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Infants' and Adults' Perception of Scale Structure

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Adults and 9-month-old infants were required to detect mistuned tones in multitone sequences. When 7-tone versions of a common nursery tune were generated from the Western major scale (unequal scale steps) or from an alternative scale (equal steps), infants detected the mistuned tones more accurately in the unequal-step context than in the equal-step context (Experiment 1). Infants and adults were subsequently tested with 1 of 3 ascending–descending scales (15 tones): (a) a potentially familiar scale (major) with unequal steps, (b) an unfamiliar scale with unequal steps, and (c) an unfamiliar scale with equal steps. Infants detected mistuned tones only in the scales with unequal steps (Experiment 2). Adults performed better on the familiar (major) unequal-step scale and equally poorly on both unfamiliar scales (Experiments 3 and 4). These findings are indicative of an inherent processing bias favoring unequal-step scales.

The diversity of musical forms across cultures (e.g., Western, Indian, Chinese, African) and even within a culture (e.g., pop, jazz, Baroque) implies that there are few defining features of music. Accordingly, definitions of music are necessarily general, as can be seen in the following examples: "the art of combining vocal or instrumental sounds (or both) to produce beauty of form, harmony, and expression of emotion" (Allen, 1990, p. 781) or "humanly produced sequences of tones or tone combinations that are non-referential" (Trehub & Schellenberg, 1995, p. 2). Nevertheless, diversity does not preclude the possibility of structural commonalities across musical cultures (Dowling & Harwood, 1986; Trehub, Schellenberg, & Hill, 1997). For example, acknowledged musical universals include the musical equivalence of tones an octave apart and the use of discrete pitches rather than infinitely variable pitches (Dowling & Harwood, 1986; Handel, 1989).

Indeed, because music and its perception are undoubtedly influenced by cognitive constraints, one would expect a number of similarities across cultures. For example, limitations of working memory constrain the size of the pitch set (i.e., the number of discrete tones) in any musical scale (Dowling & Harwood, 1986), which in turn constrains the melodies derived from such scales. Musical scales across cultures typically have five to seven pitches, remaining well within the range of working memory capacity (Miller, 1956). This limited set of pitches allows the listener to perceive each pitch as being distinct from others. Note, however, that scales are abstractions or formalizations of the collection of pitches in style-specific compositions. Thus, melodies that conform to particular scales may predate formal descriptions of those scales. Moreover, instead of finding all component pitches of a relevant scale in a single composition, a subset of pitches is often used.

Some tone patterns are more accurately perceived or remembered than others, even by relatively inexperienced listeners such as infants (A. J. Cohen, Thorpe, & Trehub, 1987; Schellenberg & Trehub, 1996b; Trainor & Trehub, 1993; Trehub, Thorpe, & Trainor, 1990). Enhanced processing in these instances may arise from inherent perceptual biases for particular musical relations. For example, infants (Schellenberg & Trehub, 1996b), 6-year-old children (Schellenberg & Trehub, 1996a), and musically untrained adults (Schellenberg & Trehub, 1994a, 1996a) exhibit processing advantages for musical intervals (tone pairs) that have component pitches related by small-integer ratios (e.g., 2:1, 3:2, 4:3) as opposed to large-integer ratios (e.g., 45:32, 32:15, 15:8). These findings are consistent with the ubiquity of the octave (2:1 ratio) and perfect-fifth (3:2 ratio) intervals across cultures (Meyer, 1956; Sachs, 1943; Sloboda, 1985; Trehub, Schellenberg, & Hill, 1997).

Compared with intervals, scales in any musical culture describe a more complex set of relations among tones, one that specifies how an octave interval is filled with intermediate pitches. The resulting scale proceeds, in ascending sequence, ending on the tone an octave above the initial tone. Although there is considerable variation in the component pitches of scales across cultures, similarities are evident aside from the number of different pitches in the scale (five to seven) and the prevalence of specific intervals (e.g., the 3:2 ratio). For example, variation in step size (e.g., 1 or 2 semitones in the case of Western scales) is the general rule for non-Western as well as Western scales. Various psychological advantages have been posited for this "unequal interval principle" (Sloboda, 1985, p. 254), or intervallic asymmetry (Handel, 1989), such as increasing the possibil-

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ity of melodic variation (Dowling & Harwood, 1986), providing the listener with a sense of location (Brown, 1988; Butler, 1989), facilitating the perception of tension and resolution (Shepard, 1982), and allowing different notes to assume distinctive functions (Balzano, 1980). Although the division of the octave into equal steps is a possible feature of scales, it is especially notable for its rarity (Jordan & Shepard, 1987; Sloboda, 1985).

The successive steps of the Western major scale (*doh re mi fa sol la ti doh*) are separated by 2 (*doh–re*), 2 (*re–mi*), 1 (*mi–fa*), 2 (*fa-sol*), 2 (*sol–la*), 2 (*la–ti*), and 1 (*ti–doh*) semitones. Another Western scale, the harmonic minor, has a contrasting sequence of unequal step sizes: 2, 1, 2, 2, 1, 3, and 1 semitones. Pentatonic scales (five tones per octave), which are found widely in folk music across cultures and date from at least 2000 B.C. (Kennedy, 1994), also have unequal step sizes such as 2, 2, 3, 2, and 3 semitones. Even though Indian music theory prescribes a 22-fold division of the octave (the *sruti* scale), Indian scales in actual use (e.g., the seven-note *sa–grama* scale) incorporate unequal steps (Jairazbhoy, 1971; Sloboda, 1985).

According to Balzano (1980, 1982), the property of uniqueness cannot be achieved if the steps between scale tones are all equivalent in size. By the term *uniqueness,* he meant that each tone in the scale has a unique set of intervals (pitch relations) in its relations with other tones in the scale. This property of the major scale makes it possible for tones to assume different functions within the scale, generating the hierarchy of stability posited by music theory (e.g., Aldwell & Schachter, 1989; Piston, 1969). The tonic (*doh*), or initial tone, of the major scale is considered to be the most stable, followed by other tones in the major triad (*mi* and *sol*), the remaining tones in the scale (*re, fa, la,* and *ti*), and tones that are not in the scale. According to music-theoretic prescriptions, unstable tones generate expectations that more stable tones will eventually follow. Empirical research reveals that goodness-of-fit ratings provided by musically trained listeners match those predicted by music theory (Krumhansl, 1990). Whether the apparent congruence of music perception and theory stems from trained listeners' long-term exposure to music (Krumhansl, 1990) or from their explicit knowledge of music theory (Butler, 1989, 1990) remains to be determined, as does the relevance of these findings for untutored listeners (Handel, 1989).

