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Infants' Perception of Musical Relations in Short Transposed Tone Sequences*

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ABSTRACT Infants 7 to 11 months of age were tested for their detection of a frequency relational change of one semitone in a five-note melody. Melodies were presented in various transpositions that altered absolute frequencies of the component tones but preserved the frequency ratios. In Experiment 1, two background melodies were based on major and minor triads, both of which occur commonly in Western tonal music. Contrast melodies were minor or major triads, respectively. Infants were able to discriminate these contrasting melodies that differed from the background melodies by one semitone. In Experiment 2, infants were found to detect a semitone difference more easily when the major triad was background and a relatively uncommon triad, the augmented triad, was the contrast. They failed to make this discrimination when the roles of these two melodies as background and contrast were reversed. In a final study, infants discriminated the major and minor backgrounds used in Experiments 1 and 2 from contrasting variations, called inversions, that did not differ in triad quality as did previous background/contrast pairs. Therefore, encoding of triad quality alone cannot account for the evidence of discriminability in Experiments 1 and 2. Rather, the ability to detect a semitone difference in transposed melodies indicates that infants can respond to precise relations between the component tones of a melody based on familiar or stable structures. These findings also imply that sets of tones that are unfamiliar or unstable may present encoding or memory difficulties for infants, as has been found for children and adults.

RÉSUMÉ Des enfants âgés de 7 à 11 mois ont été évalués sur leur capacité à détecter un changement de fréquence relationnelle d'un demi-ton dans une mélodie de cinq notes. Les mélodies étaient présentées dans diverses transpositions de façon à altérer les fréquences absolues tout en préservant les rapports de fréquence. Dans l'expérience 1, deux mélodies de fond étaient basées sur des triades majeures et mineures, les deux étant communément retrouvées dans la musique tonale occidentale. Les mélodies de contraste étaient des triades mineures ou majeures, respectivement. Les enfants étaient capables de discriminer les mélodies contrastantes qui différaient des mélodies de fond d'un demi-ton. Dans l'expérience 2, l'on rapporte que les enfants détectaient plus facilement une différence d'un demi-ton lorsque la triade majeure était en fond et qu'une triade relativement peu commune, la triade augmentée, était la triade contrastée. Ils étaient incapables de faire cette discrimination lorsque les rôles de ces deux mélodies étaient inversées. Dans l'étude finale, les enfants pouvaient discriminer les fonds majeurs et mineurs utilisés dans les expériences 1 et 2 des variations contrastantes, appelées inversions, qui ne différaient pas dans la qualité des triades telles que l'étaient les paires fond/contraste précédentes.

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The present paper concerns infants' ability to discriminate between two melodies that differ only in the frequency ratio between certain tones. The principal purpose was to determine whether infants are sensitive to precise frequency relations. A secondary goal was to explore the variables that might affect this ability. Although these questions relate directly to musical processing, they also apply to the processing of prosodic aspects of speech and to perceptual development in general.

On the basis of past research, we know that infants can categorize single sounds with common fundamental frequency, intensity, and duration (e.g., Clarkson & Clifton, 1985; Endman, 1985; Kuhl, 1979). Infants also categorize tone sequences that share melodic contour (Chang & Trehub, 1977; Thorpe, 1986; Trehub, 1984; Trehub, Bull, & Thorpe, 1984; Trehub, Thorpe, & Morrongiello, 1985), the ordinal pattern of directional frequency changes. For example, infants can discriminate a descending melodic pattern from an ascending pattern. Infants' tendency to generalize over the dimension of contour does not preclude the possibility that they can detect differences in frequency ratios in melodies with the same contour. Indeed, such precise information is relevant to the appreciation of some aspects of Western tonal music.

The smallest ratio separating tones in music is called the semitone and represents the frequency ratio of $2^{1/12}$ or 1.06 : 1.00, giving rise to the 12 semitones in the octave. The distance between tones in a melody, called an interval, is measured in semitone units. Intervals with the same number of semitones may be represented by different pairs of absolute frequencies. For example, the intervals of C4 to E4 (262-330 Hz) and D4 to F#4 (294-370 Hz) are four semitones and approximate the frequency ratio of 4 : 5. Thus, one interval is the transposition of the other, both notes of the second interval being two semitones higher than those of the first interval. Similarly, the tones of a melody can be transposed by moving each tone a constant number of semitones. This transformation preserves the interval structure but alters absolute frequency by a constant multiplier. Figure 1a illustrates, in musical notation, transpositions of the opening notes of the familiar tune, *Mary Had a Little Lamb*. Although the absolute frequencies differ, the interval size (shown below the notation) remains constant under transposition.

