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HUMAN INFANTS' PERCEPTION OF AUDITORY PATTERNS

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ABSTRACT: Human infants' perception of tone sequences or melodies is reviewed in the context of related work with human adults and nonhuman species. For the most part, infants use an adult-like pitch processing strategy that is global and relational rather than the local pitch strategy that is characteristic of the nonhuman species studied to date. Thus they encode and retain the pitch configuration or contour of a melody, with little attention to the absolute pitches of individual notes. In the case of well structured melodies, specifically, melodies that are prototypical of Western music, infants encode more precise relations, notably the intervals or exact pitch relations between adjacent notes. Finally, the functional significance of relational pitch processing in human infancy is considered.

The study of immature listeners provides opportunities for exploring the role of experience in mature listeners' perception of complex patterns. To the extent that experience plays an important role, this would increase the likelihood of cross-species parallels in early life and of cross-species differences later on. In fact, current research on the perception of complex auditory (nonspeech) patterns by human adults emphasizes the plasticity of pattern perception processes and the dependence of perceptual organizational processes on extended experience and expectations (Espinoza-Varas & Watson, 1989). It is possible, then, that the pattern processing strategies of human infants, by virtue of limited experience and the absence of language, might differ substantially from those of adults, bearing greater similarity to those of some nonhuman species.

To date, the human-nonhuman comparisons of auditory pattern perception have focused primarily on speech, specifically, single speech sounds (Kuhl, 1989). The goal of such comparisons is to determine whether phenomena that are critical to speech perception such as categorical perception (Liberman, Harris, Hoffman, & Griffith, 1957) and auditory equivalence classification (Kuhl, 1979; 1983) involve speech-specific (i.e., species-specific) mechanisms or more general auditory mechanisms that are shared by other species (for re-

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views see Dooling, Brown, Park, & Okanoya, 1990; Kuhl, 1987; Moody, Stebbins, & May, 1990). In our own research, we have departed from this approach, choosing to examine human infants' processing of serial pitch patterns, notably tunes or melodies (for reviews see Trehub, 1985, 1987, 1990; Trehub & Trainor, 1990, *in press*). This may seem like a highly specialized endeavor with limited application but music is found in every human culture, just as language is. All of us participate in music, as listeners if not performers, but the biological significance of music remains a mystery (Granit, 1977; Lerdahl & Jackendoff, 1983). Nevertheless, human music processing capacities have captured the attention of comparative researchers, leading to studies of tune discrimination in rats, songbirds, and monkeys (for reviews see D'Amato, 1988; Hulse & Page, 1988; Hulse, Page, & Braaten, 1990). This enables us to use the human adult findings as one anchor and the nonhuman findings as another in our research with human infants. For example, relational processing in the pitch domain (i.e., relative pitch) typifies human adults' processing of tunes but not that of the nonhuman species studied to date. Instead, those species that can discriminate contrasting tunes do so primarily by remembering the exact pitch levels of one or more tones (D'Amato, 1988). Indeed, Premack (1983) has commented on the human predilection for relational responding to complex stimuli and the nonhuman predilection to do otherwise. What about human infants?

To study infants' perception of tunes or melodies, we present 7- to 11-month-olds with a sequence of five or six pure tones and then test for their detection of deviations from that sequence (for methodological details see Trehub, Bull, & Thorpe, 1984; Trehub, Thorpe, & Morrongiello, 1987). We can vary the difficulty of the task by manipulating the length and complexity of the sequences, the size of the retention interval, and/or the degree of deviation from the original sequence. In this way, we can obtain information about aspects of the pattern that are salient and memorable for infant listeners.

