for Intervals from 0 to 16 Semitones

Semitones	Interval	Frequency ratio
0	Unison	1:1
1	Minor 2nd	16:15
2	Major 2nd	9:8
3	Minor 3rd	6:5
4	Major 3rd	5:4
5	Perfect 4th	4:3
6	Tritone	45:32
7	Perfect 5th	3:2
8	Minor 6th	8:5
9	Major 6th	5:3
10	Minor 7th	16:9
11	Major 7th	15:8
12	Octave	2:1
13	Minor 9th	32:15
14	Major 9th	9:4
15	Minor 10th	12:5
16	Major 10th	5:2

consisted of pure tones (rather than more familiar tone complexes) that were sufficiently distant in pitch to preclude possible cues arising from interference between tones or overtones that are proximate in pitch (i.e., no possibility of overlapping critical bands; see Plomp & Levelt, 1965). Tones on each trial were selected so that they would not unambiguously indicate a particular musical scale. Similarly, conventional transpositions between standard and comparison patterns were also avoided. In short, we expected the use of pure tones in relatively unmusical contexts with musically unsophisticated listeners to minimize the effects of learned musical relations (see Shepard, 1982).

The underlying rationale was as follows: If some sequences are more naturally coherent (i.e., inherently easier to recognize as a unit) than others, then discrimination performance should be asymmetric, with listeners more readily detecting changes from a coherent sequence to an incoherent sequence than the reverse changes (see Bharucha & Pryor, 1986). In other words, the most coherent intervals should be most distinct from other intervals just as the best instances of red (the reddest red) or other natural prototypes (Rosch, 1973, 1975b) would be most distinct from any instances of orange or blue. In fact, a number of investigators have demonstrated adults' greater ease of detecting alterations to coherent patterns than to relatively incoherent or anomalous patterns (e.g., Bharucha, Olney, & Schnurr, 1985; Bharucha & Pryor, 1986; Cuddy et al., 1979; Dowling, 1978, 1991; Dowling et al., 1995; Schellenberg & Trehub, 1994a). Our prediction, then, was that the presence of a standard tone pattern with a simple frequency ratio would facilitate discrimination of a comparison pattern with a complex frequency ratio, but that a complex-ratio standard would impede such discrimination.

The octave (12 semitones) and the tritone (6 semitones) are ideal for evaluating interval discrimination as a function of the simplicity of frequency ratios (see Table 1 for a listing of intervals from the unison, or 0 semitones, to the major tenth, or 16 semitones, with their exact frequency ratios). The octave (frequency ratio of 2:1) has the simplest possible frequency ratio other than that of a unison (1:1); intervals 1 semitone smaller (major seventh: 11 semitones, frequency ratio of 15:8) and 1 semitone larger (minor ninth: 13 semitones, frequency ratio of 32:15) have relatively complex ratios. By contrast, the tritone (frequency ratio of 45:32) has a relatively complex ratio; intervals 1 semitone smaller (perfect fourth: 5 semitones, frequency ratio of 4:3) and 1 semitone larger (perfect fifth: 7 semitones, frequency ratio of 3:2) have simple ratios. Accordingly, we contrasted octaves with major sevenths and minor ninths, and tritones with perfect fifths and fourths. Narmour (1990, 1992) considered both the octave and the tritone to be inherently distinctive intervals. Such distinctiveness could conceivably result from the marked contrast in the simplicity or complexity of their frequency ratios relative to similarly sized intervals. Octaves are also unique in another sense; when two complex tones are an octave apart, all of the overtones of the higher tone are also overtones of the lower tone. By contrast, two complex tones separated by the interval of a tritone—an interval considered to be the "devil in music" in the Middle Ages (Seay, 1975)—have no audible overtones (Plomp, 1964) that are identical.

Experiment 1

The purpose of the present experiment was to replicate earlier adult findings (Schellenberg & Trehub, 1994a) and extend them to different intervals using a method that could be adapted for children. Adults' ability to detect changes in pure-tone sequences was investigated in eight test conditions that examined the influence of the following three variables: (a) Interval size (small = 5–7 semitones, large = 11–13 semitones), (b) frequency-ratio differences (from a simple ratio to a complex ratio or vice versa), and (c) whether the change to be detected represented an increase or a decrease in interval size. If intervals with simple frequency ratios are more coherent for listeners than intervals with more complex ratios, then listeners should more readily detect changes from simple-ratio standard patterns to complex-ratio comparison patterns than the reverse changes, regardless of whether the intervals are small or large or whether the changes result in an increase or a decrease in interval size.

Method

Participants. Participants were 64 college students who had a moderate amount of musical training: 49 had less than 5 years of music lessons (M = 1.2 years), and 15 had 5 or more years of lessons (M = 6.6 years). Two additional students were tested but subsequently excluded from the final sample for failing to meet the training criterion (n = 1) or for failing to follow instructions (n = 1).

Apparatus. Participants were tested in a double-walled, sound-attenuating booth (Industrial Acoustics, Lodi, NJ). Stimuli were generated by two synthesizer-function generators (Hewlett-Packard 3325A), attenuated by two attenuators (ANL-919 and ANL-913; Med Associates, Lafayette, IN), turned on and off by two rise-fall switches (Med Associates), and presented with a stereo amplifier (Marantz 1070) and loudspeaker (Avant 2AX). Stimulus presentation and response recording were controlled by a personal computer (ECS) and custom interface. Participants used a touch-sensitive control device to initiate trials and to record responses. Toys housed in a Plexiglas box were automatically illuminated as feedback for correct responses.

Stimuli. Tone patterns consisted of two alternating pure tones arranged in a five-tone sequence. The first, third, and fifth tones were identical and lower in pitch than the second and fourth tones, which were also identical. Thus, patterns had a rise-fall-rise-fall contour. The crucial frequency ratio for each pattern was that between the high and low tones. Ratios were tuned with just intonation. Tones were contiguous, each 400 ms in duration (total of 2 s per pattern), with 10-ms linear onset and offset ramps.

Each trial consisted of the presentation of two five-tone patterns separated by a 1200-ms silent interval. The second pattern was always transposed (shifted in pitch relative to the first pattern) upward or downward by two semitones (an increase or decrease in frequency of approximately 12%) to preclude the use of absolute pitch cues. On *same* trials, the second pattern maintained the relation (frequency ratio) between tones. On *different* trials, the high tone of the second pattern was displaced one semitone upward or downward from an exact transposition, forming an interval between high and low tones that was smaller or larger than that of the first pattern, with a different frequency ratio. For conditions involving small intervals, the low tone of the first pattern was randomly selected from a set of six tones, consisting of 294 Hz (D above middle C, or D_4; the subscript denotes the octave from which a tone is drawn) and tones 2, 4, 6, 8, or 10 semitones higher (E_4, $F^{\#}_4$, $G^{\#}_4$, $A^{\#}_4$, or C_5, respectively). For large intervals, the low tone of the first pattern was randomly selected from a set of four tones (D_4, E_4, $F^{\#}_4$, and $G^{\#}_4$).