Differences in interval size make it possible to distinguish between different melodies having the same contour. For example, as shown in Figure 1b, the second and third intervals of *Mary Had a Little Lamb* differ by one semitone from corresponding intervals in *Whistle While You Work*. Note, however, that both melodies have the same contour (ups and downs). If infants encode contour only, they should be unable to distinguish between two melodies of the same contour that differ in interval size. In the present research, we sought to determine whether infants could differentiate between melodies on the basis of frequency ratios alone.

Trehub, Cohen, Thorpe, and Morrongiello (1986) demonstrated that infants could detect a semitone difference in the context of a five-tone melody. In this study, a melody was repeated continuously and, from time to time, one note in this repeating background was altered by one semitone. If the infant responded to the

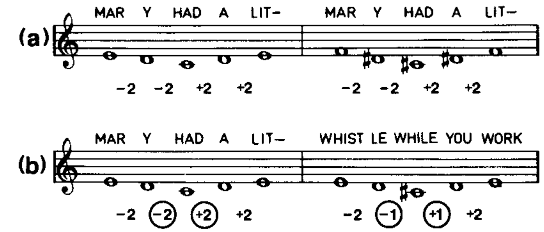

Figure 1. (a) Notation of a transposition of one raised semitone of the first five notes of a familiar tune. The interval sequence measured in semitones is preserved under this transposition (i.e., $-2-2+2+2 = -2-2+2+2$). In transposition, absolute frequency of tones is altered by the ratio 1.06. (b) Notation of the first five tones of two melodies having the same descending/ascending contour but differing in size in semitones of the second and third intervals (circled); i.e., $-2-2\ +2+2$ vs. $-2-1+1+2$.

changed melody (by turning toward the sound source), visual reinforcement was presented. Infants indicated their discrimination of the semitone change by responding more frequently when the melody changed than when it did not. Because sequences in the study were always played at the same frequencies (i.e., not transposed), the discrimination could have been based on absolute rather than on relational frequency information.

Trehub et al. (1986) examined two different sequences, one based on the major triad and the other on the augmented triad. The major triad, an important and frequent structure in music, is considered to be a prototype of tonal structure (Schenker, 1954) and has a highly stable representation (see Dowling & Harwood, 1985; Krumhansl, Bharucha, & Kessler, 1982). The tones of the major triad, commonly referred to as *do mi sol*, are related by the frequency ratios 4 : 5 : 6. The interval between *do* and *mi* is four semitones and that between *mi* and *sol* is three semitones. The augmented triad is similar to the major triad in sharing the lower interval of four semitones, but it augments the upper interval to four semitones. The ratios among the frequencies are thus more complex, 16 : 20 : 25, and the representation of this triad is considered to be unstable. Trehub et al. found similar performance by infants for the major and augmented sequences, suggesting that priority for the major triad structure may not be present in infancy. Preschool children, on the other hand, performed better on major than on augmented sequences, suggesting that they were influenced by the musical structure of such sequences.

In Western tonal music, there is a general relation between interval-ratio simplicity of triads and frequency of occurrence. For example, our analysis of 30 nursery songs arranged by Joseph Moorat (1980) indicated no augmented triads and 80% major triads. Similarly, an analysis by Roberts (1982) of the four movements of the Beethoven Waldheim Sonata, Opus 53 indicated 1% augmented triads and 67% major triads. This means that, even for very young listeners with limited musical experience, there would still be greater exposure to certain triads, which consequently could lead to priority in processing. Such priority could also stem from repeated exposure to small ratios in complex tones (Terhardt, 1974) or from pitch processing mechanisms sensitive to periodicity (Creel, Boomsliter, & Powers, 1970). In any case, it is important to establish whether sensitivity to particular relations is present in infancy.

Cohen (1982) and Dewar, Cuddy, Mewhort (1977) have shown better adult recognition performance for well-structured versus poorly-structured sequences in a paradigm in which comparison sequences were not transposed, a finding in line with Trehub et al.'s (1986) evidence for preschoolers. Edworthy (1985) has argued, however, that transposed comparison sequences eliminate the possible reliance on absolute information and provide a better test of the perception of precise frequency relations (i.e., intervals). Thus, if infants' ability to encode frequency relations of melodies is to be considered, it is preferable to minimize the role of absolute frequency.

The goal of the following experiments was to determine whether infants could detect a semitone difference in transposed comparison melodies. In Experiment 1, we focussed on sequences based on common, simple triads. In Experiment 2, we examined the role of a less well-structured triad in the detection of the semitone change. In Experiment 3, we considered the role of triad quality in melodic discrimination and examined infants' ability to discriminate between melodies with the same triad quality and contour, but different interval size.