Although scales that lack uniqueness, such as the chromatic scale (division of the octave into 12 equal steps of 1 semitone) and the whole-tone scale (division of the octave into 6 equal steps of 2 semitones), are featured in much 20th-century art music, relatively few listeners seem to understand or enjoy such compositions (Lerdahl, 1988; Meyer, 1994). Indeed, compositions based on unequal-step major and minor scales continue to dominate the symphonic and popular repertoire. These observations provided the impetus for the present research, in which we examined whether the ubiquity of unequal-step scales might be based on perceptual processing predispositions rather than historical tradition or familiarity.

Shepard and Jordan (1984; Jordan & Shepard, 1987) presented adults with the major scale or different distortions of the scale. In one case, the 1-semitone steps of the major scale were increased in size and the 2-semitone steps were decreased in size to generate an equal-step scale (1.713 semitones between tones). Listeners seemed to interpret this equal-step scale with reference to a major-scale template or schema, perceiving the steps between Tones 3 and 4 and Tones 7 and 8 (which are 1-semitone steps in the major scale) as being larger than the other steps in the scale. In the present research, we conducted four experiments to evaluate the ability of adults and 9-month-old infants to detect subtle pitch deviations (i.e., mistunings) to tone sequences that were based on the equal-step scale used by Shepard and Jordan (1984; Jordan & Shepard, 1987) or on unequal-step scales that varied in terms of potential familiarity. Inclusion of an artificial (i.e., completely unfamiliar) unequal-step scale in Experiments 2, 3, and 4 allowed us to separate the effects of exposure and familiarity from effects attributable to equal or unequal steps.

The three scales used in the present research are illustrated schematically in Figure 1. In the major scale, the pitch distance between low *doh* and high *doh* is one octave, or 12 semitones. As noted, adjacent tones in the scale are either 1 or 2 semitones apart. Multiplying the frequency of a tone by $2^{1/12}$ (i.e., by 1.059) yields a tone that is 1 semitone higher; multiplying the frequency of a tone by $2^{2/12}$ (i.e., by 1.122) yields a tone that is 2 semitones higher. Hence, the frequency of *doh* is twice that of *doh* an octave below (12 semitones = $2^{12/12}$). In the artificial, unequal-step scale, the pitch distance between the lowest and highest tones is also one octave. Instead of a division into 12 semitones, however, the octave is partitioned into 11 equal subdivisions, with the pitch distance between successive tones in the scale being either 1 subdivision (frequency multiplied by $2^{1/11}$ or 1.065)

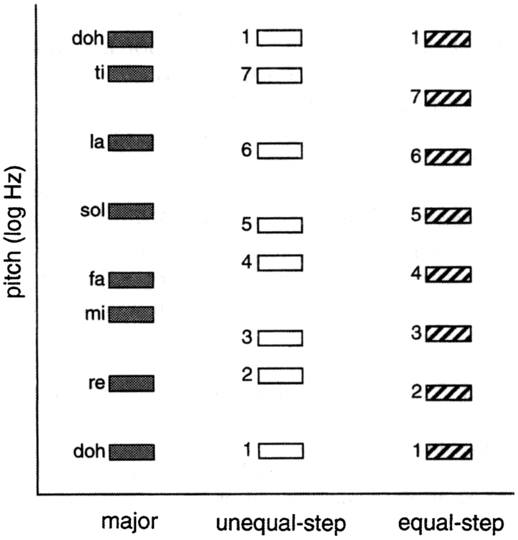

Figure 1. Schematic illustration of the major, unequal-step, and equal-step scales. Adjacent tones in the major scale are separated by a pitch distance of 1 or 2 semitones. Some steps in the unequal-step scale are twice as large as other steps; step size in the equal-step scale does not vary.

or 2 subdivisions (frequency multiplied by $2^{2/11}$ or 1.134). As with the major scale, adjacent tones in the unequal-step scale are either 1 or 2 subdivisions apart, although the unequal-step scale has three steps of 1 subdivision (vs. two 1-semitone steps in major) and four steps of 2 subdivisions (vs. five 2-semitone steps in major). In the equal-step scale, in which the lowest and highest tones are also an octave apart, multiplying a tone by $2^{1/7}$ (i.e., by 1.104) yields the next highest tone in the scale. The scale steps are all 1.713 semitones in size, which is equivalent to the mean size of scale steps in the major and unequal-step scales. Despite the apparent artificiality of equal-step scales, they are reportedly used in music from Thailand (Ellingson, 1992; Myers-Moro, 1993).

Because of the ubiquity of unequal-step scales and the rarity of equal-step scales across cultures, infant listeners were expected to perform better on unequal-step than on equal-step scales. Predictions about the two unequal-step scales (familiar and unfamiliar) were less clear. The minimal musical experience of 9-month-olds might include exposure to culture-specific music by means of caregivers' songs (Trehub & Schellenberg, 1995; Trehub & Trainor, 1998; Trehub, Trainor, & Unyk, 1993). Linguistic exposure effects have been reported as early as 6 months of age for vowels (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Polka & Werker, 1994) and 10–12 months of age for consonants (Best, 1994; Werker & Lalonde, 1988; Werker & Polka, 1993; Werker & Tees, 1983). Adults were expected to perform better on the familiar major scale than on the equal-step scale, but it was unclear whether the advantage of unequal-step scales would be evident in an unfamiliar context, that of the new, unequal-step scale. For example, redundancy (i.e., repeated tones) facilitates adults' perception and retention of melodies in familiar (i.e., conventional) contexts, but not in unfamiliar (i.e., culturally unconventional) contexts (Schellenberg & Trehub, in press).

Lynch, Eilers, Oller, and Urbano (1990) posed comparable questions about early exposure to music. They evaluated the ability of adults and 6-month-old infants to detect mistunings to tone sequences based on the major scale or a foreign unequal-step (Javanese *pelog*) scale. Musically untrained adults were superior at detecting changes to the major than to *pelog* melodies (see also Lynch, Eilers, Oller, Urbano, & Wilson, 1991), but infants detected both changes with equal ease. Similarly, Trainor and Trehub (1992) found that 8-month-old infants, unlike adults, detected pitch changes to a conventional Western melody equally well regardless of whether the changes violated major scale structure (an easy task for adults) or preserved it (a difficult task for adults). Even at 6 years of age, children's implicit knowledge of major scale structure is limited relative to that of adults (Krumhansl & Keil, 1982). Moreover, untrained 10-year-olds do not detect mistunings more readily in major-scale contexts than in *pelog-scale* contexts (Lynch & Eilers, 1991).