Specifically, we present a repeating melody (i.e., the standard or background pattern) from a loudspeaker to one side of the infant (left), and periodically substitute a melody (i.e., the comparison pattern) that is altered in some respect. The background melody is presented repeatedly from the moment the infant enters the test environment (a sound-attenuating booth) until the completion of the test session. The tester and attending parent wear headphones with masking patterns so that they remain unaware of the specific stimuli being presented to the infant at any time. The tester indicates to a computer (via a button-press) when the infant is attentive and looking directly ahead; test trials are only presented at such times. She also indicates (via another button) when the infant turns at least 45° to the loudspeaker. The computer monitors such turns, on the one

hand, and the occurrence of melody changes (i.e., the comparison pattern), on the other. Whenever the computer records a response (45° head turn) within 4 s of a melody change, it delivers reinforcement in the form of illumination and activation of one of four (randomly selected) mechanical toys in a darkened Plexiglas box near the loudspeaker. In effect, this is a GO/NO-GO procedure, with the standard stimulus functioning as S- and the comparison stimulus as S+. Trials are not signalled in any way so that S- trials are essentially indistinguishable from the background repetitions. This is rather different from the typical implementation of GO/NO-GO procedures with nonhuman or human adult listeners.

To ensure that infants understand the task demands, we require them to meet a training criterion of four successive correct responses to a salient (i.e., clearly discriminable) change within a maximum of 20 trials. Most infants initially orient to the sound change and, therefore, train relatively quickly. During the subsequent test phase, we present approximately 30 test trials (more trials in some experiments, less in others), half of which incorporate some change in the melody (more subtle than that presented in the training phase), the other half involving no change, with the change and no-change trials presented in random order. Some spontaneous turning toward the toys can be expected so that the no-change or control trials are essential for unequivocal interpretation of performance on the change trials. If infants turn significantly more on the change than on the no-change trials, this indicates that they can detect the change in question.

ADULT MELODY PERCEPTION

Some facts about adult melody perception provide a context for evaluating infant performance in this domain. Adults' recognition of melodies does not depend on specific notes or exact pitch levels but rather on the *relations* among component notes. The key to tune recognition, in the case of *familiar melodies* (i.e., those with extended exposure in everyday life, or highly overlearned melodies that can be recalled or recognized), is the pattern of *intervals* (Attneave & Olson, 1971; Dowling & Fujitani, 1971), with intervals referring to the precise relations between adjacent notes (fundamental frequency ratios or distance in semitones between successive notes). Thus we perceive transpositions, which have different notes but an identical pattern of intervals, as equivalent to the original and, in many circumstances, indistinguishable from it (Attneave & Olson, 1971). With *unfamiliar melodies* (i.e., those introduced in the test situation), tune recognition depends on configurational information about pitch (Bartlett & Dowl-

ing, 1980) or the pattern of successive directional changes (ups and downs) in pitch, which is known as *melodic contour* (Dowling, 1978). Contour refers only to directional aspects of the pitch changes (whether they rise, fall, or stay the same), not their extent (Dowling & Harwood, 1986). Finally, melodies that conform to the musical structure of our culture are processed in greater detail, learned and remembered more readily, and are preferred over melodies that violate such structure (Cuddy, Cohen, & Mewhort, 1981; Krumhansl, Bharucha, & Kessler, 1982; Krumhansl & Keil, 1982; Lynch, Eilers, Oller, Urbano, & Wilson, in press).

MELODY PERCEPTION: NONHUMAN COMPARISONS

Many nonhuman species have elaborate vocal communication systems, raising the possibility of specialized systems for processing complex auditory patterns (Beecher, Petersen, Zoloth, Moody, & Stebbins, 1979; Hulse et al., 1990; Nelson & Marler, 1990). Nevertheless, research on tune discrimination in various nonhuman species has revealed a pattern of skills and strategies that is very different from that of human adults. In these studies, the animals in question are typically trained to respond (e.g., key peck, lever press) to S+ and to withhold responding to S-, with S+ and S- being presented on distinct and clearly signalled trials. The animals are subsequently tested on their generalization of the trained response to novel exemplars.

Although initial studies with albino rats and cebus monkeys seemed to indicate that these species, after extensive training, were capable of melody discrimination (D'Amato & Salmon, 1982), such discriminations were later found to be based primarily on local (i.e., individual, absolute) pitch cues rather than global pattern cues such as contour (D'Amato, 1988; D'Amato & Salmon, 1984). When cues such as common pitches or pitch range between training and generalization stimuli were removed, the animals tended to perform at chance levels, even after thousands of training trials. Similar difficulty with pitch contour discrimination has been observed in starlings (Cynx, Hulse, & Polyzois, 1986; Hulse & Cynx, 1985, 1986) and budgerigars (Dooling, Brown, Park, Okanoya, & Soli, 1987), although there are disputed claims for rudimentary contour perception when the preferred strategy (absolute pitch) is blocked (Hulse & Cynx, 1986; Hulse et al., 1990; but see D'Amato, 1988). These findings cannot be attributed to the arbitrary nature of the tunes because, in some cases, the stimulus tunes were modeled on species-typical calls (e.g., Dooling et al., 1987).