There were eight test conditions in a 2 × 2 × 2 factorial design (see Table 2). Conditions 1 to 4 involved small intervals (5–7 semitones); Conditions 5 to 8 involved large intervals (11–13 semitones). Four conditions (1, 3, 5, and 7) tested listeners' ability to detect a change from a simple frequency ratio to a complex one; the other four conditions (2, 4, 6, and 8) involved a change from a complex to a simple ratio. In four conditions (1, 4, 5, and 8), the change represented a decrease in interval size; in the remaining four conditions (2, 3, 6, and 7), the change represented an increase in size. Because each adult listener was tested twice, a fourth variable—testing order—was also considered in the analyses.

In the first small-interval condition, Condition 1, the interval separating the low and high tones of the first pattern had a simple frequency ratio of 3:2 (a perfect fifth, 7 semitones). On same trials, the second pattern had the same simple frequency ratio; on different trials, the interval between low and high tones of the second pattern had a complex ratio, 45:32 (a tritone), and was smaller in size (6 semitones). Examples of same and different trials from Condition 1 are illustrated in Figure 1. In Condition 2, the situation was essentially reversed. The first pattern always had a complex ratio (45:32), whereas the second pattern had the same complex ratio on same trials but was larger and had a simple ratio (3:2) on different trials. In Condition 3, the interval between low and high tones of the first pattern had a simple frequency ratio, 4:3 (a perfect fourth, 5 semitones). On same trials, the second pattern had the same simple ratio; on different trials, the interval between low and high tones had a complex ratio (45:32) and was larger in size (6 semitones). In Condition 4, the situation was reversed. The first pattern always had a complex ratio (45:32), whereas the second pattern had the same complex ratio on same trials but was smaller and had a simple ratio (4:3) on different trials. The magnitude of the increase or decrease in interval size on different trials was identical (i.e., 1 semitone) for all four small-interval conditions.

The remaining four test conditions involved large intervals. In Condition 5, the low and high tones of the first pattern were an octave (12 semitones) apart, with the simple frequency ratio of 2:1. On same trials, the second pattern also had a 2:1 ratio. On different trials, the interval between low and high tones of the second pattern was smaller (11 semitones) and had a complex ratio of 15:8 (a major seventh). In Condition 6, the situation was reversed. The first pattern always had a complex ratio of 15:8, whereas the second pattern had an identical complex ratio on same trials but was larger and had a simple ratio of 2:1 on different trials. Condition 7 was identical to Condition 5 except that on different trials the interval between low and high tones of the second pattern increased in size (13 semitones) and had a complex ratio of 32:15 (a minor ninth). In Condition 8, the first pattern always had a complex ratio of 32:15; the second pattern had the same complex ratio on same trials but was smaller and had a simple ratio of 2:1 on different trials. As was the case for small intervals, the magnitude of the increase or decrease in interval size on different trials was the same (i.e., 1 semitone) in all four large-interval conditions.

Each condition began with a training phase in which same trials were identical to those of the test phase, but changes on different trials were substantially greater than those on test trials. Specifically, the high tones of the second pattern were shifted downward by one or two octaves so that the melodic contour of the pattern changed from rise-fall-rise-fall to fall-rise-fall-rise. The training phase was designed to familiarize participants with changes that warranted responding. These changes were not exact transpositions (changes in absolute pitch) but only interval changes (changes in the frequency relations among component tones).

Procedure. There were 16 participants randomly assigned to each of four pairs of conditions (Conditions 1 and 2, 3 and 4, 5 and 6, or 7 and 8). Each pair included one condition in which the change to be

Table 2
Testing Conditions as a Function of Interval Size (Semitones), Frequency Ratio, and Change in Size

	Standard pattern			Comparison pattern			
Condition	Size	Frequency ratio		Size	Frequency ratio		Change
Small intervals							
1	7	Simple	3:2	6	Complex	45:32	Decrease
2	6	Complex	45:32	7	Simple	3:2	Increase
3	5	Simple	4:3	6	Complex	45:32	Increase
4	6	Complex	45:32	5	Simple	4:3	Decrease
Large intervals							
5	12	Simple	2:1	11	Complex	15:8	Decrease
6	11	Complex	15:8	12	Simple	2:1	Increase
7	12	Simple	2:1	13	Complex	32:15	Increase
8	13	Complex	32:15	12	Simple	2:1	Decrease

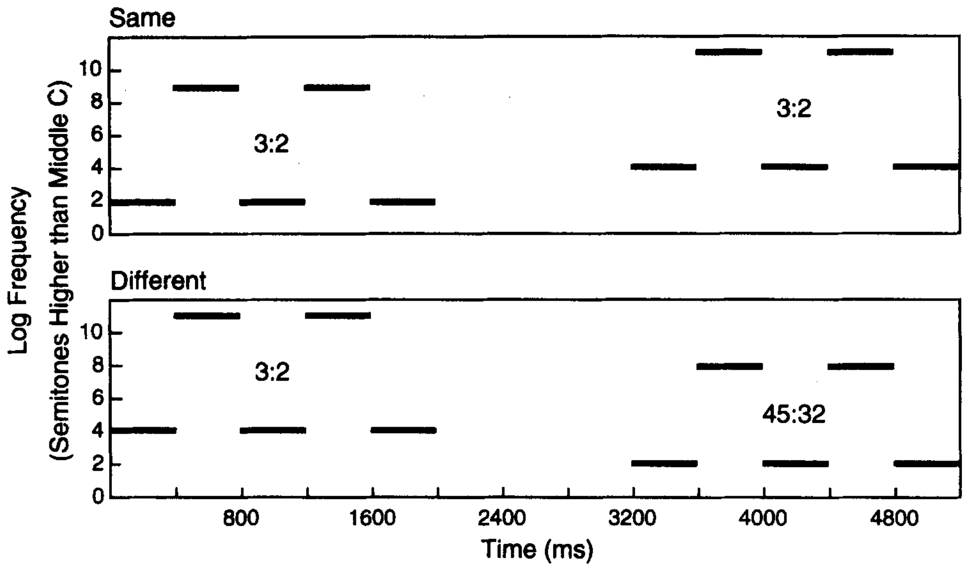

Figure 1. Two sample trials from Condition 1, Experiment 1. In the same trial (above), the second pattern is the same as the first but is transposed upward. In the different trial (below), the second pattern incorporates an interval change and is presented at a lower pitch level. In this condition, the intervals are small, and the change to be detected is from a simple frequency ratio to a complex ratio and represents a decrease in interval size.

detected was from a simple-ratio to a complex-ratio interval, and another condition where the change was from complex to simple. The two conditions in each pair had the same simple and complex frequency ratios but with their role (as standard or comparison pattern) reversed. Each participant was tested with small intervals only (Conditions 1 and 2 or Conditions 3 and 4) or with large intervals only (Conditions 5 and 6 or Conditions 7 and 8). For half of the participants, the simple-ratio interval was larger than the complex-ratio interval (i.e., Conditions 1 and 2, Conditions 5 and 6). For the other half, the simple-ratio interval was smaller than the complex-ratio interval (i.e., Conditions 3 and 4, Conditions 7 and 8). For each pair of conditions, the order of presentation was counterbalanced.