In some instances, however, infants 1 year of age or younger are reported to exhibit effects of familiarity (i.e., better discrimination performance) in major-scale contexts compared with unequal-step contexts based on the *pelog* scale (Lynch & Eilers, 1992; Lynch, Short, & Chua, 1995). In short, evidence for culture-specific knowledge of music in the first year of life is equivocal. If we could demonstrate that infants more readily detect mistunings to unequal-step scales than to equal-step scales and that this finding is independent of familiarity, then we would have evidence for an inherent perceptual bias for unequal-interval scales.

Experiment 1

We evaluated the ability of 9-month-old infants to detect subtle pitch changes in the context of a tone sequence based on the major scale or the equal-step scale. A common nursery song, "Twinkle, Twinkle, Little Star," was simplified so that its overall melodic contour conformed to a simple up–down pattern (see Figure 2). As can be seen in Figure 2, the original song and simplified versions contain six of the seven different tones of the major and equal-step scales.

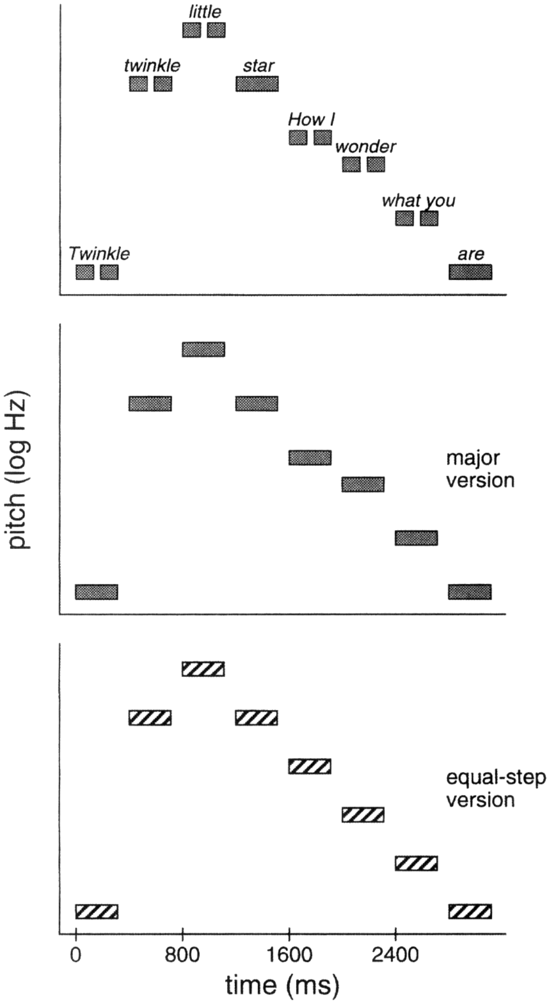

Figure 2. Schematic illustration of "Twinkle, Twinkle Little Star" (top panel) as well as the modified major version (middle panel) and equal-step version (bottom panel) used in Experiment 1.

Method

Participants. The participants were 40 healthy full-term infants between 8 months 15 days and 9 months 18 days of age (M = 8 months 27 days). Another 26 infants were excluded from the sample because of fussing ($n = 10$), parental interference ($n = 4$), or not meeting the training criterion ($n = 12$).

Apparatus. Infants were tested individually in a double-walled, sound-attenuating booth (Industrial Acoustics, Lodi, NJ). They sat in a corner of the booth on their parents' laps, with an Avant 2AX loudspeaker 45° to their left. A Plexiglas toy box that housed four mechanical toys and lights was below the loudspeaker. Stimulus presentation and response recording were controlled by an ECS microcomputer, which regulated the audio equipment and mechanical toys through a custom-built interface. A touch-sensitive buttonbox connected to the computer was used to signal the infant's readiness for a trial (i.e., facing directly forward) and turns of 45° (or more) toward the loudspeaker and toys. Stimulus tones were produced by two Hewlett-Packard 3325A synthesizer-function generators, attenuated by two Med Associates attenuators, switched on and off by two Med Associates rise–fall switches, and amplified by a Marantz 1070 amplifier.

Stimuli. Individual tones were 400-ms sine waves (pure tones), with 10-ms linear rise and decay times. The average intensity level was 75 dB (A), with an ambient noise level of 27 dB (A) or 42 dB (C) measured at the approximate location of the infant's head. Tone sequences were based on the first phrase of "Twinkle, Twinkle, Little Star," which was modified so that all tones were of equal duration and repeated tones were omitted. The modified tune consisted of Scale Steps 1, 5, 6, 5, 4, 3, 2, and 1 (see Figure 2). Tones in the sequence conformed to the major scale in one condition and to the equal-step scale in the other condition. In both conditions, the sequence was presented repeatedly in transposition, which means that pitch levels varied from one presentation to another but that pitch relations between tones were preserved. Three different transpositions, or pitch levels, were used. For both conditions, the size of the transpositions was equal to the most common step of the scale to which the sequence conformed. Specifically, on consecutive presentations, the frequencies of all component tones were multiplied or divided by $2^{2/12}$ (1.122) in the major condition and by $2^{1/7}$ (1.104) in the equal-step condition. Tones in the lowest transposition of the major-scale sequence had frequencies of 300, 449, 505, 449, 400, 378, 337, and 300 Hz, whereas tones in the lowest transposition of the equal-step sequence had frequencies of 300, 446, 492, 446, 404, 366, 331, and 300 Hz. Frequencies of the initial and final (lowest) tones of the other two transpositions equaled 337 or 378 Hz in the major condition and 331 or 366 Hz in the equal-step condition. Comparison sequences (i.e., one for each of the three transpositions) for each condition were identical to the repeating standard sequence except that the third, or highest tone, was raised by 1.5 semitones (e.g., 505 Hz changed to 551 Hz in the major condition; 492 Hz changed to 537 Hz in the equal-step condition). In the training phase, the comparison sequence incorporated a more prominent change to the third tone: 3.5 semitones (e.g., 505 Hz was raised to 618 Hz in the major condition; 492 Hz was raised to 602 Hz in the equal-step condition).