EXPERIMENT 1

In the present experiment, we attempted to determine whether infants could detect a difference of a semitone in a sequence presented in various transpositions. In its use of short melodies and a discrimination of one semitone, the present method resembled that of Trehub et al. (1986), except that the previous study used sequences that were not transposed. Trehub and her colleagues (e.g., Trehub et al., 1984) have suggested that contour is the most salient feature of infants' melodic perception. In a difficult task in which distractor tones were interpolated between successive six-tone melodies, infants confused melodies having the same contour and different intervals but did not confuse melodies that differed in contour. Frequency changes of a semitone in a melody do not alter contour. Thus, deprived of contour cues and absolute frequency cues, infants may well be unable to discriminate differences of a semitone in a transposed sequence.

In the Trehub et al. (1986) study, there was no effect of triad structure on infant performance, in contrast to findings with preschool children. It is possible, however, that the transposition of sequences in the present study would direct infants' attention to frequency relations, and would, therefore, increase the significance of musical structure. The standard and comparison sequences in the present experiment were based on major and minor triads that are commonly found in music and are considered to be similar in degree of musical structure (Roberts & Shaw, 1984). In other words, degree of musical structure in standard and comparison sequences did not provide a discriminative cue.

The minor triad has the same lowest and highest notes as the major triad but the middle tone is lowered one semitone. The discrimination of sequences based on

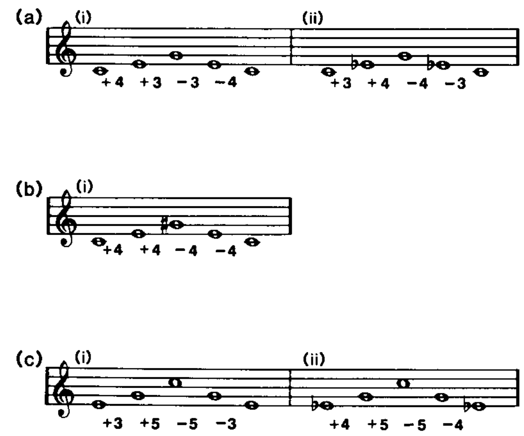

Figure 2. Notation of test melodies. (a) Experiment 1, (i) major and (ii) minor; (b) Experiment 2, (i) augmented; (c) Experiment 3, (i) major first inversion and (ii) minor first inversion. Interval size in semitones between adjacent tones is indicated below each sequence.

the major triad from those based on the minor represents a stringent test of relational encoding and memory, in that these patterns are similar with respect to structural significance in music, frequency of use, and familiarity, but differ in interval size by one semitone. Because of their greater frequency of occurrence (5:1 in nursery tunes, our count; 3:1 in classical music, Roberts's 1982 count), the frequency relations of the major triad may have priority over those of the minor triad, but this difference is slight in comparison to the virtual absence of the augmented triad, for example.

Method

Subjects: Participants included 25 healthy, full-term infants ranging in age from 7.4 to 10.7 months. Infants were excluded from the sample if they failed to meet a predetermined training criterion ($n = 0$), or if they did not complete the 30-trial testing session due to crying or fussing ($n = 1$). Each infant was tested with either the major or minor triad sequence as background. The final sample of 12 infants tested with the major triad background included 8 males and 4 females with a mean age of 9.3 months. The final sample of 12 infants in the minor triad condition comprised 9 males and 3 females with a mean age of 8.7 months.

Apparatus: The stimuli were generated on line by a synthesizer/function generator (Hewlett-Packard 3325A) and were presented via one channel of a stereo amplifier (Marantz, Model 1010) over a loudspeaker (Canton, Xi 270). Testing was carried out inside a double-walled, sound-attenuating chamber (Industrial Acoustics Co.). A microcomputer (Commodore PET, Model 2001-16N) connected to a custom-built interface controlled the synthesizer, the activation of toys, and lighting in each of the four chambers of the smoked Plexiglas box housing the reinforcers. The microcomputer also monitored the two keys of a small control box (two push buttons mounted on a Hammond chassis) by which the experimenter initiated trials and recorded responses from inside the testing booth.