Each condition had 80 trials, with 40 same and 40 different. Same and different trials were randomly ordered, with the constraint of no more than two consecutive same trials. The direction of transposition (upward or downward) was also randomly determined, constrained by equal numbers for each direction and counterbalancing across type of trial (same or different). The trials were self-paced; listeners called for trials and recorded their responses ("same" or "different") with the touch-sensitive control device. Correct responses (in the training or test phase) resulted in the illumination of a toy for 1 s.

The experimenter initially demonstrated the concept of a musical transposition by playing "Happy Birthday" in two different keys on a small keyboard. Listeners were told that their task was to judge whether the second pattern was the same as (i.e., an exact transposition) or different from the first pattern. Each condition began with a training phase that was identical to the subsequent test phase except that different trials contained a more substantial change (i.e., a change in contour). After two demonstration trials (a same trial followed by a different trial), listeners were required to respond independently. To proceed to the test phase, listeners had to achieve a training criterion of 4 consecutive correct responses within a maximum of 20 trials. On average, participants reached this criterion in approximately five trials ($M = 5.3$), at which time the training phase was terminated. Participants were told that the subsequent test phase would be identical to the training phase except that the changes would be smaller. The experimenter then left the booth for the first half of the test phase (i.e., first condition tested). After completing the first condition, listeners answered a questionnaire about their musical background and then were tested in the second condition. The second condition was identical to the first except that the role of standard and comparison interval was reversed. The entire test session took approximately 50 min.

Design. Because each participant was tested in two conditions, the design was a mixed model. The within-subjects variable was the frequency ratio manipulation (simple-to-complex [Conditions 1, 3, 5, and 7] vs. complex-to-simple [Conditions 2, 4, 6, and 8]). The between-subjects variables were interval size (small interval pairs [Conditions 1 and 2, Conditions 3 and 4] vs. large interval pairs [Conditions 5 and 6, Conditions 7 and 8]), testing order (simple-ratio condition tested first vs. complex-ratio condition tested first), and the type of condition pair (simple ratio larger than complex ratio [Conditions 1 and 2, Conditions 5 and 6] vs. simple ratio smaller than complex ratio [Conditions 3 and 4, Conditions 7 and 8]). In this design, the test of interaction between frequency ratio and type of condition is the test for performance differences due to increases or decreases in interval size.

Results and Discussion

Performance levels and confidence intervals for each testing condition (raw data) are shown in Table 3. To control for potential response bias on the part of listeners (i.e., a tendency to respond "same" or "different" regardless of trial type), proportions of hits (i.e., correct identification of different trials) and false alarms (i.e., responding "different" on same trials) were transformed to a discrimination score (d') for each listener in each testing condition using yes–no tables of signal detection theory (Elliott, 1964). To avoid the possibility of infinite d' scores (resulting from proportions of 0 or 1), proportions were adjusted by adding .5 to the number of hits or false alarms and

Table 3
Mean Discrimination Performance (Raw Data) in Experiments 1 (Adults) and 2 (Children)

	Adults		Children	
Condition	Proportion correct (%)	Confidence interval (95%)	Proportion correct (%)	Confidence interval (95%)
1	62.0	54.7–69.2	61.8	53.0–70.8
2	51.4	47.8–55.0	57.6	47.3–68.0
3	62.5	57.5–67.4	71.9	60.3–83.5
4	48.6	45.7–51.5	52.1	45.3–58.8
5	64.9	58.7–74.0	59.7	50.4–69.1
6	49.8	44.4–55.1	50.4	44.7–56.1
7	72.1	65.1–79.1	67.0	55.5–78.5
8	47.2	43.4–51.0	45.8	39.8–51.9

Note. Performance at chance levels is 50% correct.

dividing by the number of trials plus 1 (i.e., 41; see Thorpe, Trehub, Morrongiello, & Bull, 1988). Analyses were conducted using the *d'* scores. Preliminary analyses involved separate comparisons of performance with chance levels ($d' = 0$, or 50% correct) for each condition. Performance was significantly better than chance in the four conditions in which the change was from a simple to a complex ratio—Condition 1, $t(15) = 3.15$, $p < .01$; Condition 3, $t(15) = 5.04$, $p < .0005$; Condition 5, $t(15) = 3.02$, $p < .01$; and Condition 7, $t(15) = 6.04$, $p < .0001$—but at chance levels when the change was from a complex to a simple ratio.

The main analysis examined differences in discrimination performance across conditions with a repeated-measures analysis of variance (ANOVA) that included one within-subjects variable (frequency ratio: simple-to-complex vs. complex-to-simple) and three between-subjects variables: (a) interval size (small vs. large), (b) testing order (simple condition first vs. complex condition first), and (c) type of condition pair (simple ratio smaller than complex ratio vs. complex ratio smaller than simple ratio). There was a significant main effect of frequency ratio, $F(1, 56) = 50.45$, $p < .0001$, indicating that listeners were better at detecting changes from simple to complex ratios than from complex to simple ratios. All other main effects and interactions were nonsignificant. Mean *d'* scores as a function of the frequency ratio manipulation are shown in Figure 2.

Thus, performance did not depend on whether the change produced an increase or decrease in interval size or whether a particular condition was tested first or second. Moreover, overall performance did not differ across the condition pairs, indicating that the processing advantage for octaves over major sevenths or minor ninths was no different than the advantage for perfect fifths or fourths over tritones. These results replicate previous findings of superior discrimination of changes from simple to complex ratios than from complex to simple ratios (Schellenberg & Trehub, 1994a) and extend those findings by indicating that the performance asymmetry is not limited to small intervals (perfect fourths, tritones, perfect fifths) or to specific discrimination tasks (go/no-go).

An alternative interpretation of the present findings (D. Huron, personal communication, June 1993) is that listeners interpreted each trial, or combination of two patterns, as a single overall pattern that conformed to Western scale structure to varying degrees depending on the test condition. If test trials evoked listeners' musical schemas (i.e., their implicit or explicit knowledge of scale structure), performance might have varied as a function of the strength of these scale implications. In all conditions the scale implications of trials would have differed according to the direction of the transposition between the standard (first) and comparison (second) patterns. For example, in upward transpositions in Condition 5, different trials (e.g., D_4-D_5-D_4-D_5-D_4 followed by E_4-$D^{\#}_5$-E_4-$D^{\#}_5$-E_4) may have been particularly noticeable because the component tones of such trials did not belong to any single scale. For downward transpositions, however, component tones of different trials (e.g., D_4-D_5-D_4-D_5-D_4 followed by C_4-B_4-C_4-B_4-C_4) belonged to several scales (C major, G major, A minor), making them potentially less noticeable. Moreover, any interpretation based on degree of