Procedure. Infants were tested individually. They sat on their parents' laps in one corner of the sound-attenuating booth, facing an assistant. Infants were assigned randomly to one of the two conditions: major or equal step. The standard version of the sequence (major or equal step) repeated in transposition throughout the entire test session, with 1,600 ms between presentations. Transpositions were selected in a "random-walk" pattern, such that consecutive presentations were at an adjacent (next higher or lower) pitch level. Each condition had 12 change trials and 12 no-change trials in pseudorandom order, with the constraint that there would be no more than two consecutive no-change trials. On change trials, the comparison sequence replaced the standard (background) sequence. No-change trials consisted of another repetition of the standard sequence and were therefore indistinguishable from the repeating background.

The assistant used hand-held toys to attract the infant's attention. When the infant was facing directly forward, the assistant called for a trial by pressing a button on the buttonbox. Any time the infant turned toward the loudspeaker (45° or more), the assistant pressed another button. The computer recorded head turns during a response window that began with the onset of the third (potentially changed) tone and ended 4 s later (with the onset of the third tone of the subsequent sequence). Correct responses—head turns on change trials within the 4-s response window—were reinforced by the illumination and activation of a mechanical toy for 3 s. No-change trials provided an estimate of false alarms, or turning toward the loudspeaker in the absence of a change. Head turns during no-change trials or at other times had no consequence for the infant. Although the number of repeating standard sequences between trials could vary from trial to trial, the minimum was two. During testing, the parent and experimenter listened to masking music on headphones so that they were unaware of the type of trial being presented.

The test phase was preceded by a training phase designed to familiarize infants with the procedure. The training phase was identical to the test phase except for the following details: All trials were change trials, the to-be-detected change was more substantial (see the *Stimuli* section), and the intensity of the first two trials was 5 dB greater than the intensity of the repeating standard sequence. The intensity of subsequent training trials was equivalent to the intensity of the standard sequence unless the infant failed to respond on two successive trials, at which time the intensity was increased by 5 dB (to a maximum of 10 dB greater than the standard sequence). Correct responding resulted in 5-dB reductions in intensity until the intensity of the comparison stimuli matched that of the standard stimuli. Infants proceeded to the test phase after achieving four consecutive correct responses with standard and comparison sequences at an equivalent intensity. Infants who failed to meet the training criterion within 20 trials were excluded from the test phase.

Results and Discussion

Proportions of hits (head turns during change trials) and false alarms (head turns during no-change trials) were converted to d' scores for each infant according to yes–no tables of signal-detection theory (Elliott, 1964). To eliminate the possibility of infinite d' scores that could result from perfect responding, 0.5 was added to the numerator (the number of hits or false alarms) and 1 to the denominator (the number of trials), which altered the d' scores slightly but did not affect the rank ordering of scores (Thorpe, Trehub, Morrongiello, & Bull, 1988).

One-sample t tests were used to evaluate the detectability of the change, that is, whether the scores significantly exceeded chance levels ($d' = 0$, or an equal number of hits and false alarms) in each condition. Infants detected the mistunings in the major-scale condition, $t(19) = 2.47$, $p = .0229$, but not in the equal-step condition, $t(19) = -1.09$, $p = .2907$. An independent-samples t test confirmed that performance in the major-scale condition ($M = 0.30$,

$SD = 0.55$) significantly exceeded performance in the equal-step condition ($M = -0.15$, $SD = 0.62$), $t(38) = 2.45$, $p = .0190$.

This finding is consistent with the hypothesis that unequal-step scales such as the major scale confer processing advantages relative to equal-step scales. Is it possible that superior performance on the major-scale sequence stemmed from incidental listening experience? Although infants' exposure to music is admittedly limited, the tune shared by "Twinkle, Twinkle," "The ABC Song," and "Baa Baa Black Sheep" is sung more than any other tune by local mothers (Trehub, Unyk, et al., 1997). If infants treated the pure-tone sequence in the present experiment as "familiar," they had to generate an accurately tuned representation (with all pitches being members of the major scale) from the informal performances of their parents. Moreover, they had to recognize the similarity between the at-home and experimental versions, which differed in the number of tones (14 vs. 8, respectively), rhythm (unequal vs. equal durations of tones), and timbre (vocal vs. sine wave). The conceptual challenges of such a task seem daunting for 9-month-olds. Indeed, many adults found the simplified "Twinkle, Twinkle" unrecognizable. In any case, a similar pattern of performance for an unfamiliar sequence based on the major scale or on another unequal-step scale would provide unequivocal support for the notion of processing advantages for unequal- over equal-step scales.

Experiment 2

Although most North American infants have been exposed to music based on the major scale, we know of no one who has claimed that 9-month-olds are familiar with the scale itself. On the contrary, infants appear to lack implicit knowledge of major-scale structure (Lynch et al., 1990; Trainor & Trehub, 1992), and such knowledge is relatively undeveloped in young children compared with adults (Krumhansl & Keil, 1982). Accordingly, we elected to present the complete major and equal-step scales in ascending–descending form. The major scale is a familiar pattern for most adults but not for infants. In a comprehensive survey of parental singing to infants (Trehub, Unyk, et al., 1997), no parent ever reported singing scales to their infants. In fact, entire scales rarely appear in musical pieces, being the tonal material from which musical pieces are constructed. Serafine (1983, 1988) even disputed the notion of scales as the material of music, arguing instead that scales are merely by-products of music analysis. Clearly, only infants who are regularly exposed to someone engaging in scale practice would be in a position to become familiar with the major scale.

Nonetheless, the majority of musical pieces in the Western repertoire are based on major scales, and component tones of virtually all infant- and child-directed songs are drawn from the major scale. Thus, we included a third scale to control for the possibility that enhanced performance with the major scale might stem from exposure to Western music. This third scale, like the equal-step scale, was designed to be completely unfamiliar to any listener, infant or adult. Specifically, the new unequal-step scale included seven tones from an octave divided into 11 rather than 12 equal intervals. As with the major scale, adjacent tones in the new unequal-step scale were either 1 or 2 subdivisions apart, although these subdivisions were slightly larger than their counterparts in the major scale (semitones), with the frequency of the higher tone being $2^{1/11}$ (rather than $2^{1/12}$) times the frequency of the lower tone. Going from the lowest tone to the highest tone, consecutive tones in the new unequal-step scale were 2, 1, 2, 1, 2, 2, and 1 subdivisions apart.