Stimuli: The two standard sequences of five notes, as shown in Figure 2a, were the ascending-descending major triad (e.g., C4, E4, G4, E4, C4) and minor triad (e.g., C4, E♭4, G4, E♭4,

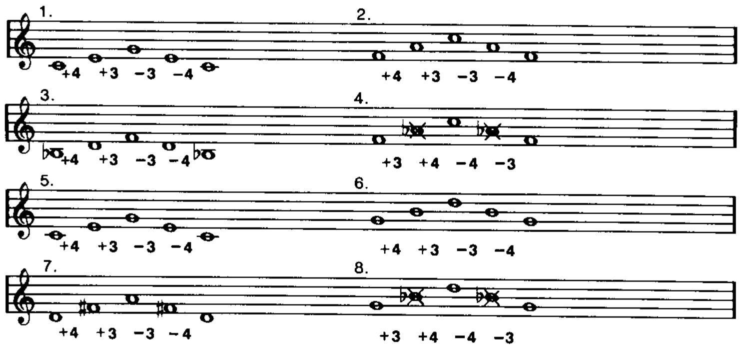

Figure 3. Notation of a typical excerpt of eight stimulus sequences in the session with major triad background and minor triad comparisons (change) presented in different transpositions; x indicates an altered note in the change sequences. Because sequences 4 and 8 are change sequences, the interval of four semitones decreases to three semitones, whereas the interval of three semitones increases to four semitones. Interval size, in semitones, between adjacent tones is shown beneath the musical notation.

C4), with frequencies specified for the tempered scale (e.g., A4 = 440, A#4 = 466, B4 = 494, C5 = 523, etc.; A#4:A4::1.06:1.00, etc., Backus, 1969, p. 134). For the training and test phase, contrasting melodies were formed for each standard by altering the frequency of the second and fourth notes of the standard by one semitone. If the standard was major, the two notes were lowered one semitone, forming the minor triad. If the standard was minor, the notes were raised one semitone, forming the major triad.

Transpositions were assigned by means of a pseudorandom walk procedure through a set of five starting tones: B♭3, F4, C4, G4, and D4. Near transpositions of one or two semitones were not chosen because of the possibility that they would not be discriminable from the original standard. Instead, musically near transpositions (cf. Attneave & Olson, 1971) were chosen that were separated by the interval of a perfect fourth (5 semitones) or perfect fifth (7 semitones). Transpositions of three semitones have been shown to be discriminable by infants (Trehub et al., 1984); hence, the larger intervals of transposition used here should present no problem of discrimination. To clarify the random walk pattern, starting tone F4 could be followed by either B♭3 or C4; starting tone C4 could be followed by either F4 or G4, and so on. Boundary members of the set could be followed by only one starting tone; otherwise, a random choice was made between the two possibilities. Once the starting tone was chosen, the same degree of transposition was applied to the remaining four notes of the melody. On any particular change trial, the change of one semitone was made to serial positions two and four of the designated background melody.

A typical excerpt of eight stimulus sequences is shown in Figure 3, indicating the pseudorandom walk between starting tones and two contrasting sequences.

The tones were sinusoidal waveforms, 200 msec in duration, linearly ramped at onset and offset, with a 30-msec rise and decay time. The intertone intervals were 200 msec; thus each sequence was 1.8 sec. The intermelody interval was 1400 msec. The ambient noise level, measured at the approximate location of the listener's head, was 42 dBC (27 dBA). Stimulus intensity, measured at this location, averaged about 70 dBC.

Procedure: Infants were tested with a conditioned headturn procedure (e.g., Eilers, Wilson, & Moore, 1977; Trehub et al., 1984), as described below. During the session, the infant was seated on the parent's lap in one corner of the testing booth, facing the experimenter. To the infant's left, at an angle of 45°, were the loudspeaker and Plexiglas display box. Each infant was presented repeatedly with either the major or minor standard tone sequences. Before initiating any training or test trials the experimenter attracted the infant's gaze with a small silent toy.

There were two kinds of trials, change trials, to monitor responses to the altered melody, and no-change (control) trials, to provide an estimate of random responses to the unchanged standard (background) melody. During the training phase, only change trials were presented. When the infant was quiet and facing directly ahead, the experimenter initiated a training trial by pressing a button. This elicited the presentation of a comparison melody at an intensity 5 dB higher than the previous standard. The change in intensity provided an additional cue to attract the infant's attention to the changed sequence. For major triad standards, the change trial was the minor triad; for minor triad standards, the change trial was the major triad. If the infant turned 45° or more toward the loudspeaker within 3 sec of the onset of the contrasting melody, one of the reinforcer toys was illuminated and activated for 4 sec. Turns at other times or in the opposite direction were not reinforced. Following the presentaion of the contrasting melody and reinforcer (if relevant), repetitions of the standard background melody continued as before at the original intensity level. When the infant was facing forward, the experimenter called for another trial, thereby initiating the contrasting melody with the possibility of visual reinforcement. If the infant turned on two consecutive trials, the intensity of the contrasting stimulus was lowered 5 dB (i.e., equivalent to intensity of background melody). If the infant failed to turn correctly on two consecutive trials, the intensity of subsequent contrasting stimuli was raised 5 dB, to a maximum of 10 dB above the background. Successive reductions or increases in intensity were contingent on correct or incorrect performance. Infants were required to meet a training criterion of 4 consecutive correct responses with background and contrasting stimuli at equal intensity within 20 training trials.