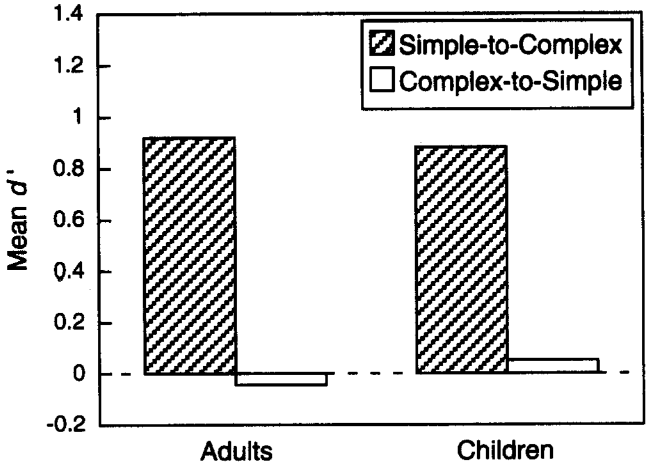

Figure 2. Mean *d'* scores for adults (Experiment 1) and children (Experiment 2) as a function of whether the change to be detected was from a simple frequency ratio to a complex ratio (Conditions 1, 3, 5, and 7), or from a complex ratio to a simple ratio (Conditions 2, 4, 6, and 8). A mean *d'* score of 0 represents performance at chance levels (i.e., no discrimination). Performance was better than chance in the simple-to-complex conditions (Experiment 1, $ps < .01$; Experiment 2, $ps < .05$), but no different from chance in the complex-to-simple conditions.

adherence to musical scale structure would predict that performance should differ as a function of the direction of transposition. To test this possibility, we conducted paired *t*-tests separately for each of the eight conditions that evaluated performance differences between upward and downward transpositions. The tests revealed no significant differences and, therefore, no support for this alternative explanation.

A subsidiary experiment. We also considered the possibility that the observed performance asymmetry may occur only for tone patterns that conform to the Western chromatic scale, which consists of 12 tones that are each a semitone apart. (The seven-tone Western major scale is a subset of the chromatic scale.) Because all intervals between tones (within trials and across trials) were integer multiples of semitones and because virtually all Western music (even atonal music) is composed with intervals that are semitone multiples, the tones in the test session may have sounded somewhat musical to the listeners. This interpretation may have contributed to the relative coherence of common (simple-ratio) musical intervals. We investigated this possibility by testing an additional 22 adult listeners in modified versions of Conditions 1 and 2. These conditions were modified so that, for each trial, transpositions between patterns were 2.5 (rather than 2) semitones upward (rather than upward or downward). This modification meant that the tones of any trial did not conform to the scale structure of any music these listeners would have heard.

We tested each listener in both conditions: half in modified Condition 1 first, the other half in modified Condition 2 first. When compared with chance levels ($d' = 0$) separately for the two conditions, performance was significantly better than chance in modified Condition 1, $t(21) = 2.93, p < .01$, but at chance levels in modified Condition 2. Differences in discrimination performance were examined by means of a repeated-measures ANOVA with one within-subjects variable (frequency ratio: modified Condition 1 vs. modified Condition 2) and one between-subjects variable (testing order). The main effect of frequency ratio was significant, $F(1, 20) = 5.23, p < .05$, indicating that listeners were better at detecting a complex-ratio comparison from a simple-ratio standard than a simple-ratio comparison from a complex-ratio standard. The main effect of testing order was not significant and did not interact with the frequency ratio manipulation. Finally, an independent-samples *t* test revealed no performance differences between the original and modified versions of Condition 1. In short, the performance asymmetry was evident whether or not the stimuli conformed to Western or chromatic scale structure.

Experiment 2

The results of Experiment 1 indicated that interval changes from simple to more complex frequency ratios are easier to detect than comparable changes from complex to simpler ratios. Although the adult listeners for the most part had modest levels of formal musical training, even those with no training would have had many years of incidental exposure to the common, simple-ratio intervals of Western musical scale structure and harmony. In principle, then, extended exposure to Western music could be the chief basis of the observed asymmetry, with listeners generalizing their acquired knowledge of musical relations to the musically impoverished contexts of Experiment 1. We explored this issue further in the present experiment by evaluating the performance of young children who had no formal musical training. Using the frequency ratios from Experiment 1, we tested 6-year-old children on their discrimination of intervallic changes from simple ratios to complex ratios and from complex ratios to simple ratios. To accommodate children's limited attention span, each child was tested in only one condition (between-subjects design) with a modified version of the adult procedure. Because the direction of transposition did not affect adults' performance in Experiment 1, the present experiment was restricted to upward transpositions.

Method

Participants. The participants were 96 middle-class children aged 6 years to 6 years 6 months who had no formal musical training (i.e., no individual or group lessons). Their mean age was 6 years 2 months. Six other children were tested but excluded from the final sample for not meeting the training criterion ($n = 4$; see *Procedure*), misunderstanding the instructions ($n = 1$), or not completing the test session ($n = 1$).

Apparatus. The apparatus was the same as that in Experiment 1.

Stimuli. We adapted the same–different task for children by adding a third pattern to each trial. Thus, a trial consisted of an initial or standard pattern (to focus children's attention on the task), a repetition of the standard pattern, and a comparison pattern that potentially incorporated an interval change. Consecutive patterns were transposed upward by two semitones. On same trials, the interval between high and low tones was the same for all three patterns; on different trials, the interval between high and low tones was identical for the first two patterns but different for the third pattern, in which the high tone was displaced by one semitone from an exact transposition. The low tone of the first pattern was chosen at random from a set of four tones that included C_4 (262 Hz) and tones 2, 4, and 6 semitones higher (D_4, E_4, and $F^{\#}_4$, respectively).

As in Experiment 1, there were eight test conditions in a $2 \times 2 \times 2$ factorial design (see Table 2). Four test conditions (1–4) involved small intervals, another four (5–8) involved large intervals. In four conditions (1, 3, 5, and 7), the change was from a simple-ratio interval to a complex-ratio interval; in the other four conditions (2, 4, 6, and 8), the change was from a complex to a simple ratio. In half of the conditions (1, 4, 5, and 8), the change represented a decrease in interval size; in the other half of the conditions (2, 3, 6, and 7), the change represented an increase in interval size.

Conditions 1 to 4 examined children's discrimination of small melodic intervals (i.e., 5–7 semitones). In Condition 1, the interval between low and high tones of the first two patterns had a simple frequency ratio of 3:2 (a perfect fifth, 7 semitones). On same trials, the third pattern also had a 3:2 ratio; on different trials the third pattern was smaller (6 semitones) and had a complex frequency ratio of 45:32 (a tritone). In Condition 2, the first two patterns of each trial had a complex ratio of 45:32; the third pattern had the same complex ratio on same trials but was larger and had a simple 3:2 ratio on different trials. In Condition 3, the first two patterns of each trial had a simple frequency ratio of 4:3 (a perfect fourth, 5 semitones); the third pattern had the same simple ratio on same trials but was larger (6 semitones) and had a complex ratio of 45:32 on different trials. In Condition 4, the first two patterns of each trial had a complex ratio of 45:32; the third pattern had the same complex ratio on same trials but was smaller and had a simple 4:3 ratio on different trials. Thus, the magnitude of the change was identical (i.e., 1 semitone) in all four small-interval conditions.