The experiment had three conditions, each corresponding to one of the scales: (a) major (unequal-step scale, potentially familiar); (b) unequal step (unfamiliar, unequal-step scale devised for this experiment); and (c) equal step (unfamiliar, from Jordan & Shepard, 1987; Shepard & Jordan, 1984). If there are inherent perceptual advantages for scales with unequal steps over those with equal steps, then infants should detect mistunings more readily in the context of both unequal-step scales. Moreover, if infants' performance on the major version of "Twinkle, Twinkle" (Experiment 1) stemmed from unequal scale steps rather than familiarity, then their performance on the major and unequal-step conditions should not differ.

Method

Participants. The participants were 36 healthy full-term infants between 8 months 15 days and 9 months 15 days of age (M = 8 months 28 days). Another 21 infants were excluded from the final sample because of fussing ($n = 5$), parental interference ($n = 1$), or not meeting the training criterion ($n = 15$).

Apparatus. The apparatus was identical to that used in Experiment 1.

Stimuli. Infants heard a standard version of a scale (see Figure 1) presented repeatedly. The repeating standard scale was a sequence of 15 pure tones (each 400 ms with 10-ms linear onsets and offsets), consisting of 8 different tones presented in ascending–descending order (lowest to highest to lowest tone), for a total of 6 s. The intensity of component tones was identical to that of Experiment 1. In each of the three conditions, consecutive presentations of the repeating scale sequence were transposed, with 800-ms silence between transpositions. As in Experiment 1, all sequences had a simple up–down contour and were presented at three different transpositions (i.e., pitch levels), selected in a different random walk for each infant. The initial and final tones of the lowest transposition were 300 Hz. Tones of the major scale in its lowest transposition had frequencies of 300, 337, 378, 400, 449, 504, 566, and 600 Hz during the ascending portion and the same frequencies in reverse order during the descending portion (the highest tone was not repeated); corresponding frequencies of tones in the unequal-step scale were 300, 340, 362, 411, 438, 497, 563, and 600 Hz, whereas frequencies in the equal-step scale were 300, 331, 366, 404, 446, 492, 543, and 600 Hz. As in Experiment 1, transpositions for each condition equaled the most common interval in the scale, such that the frequencies of consecutive presentations were multiplied or divided by $2^{2/12}$, $2^{2/11}$, or $2^{1/7}$ in the major, unequal-step, and equal-step conditions, respectively. Thus, tones of the two higher transpositions had frequencies of the lowest transposition multiplied by $2^{2/12}$ (1.122) or $2^{4/12}$ (1.260) in the major condition, frequencies multiplied by $2^{2/11}$ (1.134) or $2^{4/11}$ (1.287) in the unequal-step condition, and frequencies multiplied by $2^{1/7}$ (1.104) or $2^{2/7}$ (1.219) in the equal-step condition. In the major condition, the initial and final tones of the scale sequences were 300, 337, or 378 Hz. In the unequal-step condition they were 300, 340, or 386 Hz, and in the equal-step condition they were 300, 331, or 366 Hz.

For all conditions, a mistuned version of the scale was formed for each of the three transpositions by displacing the sixth scale step upward by three quarters of a semitone (frequency multiplied by 1.044) in both ascending and descending portions of the scale. This mistuning increased the interval size between the fifth and sixth scale steps but decreased the interval size between the sixth and seventh steps. The sixth step was selected because, in all three scales, it is preceded and followed by intervals of equal size (2 semitones in the major condition, 2.182 semitones in the unequal-step condition, and 1.713 semitones in the equal-step condition). In the lowest transposition, the frequency of the sixth scale step was mistuned upward from 504 to 526 Hz for the major scale, from 497 to 519 Hz for the unequal-step scale, and from 492 to 514 Hz for the equal-step scale. For all three conditions, a more substantial mistuning (1.1 semitones upward, or frequency multiplied by 1.066) was used in an initial training phase (e.g., the sixth scale step was mistuned from 504 to 537 Hz, from 497 to 530 Hz, or from 492 to 524 Hz in the major, unequal-step, and equal-step scales, respectively). As in Experiment 1, each condition had 12 change and 12 no-change trials in pseudorandom order, and changes in intensity were included in the training phase.

Procedure. Infants were tested individually and assigned randomly to the major condition ($n = 12$), the unequal-step condition ($n = 12$), or the equal-step condition ($n = 12$). The procedure was otherwise identical to that used in Experiment 1, except that the response window began with the onset of the sixth (potentially changed) tone of trial sequences and ended 4.8 s later (with the onset of the subsequent sequence).

Results and Discussion

Discrimination (d') scores were calculated separately for each infant, as described in Experiment 1. Performance is shown in Figure 3 as a function of condition. Although the detection of mistunings was significantly greater than chance in the major condition, $t(11) = 2.62$, $p = .0238$, and in the unequal-step condition, $t(11) = 2.23$, $p = .0472$, performance was at chance levels in the equal-step condition, $t(11) = -1.36$, $p = .2005$. An analysis of variance (ANOVA) confirmed that differences in performance across conditions were statistically reliable, $F(2, 33) = 4.64$, $p = .0167$. Post hoc comparisons (Tukey's honestly significant differences [HSD] test) revealed that 9-month-old infants performed significantly better on the major scale ($M = 0.39$, $SD = 0.52$) than on the equal-step scale ($M = -0.14$, $SD = 0.44$; $p = .0286$). Performance on the unequal-step scale ($M = 0.37$, $SD = 0.57$) also exceeded performance on the equal-step scale ($p = .0385$) but did not differ from performance on the major scale ($p = .9909$).

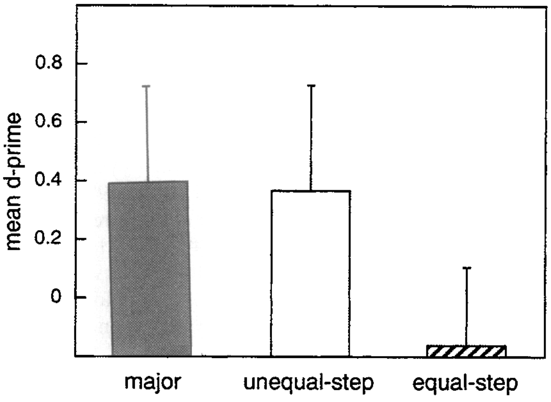

Figure 3. Infant performance on the major, unequal-step, and equal-step versions of the ascending–descending scale (Experiment 2). Error bars are 95% confidence intervals.

Thus, infants' superior performance on the major version of "Twinkle, Twinkle" (Experiment 1) cannot be attributed to familiarity with the major scale. Rather, the results of the present experiment are consistent with our proposal of an inherent perceptual bias favoring unequal-step over equal-step scales. In two other experiments, we examined the effects of long-term listening experience on the perception of scale structure.