Once the training criterion was met, the test phase began immediately. The experimenter and parent both wore headphones carrying music to mask the nature of the trial (change or no-change) presented to the infant. The standard repeating background melody (major or minor triad) remained the same, and at least two presentations of the background sequence were required prior to the presentation of any trial. There were equal numbers of change and no-change trials. As in training, change trials consisted of the substitution of the contrasting melody for the background melody. No-change trials involved the monitoring of infant turns during an equivalent period while the background melody continued to play. The response interval for all trials began with the onset of the first tone and ended 3 sec later. Headturns to the sound change were reinforced only during this interval.

The test phase consisted of 30 trials: 15 change trials and 15 no-change trials. Presentation of trials was randomized for each infant, with the constraint that no more than two no-change trials would be presented consecutively.

Results and Discussion

The data consisted of the proportion of turns on change trials and on no-change trials for each infant. A two-factor analysis of variance was carried out on the proportion of correct headturns on change trials and incorrect headturns on no-change trials for each trial type (change, no-change) and melody standard (major, minor). These data are shown in Figure 4.

There was a main effect of trial type, $F\ (1, 22) = 18.45, p < .0005$, indicating that infants can detect a change of one semitone in these transposed background sequences. There was a significant interaction between trial type and melody standard, $F\ (1, 22) = 4.28$, $p < .05$. For both major and minor standards, the mean number of headturns on change trials was equal, but there were less headturns on no-change control trials when the major triad was the standard.

The present findings confirm and extend previous evidence of infants' detection of a semitone change in a five-tone sequence (Trehub et al., 1986) by indicating that the discrimination is not dependent upon retention of absolute

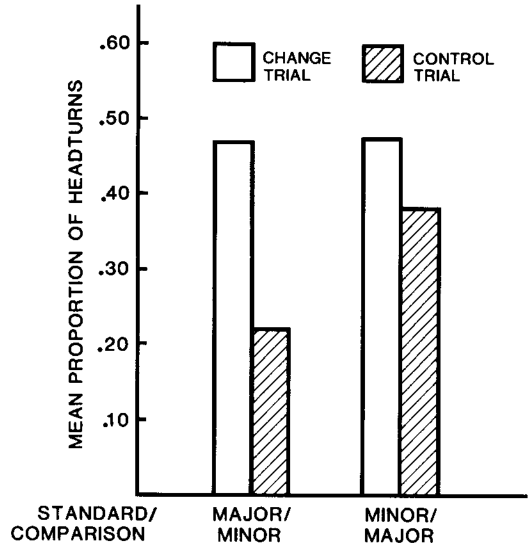

Figure 4. Mean proportion headturns as a function of major-background/minor-comparison and minor-background/major-comparison.

frequency information. This is noteworthy in view of previous indications that contour changes are critical to infants' discrimination of melodies (Trehub et al., 1984, 1985).

Both standard sequences in the present study were structurally significant in music. Thus, it was unclear whether the detection of the semitone difference depended upon such structure and whether differences in the degree of musical structure between standard and comparison melodies could be used as a discriminative cue, as is the case for older listeners (Dewar et al., 1977; Trehub et al., 1986).

EXPERIMENT 2

The principal purpose of this experiment was to examine semitone discrimination in the context of well-structured and poorly-structured sequences. The augmented triad was selected as the basis for the poorly-structured sequence (see Figure 2b) because, in contrast to the major and minor triads, the augmented triad is uncommon, has more complex frequency ratios, and less structural significance. If structure is not important, then detection of a difference in a transposed augmented standard should be equivalent to that of the transposed major and minor triads in Experiment 1. Conversely, if good structure is essential to accurate encoding and retention, then the ability to detect the semitone change in the augmented triad sequence would be impeded compared to that of the major and minor standards.

Research with adults on the similarity of pairs of triads, including the major, minor, and augmented, has revealed that highly trained musicians regard major and minor triads as most similar and major and augmented as least similar (Roberts & Shaw, 1984). Less trained listeners also rate the similarity of major and minor triads as highest, but they rate major and augmented triads as next most similar. These findings, especially those for highly trained musicians, are consistent with a theory of consonance based on the degree of overlap in overtones of the component tones of the triad. Given the possible role of training or experience in the determination of such similarity judgements, it would seem unlikely that infants would find differences between major and augmented melodies more salient than those between major and minor melodies. Nevertheless, following Demany and Armand's (1984) evidence for octave equivalence in infants, it is possible that infants are differentially sensitive to tones related by small ratios, and this would provide a basis for perceived similarity of major and minor triads and perceived difference between major and augmented triads. The concept of differential stability of the representations of triad structure (Krumhansl et al., 1982) is neutral with regard to innate or experiential origin.