The remaining four test conditions involved large intervals. The interval between the low and high tones of the first and second patterns in

Condition 5 had a simple frequency ratio of 2:1 (octave, 12 semitones). On same trials, the third pattern also had a 2:1 ratio; on different trials, the third pattern was smaller (11 semitones, a major seventh) and had a complex ratio of 15:8. In Condition 6, the first two patterns of each trial had a complex ratio of 15:8; the third pattern had the same complex ratio on same trials but was larger and had a simple ratio of 2:1 on different trials. In Condition 7, the first two patterns of each trial had a simple ratio of 2:1, the third pattern had the same simple ratio on same trials but was larger (13 semitones, a minor ninth) and had a complex ratio of 32:15 on different trials. In Condition 8, the first two patterns of each trial had a complex ratio of 32:15; the third pattern had either the same complex ratio (same) or was smaller with a simple ratio of 2:1 (different). As for small intervals, then, the magnitude of the change was identical (i.e., 1 semitone) in all four large-interval conditions.

Changed patterns in the training trials were formed as in Experiment 1.

Procedure. There were 12 children randomly assigned to each of the eight conditions. The experimenter first introduced the concept of transposition by playing "Happy Birthday" on a small keyboard and asking the child to identify the song. The experimenter played "Happy Birthday" again, transposed upward, and asked the child if the new song was also "Happy Birthday." The experimenter stressed that a song could be the same even though it was higher or lower. Children were then told that they would hear a song that would be played three times. The second time, the song would be the same as the first but higher in pitch. The third time, the song would be even higher, and it might be the same or it might have a change. The children's task was to determine if the third song had a change. They were asked to nod their head and say "yes" if they heard a change or to shake their head and say "no" if they did not hear a change.

The test phase was preceded by a training phase that began with two demonstration trials, the first a same trial, the second a different trial. Changed patterns in the training phase were formed as in Experiment 1. After the demonstration trials, children were asked whether they heard a change in the third pattern of each training trial. Correct responses ("yes" on different trials, "no" on same trials) were rewarded by the illumination and activation of a mechanical toy for 4 s. Children proceeded to the test phase only if they met the training criterion (4 consecutive correct responses within a maximum of 20 trials), at which time training was discontinued. Children typically reached the criterion in five trials ($M = 5.0$). After meeting the training criterion, children were told that the "new game" (the test phase) would be just like the "old game" (the training phase), except that the changes would be smaller. Thus, they would have to listen very carefully. The experimenter wore headphones (with masking music) during the test phase to preclude detection of the type of trial. The experimenter recorded children's yes and no responses (head nods and head shakes) with the touch-sensitive control device. As in the training phase, correct responses were rewarded with the illumination and activation of a mechanical toy for 4 s. Each condition had 24 test trials: 12 same (no change) and 12 different (change). The entire test session took approximately 15 min.

Results and Discussion

Children's discrimination performance (raw data) for each condition is summarized in Table 3. To eliminate response bias, we transformed proportions of hits and false alarms to d' scores for each child, as in Experiment 1. Analyses were conducted with the d' scores. Preliminary analyses involved separate comparisons of performance with chance levels for each condition. As was the case for Experiment 1, performance was significantly better than chance in all conditions in which the change was from a simple to a complex ratio—Condition 1, $t(11) = 2.76$, $p < .05$; Condition 3, $t(11) = 3.88$, $p < .005$; Condition 5, $t(11) = 2.23$, $p < .05$, and Condition 7, $t(11) = 2.87$, $p < .05$—but at chance levels when the change was from a complex to a simple ratio.

In the main analysis, we examined differences in discrimination performance across conditions with a between-subjects ANOVA that included two levels of interval size (small vs. large), two levels of change in frequency ratio (simple-to-complex vs. complex-to-simple), and two levels of change in interval size (increase vs. decrease). The main effect of frequency ratio was significant, $F(1, 88) = 22.02$, $p < .0001$, and there were no interactions between variables. As with adults, children were significantly better at detecting changes from simple frequency ratios to complex ratios than they were at detecting changes from complex ratios to simple ratios. Mean d' scores as a function of the frequency ratio manipulation are shown in Figure 2.

The main effect of the change in interval size (increase or decrease) was also significant, $F(1, 88) = 6.54$, $p < .05$. This result indicates that children were better at detecting increases in interval size than they were at detecting decreases. The exclusive use of upward transpositions in the present experiment meant that whenever interval size increased, the tones of the third pattern on different trials extended beyond the range of the third pattern on same trials; when interval size decreased, the tones on different trials remained within that range. Thus, frequency range cues may have made interval size increases more salient than interval size decreases.

The significant effect of increasing or decreasing interval size for children but not for adults may also reflect developmental differences in perceptual processing strategies. Children may focus less on relative pitch cues and more on absolute cues (e.g., pitch range) than adults do. In this regard, children may be more similar to infants who detect pitch changes outside the range of a tone pattern more easily than those within the range (Trehub, Thorpe, & Morrongiello, 1985). Further evidence that absolute pitch processing is a relatively primitive strategy comes from songbirds (Hulse & Cynx, 1985; Page, Hulse, & Cynx, 1989), who outperform humans on some tasks that depend upon memory for absolute pitch (Njegovan, Ito, Mewhort, & Weisman, 1995; Weisman, Njegovan, & Ito, 1994). Even though 6-year-olds may have focused more on absolute pitch cues than did adults, they still exhibited asymmetric performance based on the relative simplicity of frequency ratios regardless of whether the changes produced increases or decreases in interval size.

General Discussion

Changes from simple frequency ratios (2:1, 3:2, or 4:3) to more complex ratios (15:8, 32:15, or 45:32) were easier to detect than were changes from complex to simpler ratios. Such asymmetries in performance were evident in adults and in 6-year-old children who had never taken music lessons. The results from adult listeners replicate and extend previous research with a different discrimination task and different intervals (Schellenberg & Trehub, 1994a). Children's adultlike pattern of asymmetries implies that simple-ratio intervals are relatively more coherent than complex-ratio intervals across development, which is consistent with the notion that scale structures reflect natural (psychoacoustic) as well as cultural factors (Terhardt, 1977, 1984).