Experiment 3

We evaluated adults' ability to detect mistunings to the same major scale, unequal-step scale, and equal-step scale that had been used with infants in Experiment 2. Because the major scale is familiar to many adults in the western world regardless of their musical experience or training, we expected them to exhibit reasonably high levels of performance in major-scale contexts. Our predictions regarding the unfamiliar equal- and unequal-step scales were less clear. On the one hand, adults might exhibit better performance in unequal-step than in equal-step contexts, in line with the proposed perceptual bias for unequal-step scales. On the other hand, adults' poor discrimination of some foreign-language contrasts reflects interference from their native phonological system (Best & Strange, 1992; Polka, 1995; Werker & Polka, 1993). Moreover, adults are unable to profit from the redundancy of melodic patterns when the musical context is unfamiliar (Schellenberg & Trehub, in press). Because adults have a lifetime of exposure to Western music, most of which is based on the major scale, they might have difficulty perceiving and remembering unfamiliar scales regardless of their structure.

Method

Participants. The listeners were 21 undergraduates who received partial credit in an introductory psychology course.

Apparatus. Scale sequences were generated and stored in 16-bit format (sampling rate of 22.05 kHz) using SoundEdit 16 software installed on a Macintosh Power PC 7100/66 AV computer. A customized program generated with PsyScope 1.1 software (J. D. Cohen, MacWhinney, Flatt, & Provost, 1993) was used to control stimulus presentation and to record responses. Stimuli were sent from the computer to a mixer (Yamaha Mixing Console MR842) and then presented over headphones (SONY CD 550) at a comfortable listening level while listeners sat in a sound-attenuating booth (Eckel Industries) and looked at the computer monitor through a window in the booth. Listeners used a buttonbox connected to the computer to initiate trials and to record their responses.

Stimuli. The standard stimuli were essentially identical to those used in Experiment 2. As in Experiments 1 and 2, stimulus tones were 400-ms sine waves with 10-ms linear onsets and offsets. On each trial, listeners heard two complete ascending–descending scales. The first scale was always the well-tuned (standard) version. On "same" trials, the second scale was identical to the first (no mistuning), except that it was transposed upward by 2.5 semitones (all frequencies were multiplied by 1.155). This transposition is unrelated to the scale steps of the three experimental scales and was therefore neutral with respect to the hypotheses. On "different" trials, the second (transposed) scale of each trial was the mistuned (comparison) scale.

The initial tone of each trial was selected randomly from a set of five tones: 250, 290, 330, 370, or 410 Hz. These initial tones are related by a constant difference in frequency rather than a constant frequency ratio and therefore have no association with scales from any culture (Dowling & Harwood, 1986). Tones of the first scale of "same" trials presented at the lowest pitch level had frequencies of 250, 281, 315, 334, 375, 420, 472, and 500 Hz in the major condition; frequencies of 250, 284, 302, 343, 365, 414, 469, and 500 Hz in the unequal-step condition; and frequencies of 250, 276, 305, 336, 371, 410, 453, and 500 Hz in the equal-step condition. Tones of the second scale had the same frequencies multiplied by 1.554 (e.g., 250 Hz was changed to 289 Hz, 281 Hz was changed to 324 Hz, etc.). On "different" trials, the sixth tone of the second scale was mistuned upward by 0.5 semitones (i.e., frequency multiplied by 1.029) relative to "same" trials (e.g., from 486 to 500 Hz, from 478 to 492 Hz, and from 474 to 488 Hz in the major, unequal-step, and equal-step conditions, respectively). "Different" trials in the practice session had a larger mistuning: 1.5 semitones (i.e., frequency multiplied by 1.091; e.g., from 486 to 530 Hz, from 478 to 521 Hz, and from 474 to 517 Hz in the major, unequal-step, and equal-step conditions, respectively). Practice "same" trials were identical to those used in the actual test session. Thus, the principal differences between the adult and infant versions (five vs. three starting pitch levels, a 0.5- vs. 0.75-semitone change to be detected, and same–different versus go/no-go procedure) were designed to provide appropriate levels of task difficulty for the two age groups.

Procedure. Adult listeners were tested individually and assigned randomly to one of three conditions (major, unequal step, or equal step), with 7 listeners per condition. After listeners completed a musical background questionnaire, we used a musical demonstration to inform them that a melody could be transposed in pitch and maintain its identity and that "same" in a musical context included exact transpositions. Listeners were then seated in the sound-attenuating booth and the experimenter explained the procedure, including the use of the buttonbox. Listeners were told that they would hear a standard and a comparison scale on each trial and that their task was to decide whether the standard and comparison were the same or different.

Listeners signaled to the computer (by pressing a button on the buttonbox) when they were ready for a trial. Each condition had 50 "same" trials and 50 "different" trials. Listeners pressed one button on the buttonbox if they thought the two scales were the same and another button if they thought the scales differed. Visual feedback ("correct" or "incorrect") was provided on the computer monitor after each trial. The test phase was preceded by four practice trials: two "same" and two "different."

Results and Discussion

A discrimination (d') score was calculated for each listener, as in Experiment 1. Performance (see Figure 4, upper panel) exceeded chance levels in all conditions: major, $t(6) = 8.06, p = .0002$ ($M = 2.40$, $SD = 0.79$); equal-step, $t(6) = 4.08, p = .0065$ ($M = 0.39$, $SD = 0.25$); and unequal step, $t(6) = 4.32$, $p = .0050$ ($M = 0.42$, $SD = 0.26$). An ANOVA confirmed that differences among conditions were statistically reliable, $F(2, 18) = 37.28, p < .0001$. Pairwise comparisons (Tukey's HSD test) revealed that performance on the familiar major scale exceeded performance on the equal-step scale ($p = .0002$) and on the unequal-step scale ($p = .0002$). Performance was virtually identical for the two unfamiliar scales ($p = .9910$). This pattern of results was identical when a covariate measuring listeners' years of music lessons was included in the analyses; the strength of the covariate did not differ across testing conditions.