Roberts and Shaw (1984) observed asymmetries resulting from the order of presentation of triads. When the first triad was more stable (e.g., major) and was followed by a less stable triad (augmented), the similarity was lower than when the less stable triad was presented first. Moreover, Krumhansl et al. (1982) observed that the initial presentation of the less stable triad increased the judged suitability of the triads to a preceding musical context. This asymmetry may be attributable to degradation toward the more stable pattern (cf. Garner, 1974; Trehub et al., 1986). If the stability of the representation of relations also varies for infants, then discriminability of an unstable contrast from a stable background should exceed the discriminability of a stable contrast from an unstable background. In other words, the mental representation of a stable background would retain its uniqueness, against which the unstable contrast could be compared, whereas that of an unstable background would degenerate into the stable configuration, providing little basis for discrimination from the stable contrast. More specifically, an augmented triad background and major triad comparison would lead to lower performance than a major triad background and augmented triad comparison. Comparisons involving major and minor triads could be expected to fall midway between these extremes, with the major triad leading to higher performance as a standard than as a comparison.

In Experiment 1, the changed melodies differed from the standard in two notes, that is, in serial positions two and four. In the present study, the change from the augmented to major triad involved only one note in serial position three, raising the possibility that detection of the difference between sequences might be influenced by the number of changed notes. Research with adults reveals, however, that difference in overall structure is more important than the size of interval change, at least when listeners are highly trained (Roberts & Shaw, 1984). In Trehub et al.'s study (1986), infants detected a difference between sequences when only one note was changed by one semitone, but with the remaining notes of the comparison sequence presented at the original frequencies.

In the present study with transposed sequences, the major and minor conditions of Experiment 1 were repeated. Two conditions were added, with major and augmented triads serving as standard and comparison. If infants' ability to detect an altered transposed sequence depends upon the number of notes changed, then major/minor discrimination involving two changed notes should exceed that for major/augmented discrimination in which only one note was changed. If structural difference plays a role, then the major background and augmented comparison should lead to the highest performance.

Method

Subjects: Participants included 52 healthy, full-term infants ranging in age from 7.0 to 11.0 months. Infants were excluded from the sample if they failed to meet a predetermined training criterion (n = 3), or if they did not complete the 30-trial testing session (n = 1). Each infant was tested with either the major, minor, or augmented sequence as background. The final sample of 12 infants tested with the major triad background and minor comparison included 4 males and 8 females with a mean age of 9.0 months. The final sample of 12 infants tested with the major triad background and augmented comparison included 10 males and 2 females with a mean age of 8.5 months. The final sample of 12 infants tested with the minor triad as background and major comparison included 5 males and 7 females with a mean age of 9.8 months. The final sample of 12 infants in the augmented triad standard and major comparison comprised 8 males and 4 females, with a mean age of 10.2 months.

Apparatus and Procedure: The apparatus and procedure were the same as for Experiment 1.

Stimuli: For major/minor standard/comparison conditions, the stimuli were identical to those of the previous study. For conditions involving the augmented sequences, five different transpositions of the augmented triad, (e.g., C4, E4, G#4, E4, C4) were composed to be randomly selected as in the previous study.

Results and Discussion

A three-factor analysis of variance was carried out on the proportion of headturns on change trials and no-change trials for trial type (change, no-change), melody comparison pair (major/minor and major/augmented), and role of the major triad (standard or comparison). These data are shown in Figure 5.

There was a main effect of trial type, $F(1, 44) = 28.77, p < .0001$, replicating the findings of Experiment 1 that infants detected a semitone difference in transposed melodies. There was a significant interaction between trial type, melody comparison pair, and role of the major triad, $F(1, 44) = 5.33, p < .025$. The principal finding is that, consistent with observations for adults, the major triad standard and augmented triad comparison were most discriminable, whereas the augmented triad standard and major triad comparison were least discriminable. The number of notes changed was not a significant factor in discriminability, as only one changed tone occurred with the best and worst performance.