What is the origin of perceptual asymmetries for intervals based on the simplicity of their frequency ratios? The relative coherence of simple ratios could arise from processing predispositions (i.e., inherent processing tendencies) or innate learning preferences (Marler, 1990). In either case, the implication is that musical scale structures have a psychoacoustic basis in simple frequency ratios. The obtained asymmetries in interval discrimination have parallels in similarity judgments between pairs of tones (Bharucha, 1984; Krumhansl, 1979), chords (Bharucha & Krumhansl, 1983), and melodies (Bartlett & Dowling, 1988). Such asymmetries may signal the presence of cognitive reference points (Rosch, 1975a) or perceptual anchors that promote efficient processing of particular auditory patterns (e.g., intervals with simple frequency ratios) relative to others (e.g., intervals with complex frequency ratios). Intervals with simple ratios may function as natural prototypes (Rosch, 1973, 1975b), or inherently good (coherent) instances of intervals. As a result, such intervals would be more easily learned than other less prototypical intervals and more readily differentiated from other intervals. Indeed, the worldwide influence of Western music (Nettl, 1985) may stem in part from the structural significance of natural, or prototypical, intervals in Western scales. Nevertheless, the source of their status as natural prototypes remains unclear. Although some theorists (Boomsliter & Creel, 1961; Patterson, 1986; Roederer, 1979) contend that pairs of tones related by simple ratios create more regular patterns of neuronal activity than do pairs with complex ratios, there is no evidence to support such claims (see Burns & Ward, 1982). If simple frequency ratios are inherently good intervals for human listeners, one could look for similar evidence among certain nonhuman species. Unfortunately, evidence of relative pitch processing in songbirds is equivocal (Hulse & Cynx, 1985; Hurly, Ratcliffe, Weary, & Weisman, 1992; Page et al., 1989; Weisman et al., 1994; Weisman & Ratcliffe, 1989), and there are no indications that songbirds favor some frequency ratios over others. Nevertheless, songbirds seem to perceptually group tone patterns on the basis of the simplicity or complexity of their frequency ratios (Hulse, Bernard, & Braaten, 1995).

The coherence of simple frequency ratios could also stem from exposure to the overtone series of complex tones. For example, Terhardt (1974, 1978, 1984) claimed that infants are predisposed to attend to human speech (see also Fernald, 1992)—rather than simple frequency ratios per se—just as songbirds selectively attend to the songs of conspecifics (Dooling, 1989; Marler & Peters, 1989; Sinnott, 1989). He argued, further, that exposure to speech leads to familiarization with the simple frequency ratios among its simultaneous components. In turn, pairs of nonspeech tones that are related by simple ratios have an affinity (i.e., a coherence) that distinguishes them from other pairs. For Terhardt's views to be relevant to the present findings, however, 6-year-old children would have to be able to generalize implicit knowledge of relations between the simultaneous components of speech to patterns of successive pure tones.

Because of the prominence of simple frequency ratios in Western scale structure and harmony, it is also possible that these intervals are learned rapidly and effortlessly simply by means of informal exposure to music. Krumhansl (1990) found that tones judged to be more stable in a musical key occur more frequently in a variety of Western musical styles. These stability judgments are also highly correlated with the relative simplicity of the frequency ratio between individual tones and the reference tone (tonic) of a key (Schellenberg & Trehub, 1994b). Thus, although complex ratios are common in Western music (e.g., in dominant seventh chords), these associations imply that simple ratios are relatively more common. Hence the superior performance on changes from simple to complex ratios than on the reverse changes could stem from the relative familiarity and perceptual stability of the simple-ratio standard pattern, the relative unfamiliarity and salience of the complex-ratio comparison pattern, or both (see Schellenberg & Trehub, 1994a). There is considerable evidence, however, that culture-specific tonal relations are acquired throughout childhood (Andrews & Dowling, 1991; Bartlett & Dowling, 1980; Krumhansl & Keil, 1982; Lynch & Eilers, 1991; Morrongiello & Roes, 1990; Sloboda, 1985; Trainor & Trehub, 1994; Zenatti, 1993) and at an accelerated pace for children with musical training (Dowling & Harwood, 1986; Lynch & Eilers, 1991; Morrongiello & Roes, 1990; Morrongiello, Roes, & Donnelly, 1989). For example, although first- and second-grade children have some sense of which tones belong to a particular scale (Trainor & Trehub, 1994), hierarchical differentiation of tones remains incomplete even after the sixth grade (Krumhansl & Keil, 1982). Thus, if knowledge of scale structure is the principal source of the observed asymmetries, these asymmetries should increase with age as such knowledge increases. Our results indicate, however, that despite the differences in overall performance efficiency between 6-year-old children and adults, the asymmetries are essentially equivalent across these age groups. These findings are inconsistent with the interpretation that young children's performance asymmetries reflect generalization of acquired musical knowledge to the musically impoverished contexts of the present investigation. Moreover, because adults' performance was unaffected by differences in the degree to which the stimuli adhered to known scale structures, it seems unlikely that knowledge of such structures would be the principal source of children's response patterns.

In some contexts, however, first- and second-grade children seem to be sensitive to the complete hierarchy of tonal relations within a major scale (Cuddy & Badertscher, 1987; Speer & Meeks, 1985), implying that enculturation (i.e., greater familiarity with simple than complex ratios because of exposure to music) cannot be ruled out as a source of the processing asymmetries. Cuddy and Badertscher (1987) reported that first- and second-grade children's ratings of how test tones fit to different melodic contexts were highly correlated with adult musicians' ratings in similar contexts, $r = .92$ (Krumhansl, 1990, p. 30). However, a reanalysis of these ratings (Cuddy & Badertscher, 1987, Table 1) revealed that they were also highly correlated with the durations of tones in the stimulus context, $r = .88$ (see D. Butler, 1989), and with the relative simplicity of frequency ratios between individual test tones and the most frequently occurring tone in the stimulus context, $r = .90$ (see Schellenberg & Trehub, 1994b). As a result, it is unclear whether these children were responding on the basis of their knowledge of musical scale structure, the durations of the tones, or the relative simplicity of frequency ratios.

Definitive evidence for inherent processing advantages for simple frequency ratios and their status as natural prototypes would require evidence from listeners with no exposure to Western music or to any musical system in which these ratios predominate. The worldwide influence of Western music (Nettl, 1985) and the cross-cultural prominence of simple frequency ratios (Meyer, 1956; Trehub et al., in press) provide significant obstacles to the accumulation of appropriate evidence. Having established that untrained 6-year-olds exhibit perceptual asymmetries that are comparable to adults, it is reasonable to consider the interval processing skills of listeners who are substantially younger. Previous studies provide indirect but highly suggestive evidence of sensitivity to simplicity of frequency ratios in infancy. For example, infants perceive tones an octave apart (2:1 ratio) as more similar than tones slightly less or slightly more than an octave apart (Demany & Armand, 1984). Infants also show superior discrimination of alterations to pure-tone sequences that conform to Western scale structure compared with those that do not (Cohen, Thorpe, & Trehub, 1987; Trainor, 1991; Trainor & Trehub, 1993a, 1993b), as is the case for young children (Trehub, Cohen, Thorpe, & Morrongiello, 1986). Because the five-tone sequences in the studies of Trehub and her associates had three different tones (i.e., more than one interval), the perfect fifth interval (3:2 ratio), which was present (between nonadjacent tones) in the Western sequences, cannot be unequivocally interpreted as the factor responsible for the enhanced performance. A further study that preserved the perfect fifth relation but disrupted the remaining relations among component tones (Trainor & Trehub, 1993b) also revealed superior performance for tone sequences with the perfect fifth. Finally, Schellenberg and Trehub's (1994b) reanalysis of Trainor's (1991) infant discrimination data revealed that performance improvements were associated with greater disparities in ratio simplicity between the standard and comparison patterns.