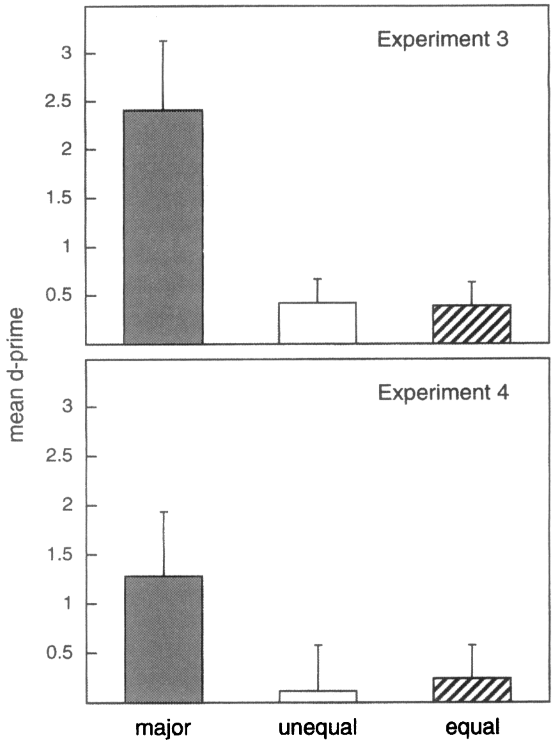

Figure 4. Adult performance on the ascending–descending major, unequal-step, and equal-step scales in Experiment 3 (upper panel) and Experiment 4 (lower panel). Error bars are 95% confidence intervals.

In short, adults were better at detecting changes to the major scale than to the equal-step scale or the unequal-step scale. The results reveal clear effects of familiarity, with superior performance for familiar over unfamiliar scale structures. Because the effect was evident when years of musical training were held constant, it is safe to conclude that such familiarity effects arise from passive exposure to music. Interestingly, performance was equally poor for both unfamiliar scales despite the presence of equal steps in one case and unequal steps in the other.

Experiment 4

In the present experiment, we examined the generalizability of the findings obtained in Experiment 3. Specifically, we evaluated adult listeners' ability to detect a downward mistuning of the fifth step of three scales rather than an upward mistuning of the sixth step. Two of the scales were the same major and equal-step scales used in Experiments 2 and 3. Because the location of the single and double steps of the unequal-step scale of Experiments 2 and 3 was arbitrary, we created a new unequal-step scale from the 11-fold division of the octave.

Method

Participants. The listeners were 21 undergraduate students who received partial course credit for their participation.

Apparatus. The equipment was identical to that of Experiment 3.

Stimuli. Like the unequal-step scale in Experiments 2 and 3, the new unequal-step scale was formed by selecting seven tones from an octave subdivided into 11 equal steps, with adjacent tones in the resulting scale separated by single or double subdivisions. The single subdivisions in the new scale were between Steps 1 and 2, Steps 3 and 4, and Steps 6 and 7, with other adjacent tones being separated by double subdivisions. At the lowest pitch level, tones of the first scale on trials in the unequal-step condition had frequencies of 250, 266, 302, 322, 365, 414, 441, and 500 Hz. The first and second scales of test trials were otherwise formed as in Experiment 3 for all three conditions, except that the fifth tone of the second scale on "different" trials was mistuned downward by 0.5 semitones (i.e., frequency divided by 1.029) relative to "same" trials (e.g., from 433 to 420 Hz, from 422 to 410 Hz, and from 429 to 417 Hz, in the major, unequal-step, and equal-step conditions, respectively). As in Experiments 2 and 3, the potentially mistuned (fifth) tone of well-tuned sequences was equidistant from adjacent lower and higher tones for each of the three scales. For the two "different" trials in the practice session, the fifth tone was mistuned upward by 3 semitones relative to "same" trials (e.g., from 433 to 515 Hz in the major condition, from 422 to 501 Hz in the unequal-step condition, and from 429 to 510 Hz in the equal-step condition).

Procedure. The procedure was identical to that used in Experiment 3.

Results and Discussion

As in Experiment 1, a discrimination (d') score was formed for each listener. Performance (see Figure 4, lower panel) exceeded chance levels in the major condition, $t(6) = 4.57$, $p = .0038$, but not in the equal-step or unequal-step conditions. Differences among conditions were statistically reliable, $F(2, 18) = 9.15$, $p = .0018$, with post hoc comparisons (Tukey's HSD test) revealing a pattern identical to that observed in Experiment 3. Performance in the major condition was superior to performance in the equal-step and unequal-step conditions (ps = .0071 and .0031, .0031, respectively), which did not differ ($p = .9174$). The pattern of results did not change when a covariate measuring years of music lessons was included in the analysis, and there was no interaction between the covariate and testing condition. Thus, adults' performance on familiar and unfamiliar scales generalized across mistunings (upward or downward), location of the mistuned tone (sixth or fifth scale step), and pattern of scale steps in the unfamiliar, unequal-step scale.

General Discussion

Infants who were 9 months of age more readily detected mistunings to a simplified version of "Twinkle, Twinkle, Little Star" based on the major scale—an unequal step scale—than to an alternate version based on an equal-step scale. Infants were also better at detecting mistunings to two unequal-step scales (the major scale and an artificial scale) than to an equal-step scale when the scales were presented in ascending–descending form. The absence of performance differences between the two unequal-step scales rules out familiarity as a factor contributing to better infant performance on the major scale than on the equal-step scale. Instead, our findings offer further support for the view that unequal-step sizes in scales contribute to their ease of processing and to their common occurrence across cultures (Brown, 1988; Butler, 1989; Jordan & Shepard, 1987; Sloboda, 1985).

In the case of adults, superior processing of the major scale over the equal-step scale could be attributed to long-term exposure to music based on the major scale (Cuddy, Cohen, & Mewhort, 1981; Cuddy, Cohen, & Miller, 1979) or to structural differences between the scales. Although the findings on infants imply that unequal-step scales are inherently easier to perceive than are equal-step scales, adults' superior performance on familiar (the major scale) over unfamiliar (the artificial scale), unequal-step scales underlines the importance of culture-specific exposure. Knowledge of the major scale likely interfered with adults' processing of other unequal-step scales, just as adults' knowledge of native-language sounds interferes with their perception of some nonnative phones (Best, 1994; Polka, 1995).