Whereas the mean proportion of headturns on change trials was highest for the major-background/minor-comparison, this was associated with a relatively high false alarm rate and, therefore, the actual discriminability was lower than that of Experiment 1. The similarity in performance for conditions involving both major

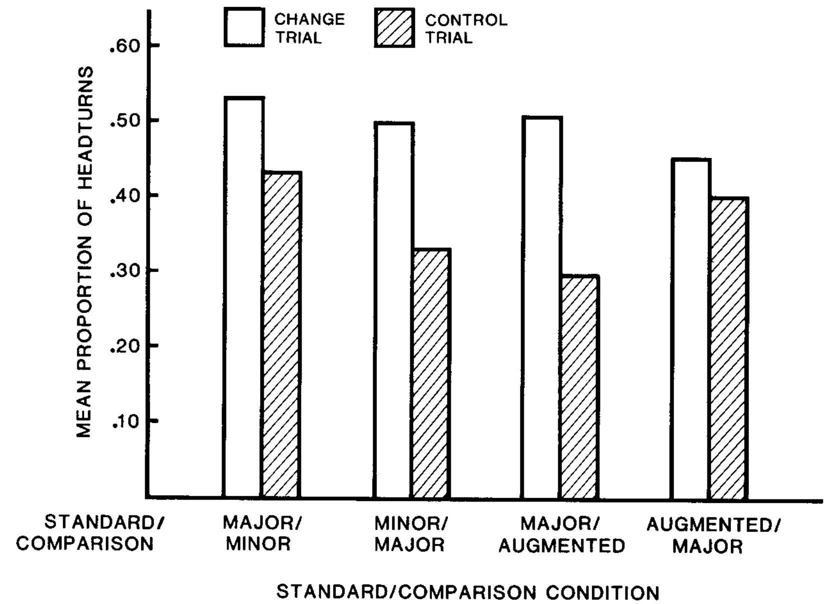

Figure 5. Mean proportion headturns as a function of major-background/minor-comparison, minor-background/major-comparison, major-background/augmented-comparison, and augmented-background/major-comparison.

and minor triads is consistent with adult data and with arguments based on similarity in terms of simple ratios, structural significance, and familiarity. Nevertheless, the data from Experiments 1 and 2 differ in the importance of the major triad as standard and comparison when paired with the minor triad.

EXPERIMENT 3

Because structure played a significant role in the discrimination of transposed sequences in the major/augmented conditions of Experiment 2, and because the role of structure was more equivocal in the major/minor conditions of both experiments, a further study was designed to examine infants' ability to discriminate melodies that are equal in quality (e.g., both major). More specifically, we explored infants' ability to detect differences between two versions of the major triad or two versions of the minor triad. Different versions of a triad can be formed by transposing any tone by an octave. When the tones are as close as possible in frequency, the structure is referred to as the root (e.g., for the major triad frequencies are related as 4:5:6). If the lowest tone of the root is raised one octave to become the highest, the configuration is called the first inversion. (In order of increasing frequency, the ratios are now 5:6:8). Thus, inversions have the same note names but may differ in relative octave placement of the tone. Figure 2c represents the first inversions of the notated roots in Figure 2a.

Comparing Figures 2a(i) and 2c(i), the major root contains intervals of four and three semitones between adjacent tones, and the major first inversion contains the intervals of three and five semitones. As well, the relative size of intervals is reversed by the inversion. Therefore, there are two kinds of cues for distinguishing an inversion from its root: interval size and relative ordering of the intervals of different sizes. Both cues were available in the discriminations of the previous experiments, but in those studies there was also the difference of triad quality. In contrast, similar quality of inversions in music is indicated by the interchangeability of inversions in accompaniment of melodies. Zatorre (1985) has suggested that equivalence of inversions may be based upon pitch processing mechanisms that represent a tone and its octaves (i.e., the representation of octaves is partially overlapping). Research by Roberts and Shaw (1984) suggests that inversions do not produce the distinctive quality of a triad as clearly, but the difference is smaller than that between two triads of different type but of the same inversion.

If triad quality is the primary basis for infants' detection of differences between transposed melodic patterns, then it should be very difficult for infants to distinguish differences between a major standard and its first inversion, or between a minor standard and its first inversion. If, on the other hand, interval size provides a basis for detection, then the difference between root and first inversion should be discriminable. In order to examine the role of quality, the present study evaluated the discriminability of a melody based on the major root from a melody based on the first inversion. In addition, the experiment provided a replication of infants' sensitivity to alterations in frequency ratio.

Method

Subjects: Participants included 27 healthy, full-term infants ranging in age from 7.3 to 11.4 months. Infants were excluded from the sample if they failed to meet a predetermined training criterion ($n = 3$), or if they did not complete the 30-trial testing session ($n = 0$). Each infant was tested with either the major or minor root sequence as background and the respective first inversion as comparison. The final sample of 12 infants tested with the major triad background included 9 males and 3 females with a mean age of 9.5 months. The final sample of 12 infants tested with the minor triad background included 9 males and 3 females with a mean age of 8.5 months.