We can use Geary's (1995) formulation of evolutionary and cultural influences on cognitive development as a means of placing the alternative interpretations of the present findings in perspective. Geary distinguished between biologically primary cognitive abilities—those evolved through natural selection, which are therefore universal—and secondary abilities—those that stem from primary abilities but are transferred to another domain and are subject to cultural influences. Simple-ratio intervals may be natural prototypes with corresponding processing advantages that reflect a primary ability. Alternatively, coherence may result from culture-specific exposure or familiarity to a music of a particular culture, indicating a secondary ability. A further possibility is that the asymmetry is a by-product of innate sensitivity to speech, being secondary in the sense that it co-opts an innate ability, but primary because of the universality of speech. Regardless of the explanation, our finding of perceptual asymmetries based on frequency ratios in young listeners with no musical training provides the impetus for further research with younger and less experienced children from our own and other cultures. Such research would shed light on the requisite experiences for the development of the asymmetries reported here.

References

Andrews, M. W., & Dowling, W. J. (1991). The development of perception of interleaved melodies and control of auditory attention. *Music Perception, 8,* 349–368.

Attneave, F., & Olson, R. K. (1971). Pitch as a medium: A new approach to psychophysical scaling. *American Journal of Psychology, 84,* 147–166.

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.

Bartlett, J. C., & Dowling, W. J. (1988). Scale structure and similarity of melodies. *Music Perception, 5,* 285–314.

Bernstein, L. (1976). *The unanswered question: Six talks at Harvard.* Cambridge, MA: Harvard University Press.

Bharucha, J. J. (1984). Anchoring effects in music: The resolution of dissonance. *Cognitive Psychology, 16,* 485–518.

Bharucha, J. J., & Krumhansl, C. L. (1983). The representation of harmonic structure in music: Hierarchies of stability as a function of context. *Cognition, 13,* 63–102.

Bharucha, J. J., Olney, K. L., & Schnurr, P. P. (1985). Detection of coherence-disrupting and coherence-conferring alterations in text. *Memory & Cognition, 13,* 573–578.

Bharucha, J. J., & Pryor, J. H. (1986). Disrupting the isochrony underlying rhythm: An asymmetry in discrimination. *Perception & Psychophysics, 40,* 137–141.

Blacking, J. (1992). The biology of music-making. In H. Myers (Ed.), *Ethnomusicology: An introduction* (pp. 301–314). New York: Norton.

Boomsliter, P., & Creel, W. (1961). The long pattern hypothesis in harmony and hearing. *Journal of Music Theory, 5,* 2–31.

Burns, E. M., & Ward, W. D. (1978). Categorical perception—phenomenon or epiphenomenon: Evidence from experiments in the perception of melodic musical intervals. *Journal of the Acoustical Society of America, 63,* 456–468.

Burns, E. M., & Ward, W. D. (1982). Intervals, scales, and tuning. In D. Deutsch (Ed.), *The psychology of music* (pp. 241–269). New York: Academic Press.

Butler, D. (1989). Describing the perception of tonality in music: A critique of the tonal hierarchy theory and proposal for a theory of intervallic rivalry. *Music Perception, 6,* 219–242.

Butler, J. W., & Daston, P. G. (1968). Musical consonance as musical preference: A cross-cultural study. *Journal of General Psychology, 79,* 129–142.

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.

Cuddy, L. L., & Badertscher, B. (1987). Recovery of the tonal hierarchy: Some comparisons across age and levels of musical experience. *Perception & Psychophysics, 41,* 609–620.

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

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

Dooling, R. J. (1989). Perception of complex, species-specific vocalizations by birds and humans. In R. J. Dooling & S. H. Hulse (Eds.), *The comparative psychology of audition: Perceiving complex sounds* (pp. 423–444). Hillsdale, NJ: Erlbaum.

Dowling, W. J. (1978). Scale and contour: Two components of a theory of memory for melodies. *Psychological Review, 85,* 341–354.

Dowling, W. J. (1991). Tonal strength and melody recognition after long and short delays. *Perception & Psychophysics, 50,* 305–313.

Dowling, W. J., & Harwood, D. L. (1986). *Music cognition.* San Diego, CA: Academic Press.

Dowling, W. J., Kwak, S., & Andrews, M. W. (1995). The time course of recognition of novel melodies. *Perception & Psychophysics, 57,* 136–149.

Elliott, P. B. (1964). Tables of *d′*. In J. A. Swets (Ed.), *Signal detection and recognition by human observers: Contemporary readings* (Appendix 1, pp. 651–684). New York: Wiley.

Fernald, A. (1992). Human maternal vocalisations to infants as biologically relevant signals: An evolutionary perspective. In J. H. Barkow, L. Cosmides, & J. Tooby (Eds.), *The adapted mind: Evolutionary psychology and the generation of culture* (pp. 345–382). London: Oxford University Press.

Garner, W. R. (1974). *The processing of information and structure.* Hillsdale, NJ: Erlbaum.

Geary, D. C. (1995). Reflections of evolution and culture in children's cognition: Implications for mathematical development and instruction. *American Psychologist, 50,* 24–37.

Handel, S. (1989). *Listening: An introduction to the perception of auditory events.* Cambridge, MA: Bradford.

Hargreaves, D. J. (1986). *The developmental psychology of music.* Cambridge, England: Cambridge University Press.

Houtsma, A. J. M. (1968). Discrimination of frequency ratios. *Journal of the Acoustical Society of America, 44,* S383(A).

Hulse, S. H., Bernard, D. J., & Braaten, R. F. (1995). Auditory discrimination of chord-based spectral structures by European starlings (*Sturnus vulgaris*). *Journal of Experimental Psychology: General, 124,* 409–423.

Hulse, S. H., & Cynx, J. (1985). Relative pitch perception is constrained by absolute pitch perception in songbirds (*Mimus, Molothrus,* and *Sturnus*). *Journal of Comparative Psychology, 100,* 215–228.

Hurly, T. A., Ratcliffe, L., Weary, D. M., & Weisman, R. (1992). White-throated sparrows (*Zonotrichia albicollis*) can perceive pitch change in conspecific song by using the frequency ratio independent of the frequency difference. *Journal of Comparative Psychology, 106,* 388–391.

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

Kallman, H. J. (1982). Octave equivalence as measured by similarity ratings. *Perception & Psychophysics, 32,* 37–49.

Kameoka, A., & Kuriyagawa, M. (1969). Consonance theory: Part I. Consonance of dyads. *Journal of the Acoustical Society of America, 45,* 1451–1459.

Kolinski, M. (1967). Recent trends in ethnomusicology. *Ethnomusicology, 11,* 1–24.

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., & Keil, F. C. (1982). Acquisition of the hierarchy of tonal functions in music. *Memory & Cognition, 10,* 243–251.