The growing list of adult–infant similarities in music perception is suggestive of biological preparedness for the processing of musical sequences. For example, infants respond primarily to relational pitch information in melodies (Trehub, Bull, & Thorpe, 1984; Trehub, Thorpe, & Morrongiello, 1987), as do adults (Bartlett & Dowling, 1980; Dowling, 1978). Specifically, they readily retain the melodic contour, or pattern of successive pitch changes (up, down, or level), in a melody but have difficulty retaining exact pitch information (i.e., absolute pitches). Infants' attention to the pitch contours of speech sequences (Fernald, 1991, 1993; Fernald & Kuhl, 1987) is a notable linguistic parallel. Infants and adults also show superior processing of melodies whose component tones are related by small-integer ratios rather than large-integer ratios (A. J. Cohen et al., 1987; Schellenberg & Trehub, 1994a, 1996b; Trainor & Trehub, 1993; Trehub et al., 1990). Moreover, infants are similar to adults in their perception of consonance and dissonance. Like adults, they group patterns on the basis of their consonance (Schellenberg & Trainor, 1996) and "prefer" consonant, or smooth-sounding, combinations of tones over dissonant, or rough-sounding, combinations (Trainor & Heinmiller, 1998; Zentner & Kagan, 1996). Infants' responses to consonant and dissonant patterns are consistent with the view that sensory consonance has influenced the scales of most cultures (Burns & Ward, 1982). Finally, not only do infants recognize the rhythmic invariance of tone patterns across variations in tempo (Trehub & Thorpe, 1989), but they also show more precise pitch and temporal processing of melodies that are rhythmically "good" (as judged by adults) compared with those that are rhythmically "bad" (Trehub, Hill, & Kamenetsky, 1997).

It would seem, then, that the similarities between listeners with minimal exposure to music (i.e., infants) and those with extensive incidental exposure (i.e., adults) make a compelling case for innate perceptual biases, or "learning preferences" (Marler, 1990), in relation to music. How can one reconcile the numerous parallels between adults and infants, which some researchers (e.g., Trehub, Schellenberg, & Hill, 1997) attribute to processing predispositions, with the performance differences observed in the present research, which are obviously attributable to exposure? An analogy from *principles and parameters theory* (Atkinson, 1992; Hyams, 1986) may be useful here. According to the theory, children have innate knowledge of universal grammar, which consists of principles common to all languages, and options, or parameters, that are set by experience with a specific language. The substantial innate component reduces the enormous challenge of language acquisition from one of learning the entire rule system to that of setting parameters. In the case of music, universal principles would include relational pitch processing, pitch-contour processing, as well as perceptual biases for small-integer ratios (in pitch and temporal patterning) and unequal-step scales. The flexible parameters might include supplementary intervals (beyond the core set of universal intervals), pitch range (e.g., within or beyond one octave), and higher order rules of harmony (simultaneous combinations of notes). For example, many rules of Western harmony (Aldwell & Schachter, 1989) apply exclusively to Western music.

Adults exposed to a second language are presumed to engage in parameter *resetting* (White, 1989, 1990) or to use less efficient mechanisms because of the inaccessibility of universal grammar beyond childhood (Wong Fillmore, 1991). Similarly, adults exposed to a new musical system would experience *transfer* with respect to universal musical principles and *interference* with respect to differences in required parameter settings. Although the infant findings imply that unequal-step scales are among the universal principles, the adult findings indicate that new scales whose features conflict with those of highly overlearned scales will be difficult to perceive and remember.

It is important to emphasize, however, that our use of the principles and parameters analogy does not represent a commitment to domain-specific principles or to localized neuronal architecture (e.g., Chomsky, 1991; Pinker, 1984) comparable to a language acquisition device. In other words, we are not proposing a music acquisition device. Indeed, there is no compelling reason to posit anything beyond general constraints that arise from the nature of the human auditory system and from limitations of working memory. For example, the processing of pitch contours and rhythms is relevant to all auditory sequences, whether they involve speech, music, or environmental sounds. Information-processing constraints are reflected not only in infants' enhanced processing of particular melodic structures but also in the basic design of musical systems across cultures (Lerdahl, 1988; Trehub, Schellenberg, & Hill, 1997; Trehub & Trainor, 1993). As Nettl (1983) noted, the variety of extant music is considerably more restricted than "the boundaries of the imaginable" (p. 43). One consequence of musical cultures building on perceptual processing predispositions is that exposure and training often result in progressive improvement of the very skills that are favored by nature.

If equal-step scales provide inherently unsuitable material for melodies, then why would any culture develop music based on such scales? The strongest claims about the role of equal-step scales have been made in relation to the music of Thailand (Montri Tramote, cited in Morton, 1976; Myers-Moro, 1993), where the hypothesized scale corresponds to a division of the octave into seven equal steps, essentially the equal-step scale used in the present research and that of Shepard and Jordan (1984; Jordan & Shepard, 1987). Nonetheless, Morton's (1976) extensive analysis of compositions from the traditional Thai repertoire led him to reject the equal-step scale as the basis of Thai melodies.

> The music never uses all seven pitches of its tuning system as principal pitches.... Some occur on the emphasized beats, others only as passing tones in secondary position—and the result is in effect a mode or scale of five pitches (pentatonic) and an auxiliary, additional secondary pitch (or pitches) used for decoration. In practical modes and/or scales a gapped or nonequidistant pattern occurs. (p. 24)

In fact, the pentatonic scale that was evident—Steps 1, 2, 3, 5, and 6 of the equal-step scale (Morton, 1976)—is structurally comparable to the most common pentatonic scale formed from the chromatic pitch set (Lerdahl & Jackendoff, 1983).

The equal-step scale is inadequate for indicating the functional significance of particular pitches as well as the pitch content in Thai melodies. Scales, which are music theorists' conception of the pitch materials of existing musical compositions, fail to reveal critical information about pitch relations or the unfolding of pitches over time (Butler & Brown, 1994, p. 195). Indeed, the interval formed by the first and fifth scale steps, which approximates a 3:2 ratio in equal-step and major scales, seems to have special significance in Thai music (Morton, 1976), as it does in Western music and in other music of the world (Schellenberg & Trehub, 1994b; Trehub, Schellenberg, & Hill, 1997). The status of the equal-step scale in Thai music may well be comparable to that of the chromatic scale in Western music, which divides the octave into 12 equal steps and appeared some centuries after the emergence of Western tonal music. Just as the chromatic scale does not reflect the pitch content of Western compositions—except for 20th-century art music—equal-step scales may not reflect the pitch content of the music from any culture.

In short, infants more readily detected subtle pitch changes in two unequal-step scales—the Western major scale and a novel, unequal-step scale—than in an equal-step scale. Adults more readily detected subtle pitch changes in a familiar, unequal-step scale than in unfamiliar scales that contained equal or unequal steps. The most parsimonious interpretation of these findings involves processing predispositions favoring scales with unequal steps coupled with familiarity effects resulting from long-term exposure.

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