Apparatus and Procedure: The apparatus and procedure were the same as for Experiments 1 and 2.

Stimuli: The major and minor root background stimuli were identical to those of the previous experiments. For each comparison, five different transpositions of the first inversion major (e.g., E4, G4, C5, G4, E4) and first inversion minor (E♭4, G4, C5, G4, E♭4 respectively), were composed (see Figure 1c). Change trials began four semitones (for major background) and three semitones (for minor background) higher than the tone selected by the random walk procedure used in Experiments 1 and 2. Thus, if F was selected in the random walk, the comparison began on A for the major triad condition and on A♭ for the minor triad. The set of randomly chosen starting notes for major inversions was therefore D4, A4, E4, B4, and F#4, and for minor inversions, D♭4, A♭4, E♭4, B♭4, and F4.

Results and Discussion

A two-factor analysis of variance was carried out on the proportion of correct headturns on change trials and incorrect headturns on no-change trials for each trial type (change, no-change) and melody standard (major, minor). Mean proportion of change trials associated with a headturn, collapsed over major and minor conditions, was 0.48 as compared to 0.34 for no-change trials. There was a main effect of trial type, $F(1, 22) = 20.07, p < .0004$, indicating infants' ability to discriminate between melodies based on first inversions and root structure. Therefore, infants can rely on other cues besides chord quality. Nevertheless, their performance may have been aided by additional distinctions between inversions (e.g., relative size of first and last interval) that are not available in comparisons that preserved relative size of intervals in Experiments 1 and 2. Performance differences between the minor triad condition (.46 change vs. .36 no-change) and major triad condition (.49 change vs. .33 no-change) were not significant.

GENERAL DISCUSSION

The foregoing experiments provide evidence of infants' ability to detect small differences in transposed sequences. There is no obvious basis for the alternative contention that infants retained precise frequency information about each of the five standard sequences. The present finding may be limited to melodies with stable structures and, perhaps, to melodies based on major and minor triads. How can these results be reconciled with previous evidence that infants encode contour but not interval size (e.g., Trehub et al., 1984)? In the Trehub et al. study, melodies were six notes long instead of five and were separated by longer temporal intervals and by interpolated distractor tones. Under these more difficult conditions, infants may be unable to retain previously encoded information about absolute interval size.

The asymmetric effects of major and augmented triads (Exp. 2) may imply that infants represent the relative stability of such sequences, as do preschool children (Trehub et al., 1986) and adults (Cuddy, Cohen, & Mewhort, 1981; Cuddy, Cohen, & Miller, 1979). Stability could be related to simplicity of the ratio relations, degree of exposure, or both. Because the reverse pattern of asymmetry, superior performance with augmented triad background and major contrast, would not be compatible with either of these interpretations, it is important that this particular pattern was obtained. Future cross-cultural research may be necessary to establish the relative significance of these two accounts.

In contrast to Trehub et al.'s (1986) study, in which melodic discriminations could be based on absolute frequency, the present paradigm may have compelled infants to focus on frequency ratio relations. The present findings also indicate infants' ability to perceive the smallest frequency relation significant in Western tonal music, the semitone. This sensitivity also implies an ability to encode subtle differences in speech intonation that may distinguish between speakers and between intended meanings.

Infants' ability to perform the present task has general perceptual-cognitive as well as musical significance. The task involved detecting and storing frequency information in a complex pattern and comparing this representation to another pattern. Although sensitivity to global frequency (i.e., melodic contour) relations has been shown previously (Trehub et al., 1984), there is no previous evidence of infants' sensitivity to frequency relations as precise as those in the present investigation.

One aspect of all three experiments that bears further examination is the choice of the interval of transposition. The starting notes of the background sequence came from a set of tones that is closely related in terms of frequency, all having the ratio of 2:3 or 3:2 to its nearest neighbour. The set of five notes chosen in the present study represents a compact region of what is known as the cycle of fifths, through which all 12 tones of the octave can be represented (i.e., C, G, D, A, E, B, F#, C#, A♭, E♭, B♭, F, and C). The choices in the present study were B♭, F, C, G, and D. The extent to which the results are attributable to the use of this related set is unknown; however, research with children (Bartlett & Dowling, 1980; Trehub, Morrongiello, & Thorpe, 1985) and adults (e.g., Cuddy et al., 1981) has shown effects of the interaction between melodic structure and key of transposition, and it might be important to explore the earliest possible appearance of such effects in future work with infants.

Finally, we have made reference throughout to relations between small ratios, familiarity, function, and stability. The significance of these factors on infant perception of frequency relations should be examined independently in future research.

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