Lynch, M. P., & Eilers, R. E. (1991). Children's perception of native and non-native musical scales. *Music Perception, 9,* 121–132.

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

Malmberg, C. F. (1918). The perception of consonance and dissonance. *Psychological Monographs, 25,* 93–133.

Marler, P. (1990). Innate learning preferences: Signals for communication. *Developmental Psychobiology, 23,* 557–568.

Marler, P., & Peters, S. (1989). Species differences in auditory responsiveness in early vocal learning. In R. J. Dooling & S. H. Hulse (Eds.), *The comparative psychology of audition: Perceiving complex sounds* (pp. 243–273). Hillsdale, NJ: Erlbaum.

Meyer, L. B. (1956). *Emotion and meaning in music.* Chicago: University of Chicago Press.

Morrongiello, B. A. (1992). Effects of training on children's perception of music: A review. *Psychology of Music, 20,* 29–41.

Morrongiello, B. A., & Roes, C. L. (1990). Developmental changes in children's perception of musical sequences: Effects of musical training. *Developmental Psychology, 26,* 814–820.

Morrongiello, B. A., Roes, C. L., & Donnelly, F. (1989). Children's perception of musical patterns: Effects of music instruction. *Music Perception, 6,* 447–462.

Narmour, E. (1990). *The analysis and cognition of basic melodic structures: The implication-realization model.* Chicago: University of Chicago Press.

Narmour, E. (1992). *The analysis and cognition of melodic complexity: The implication-realization model.* Chicago: University of Chicago Press.

Nettl, B. (1985). *The Western impact on world music.* New York: Schirmer.

Njegovan, M., Ito, S., Mewhort, D., & Weisman, R. (1995). Classification of frequencies into ranges by songbirds and humans. *Journal of Experimental Psychology: Animal Behavior Processes, 21,* 33–42.

Page, S. C., Hulse, S. H., & Cynx, J. (1989). Relative pitch perception in the European starling (*Sturnus vulgaris*): Further evidence for an elusive phenomenon. *Journal of Experimental Psychology: Animal Behavior Processes, 15,* 137–146.

Patterson, R. D. (1986). Spiral detection of periodicity and the spiral form of musical scales. *Psychology of Music, 14,* 44–61.

Plomp, R. (1964). The ear as a frequency analyzer. *Journal of the Acoustical Society of America, 36,* 1628–1636.

Plomp, R., & Levelt, W. J. M. (1965). Tonal consonance and critical bandwidth. *Journal of the Acoustical Society of America, 38,* 548–560.

Roederer, J. G. (1979). *Introduction to the physics and psychophysics of music* (2nd ed.). New York: Springer-Verlag.

Rosch, E. (1973). On the internal structure of perceptual and semantic categories. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language.* New York: Academic Press.

Rosch, E. (1975a). Cognitive reference points. *Cognitive Psychology, 7,* 532–547.

Rosch, E. (1975b). Universals and cultural specifics in human categorization. In R. Breslin, S. Bochner, & W. Lonner (Eds.), *Cross-cultural perspectives on learning* (pp. 117–206). New York: Halsted Press.

Schellenberg, E. G., & Trehub, S. E. (1994a). Frequency ratios and the discrimination of pure tone sequences. *Perception & Psychophysics, 56,* 472–478.

Schellenberg, E. G., & Trehub, S. E. (1994b). Frequency ratios and the perception of tone patterns. *Psychonomic Bulletin & Review, 1,* 191–201.

Seay, A. (1975). *Music in the medieval world* (2nd ed.). Englewood Cliffs, NJ: Prentice Hall.

Serafine, M. L. (1983). Cognition in music. *Cognition, 14,* 119–183.

Shepard, R. N. (1982). Structural representations of musical pitch. In D. Deutsch (Ed.), *The psychology of music* (pp. 343–390). New York: Academic Press.

Sinnott, J. M. (1989). Internal cognitive structures guide birdsong perception. In R. J. Dooling & S. H. Hulse (Eds.), *The comparative psy-*

chology of audition: Perceiving complex sounds (pp. 447–463). Hillsdale, NJ: Erlbaum.

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

Speer, J. R., & Meeks, P. U. (1985). School children's perception of pitch in music. *Psychomusicology, 5,* 49–56.

Terhardt, E. (1974). Pitch, consonance, and harmony. *Journal of the Acoustical Society of America, 55,* 1061–1069.

Terhardt, E. (1977). The two-component theory of musical consonance. In E. F. Evans & J. P. Wilson (Eds.), *Psychophysics and physiology of hearing* (pp. 381–390). London: Academic Press.

Terhardt, E. (1978). Psychoacoustic evaluation of musical sounds. *Perception & Psychophysics, 23,* 483–492.

Terhardt, E. (1984). The concept of musical consonance: A link between music and psychoacoustics. *Music Perception, 1,* 276–295.

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. (1993a). Musical context effects in infants and adults: Key distance. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 615–626.

Trainor, L. J., & Trehub, S. E. (1993b). What mediates infants' and adults' superior processing of the major over the augmented triad? *Music Perception, 11,* 185–196.

Trainor, L. J., & Trehub, S. E. (1994). Key membership and implied harmony in Western tonal music: Developmental perspectives. *Perception & Psychophysics, 56,* 125–132.

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. (1985). Infants' perception of melodies: Changes in a single tone. *Infant Behavior and Development, 8,* 213–223.

Trehub, S. E., Schellenberg, E. G., & Hill, D. S. (in press). The origins of music perception and cognition: A developmental perspective. In I. Deliège & J. A. Sloboda (Eds.), *Perception and cognition of music.* Mahwah, NJ: Erlbaum.

Trehub, S. E., & Unyk, A. M. (1991). Music prototypes in developmental perspective. *Psychomusicology, 10,* 73–87.

Valentine, C. W. (1913). The aesthetic appreciation of musical intervals among school children and adults. *British Journal of Psychology, 6,* 190–216.

Vos, J. (1986). Purity ratings of tempered fifths and major thirds. *Music Perception, 3,* 221–258.

Weisman, R., Njegovan, M., & Ito, S. (1994). Frequency ratio discrimination by zebra finches (*Taeniopygia guttata*) and humans (*Homo sapiens*). *Journal of Comparative Psychology, 108,* 363–372.

Weisman, R., & Ratcliffe, L. (1989). Absolute and relative pitch processing in black-capped chickadees, *Parus atricapillus. Animal Behaviour, 38,* 685–692.

Winnington-Ingram, R. P. (1980). Pythagoras. In S. Sadie (Ed.), *The new Grove dictionary of music and musicians* (Vol. 15, p. 485). London: Macmillan.

Zenatti, A. (1993). Children's musical cognition and taste. In T. J. Tighe & W. J. Dowling (Eds.), *Psychology and music: The understanding of melody and rhythm* (pp. 177–196). Hillsdale, NJ: Erlbaum.

Received July 12, 1994
Revision received November 11, 1995
Accepted December 5, 1995 ■