An absolute pitch strategy can be seen as highly appropriate for

avian, if not for human, listeners. Although there is insufficient documentation of the acoustic cues for individual and species recognition in most bird species, the available research seems to indicate that absolute pitch is the principal cue (Brooks & Falls, 1975; Nelson & Marler, 1990). Brooks and Falls' (1975) research on the white-throated sparrow is especially informative in this regard. In the songs of the white-throated sparrow, pitch is relatively constant for each individual and varies over a narrow range within the species. By contrast, there is little consistency in the number or duration of notes in a song. In fact, the absolute pitch of the first one or two notes seems to be critical in the identification of individual, white-throated sparrows and of conspecific neighbors. This focus on absolute as opposed to relative pitch in sparrows, budgerigars, and many other species is not attributable to inadequate resolution of the relative pitch differences but rather to the greater salience of absolute cues in the sound environment of these species (Brooks & Falls, 1975; Dooling et al., 1987; Nelson & Marler, 1990).

INFANT MELODY PERCEPTION: CONTOUR PROCESSING

If human infants were exposed to a melody in the context of the conditioned head turn procedure described previously, what would they encode and remember? There are several possibilities. They might recognize all of the notes of a very brief melody and, perhaps, the first or last few notes of a longer melody. This would involve a local or absolute pitch strategy, one that is congenial to songbirds (Brooks & Falls, 1975; Dooling et al., 1987; Hulse & Cynx, 1986; Hulse, Cynx, & Humpal, 1984), rats, and monkeys (D'Amato & Salmon, 1984). Alternatively, they might encode the melody relationally, attending to a global property such as its pitch contour (adults' strategy with unfamiliar melodies) or to a more precise property such as its pattern of intervals (adults' strategy with familiar or highly overlearned melodies). The interval strategy would seem to be unlikely for a number of reasons. Adult-like processing of specifically musical as opposed to general auditory information is thought to require extended exposure to the music of one's culture (Jones, 1982; Krumhansl, 1990). Moreover, no tunes could possibly have the status of familiar or highly overlearned melodies in infancy. Nevertheless, it should be possible to gain information about melodic processing strategies in infancy from the kinds of melodic changes that infants can detect together with those that they cannot detect.

In one study (Trehub et al., 1984), we tested infants for their discrimination of various changes to a six-note melody (i.e., a sequence of six pure tones), including *transpositions* (different notes,

same intervals and contour), *contour-preserving* changes (different notes and intervals, same contour), and *contour-violating* changes (same notes in different order, resulting in different intervals and contour). With the exception of the transpositions, all contrasting melodies began and ended on the same note as the standard melody, thereby precluding the use of single-note cues. From the perspective of human adults, the transposed tunes would be most similar to the original melody by virtue of identical pitch relations; those with altered contour would be least similar by virtue of altered pitch relations. From the perspective of songbirds, rats, or monkeys, however, the patterns with altered contour (identical first and last notes, internal notes permuted) might be most similar to the original melody on the basis of absolute pitch cues. Moreover, the transpositions, which embodied more absolute pitch changes than the other comparisons, would be least similar for nonhuman listeners.

In one condition (Experiment 1), the standard and test melodies were separated by 800 ms (brief retention interval); in another (Experiment 2), they were separated by 2.6 s (longer retention interval) and the interpattern interval was filled with repeating notes. When the retention interval was brief, infants detected all of the changes, performing best, however, on the contour changes. With longer retention intervals, they readily detected the contour changes (identical but permuted notes) but failed to respond to the transpositions (all new notes) or to the contour-preserving changes (some new notes). It appeared, then, that precise pitch and interval information decayed rapidly, leaving global information about contour intact. In fact, infants were subsequently shown to detect subtle contour changes generated by a single-note change within a six-note melody (Trehub, Thorpe, & Morrongiello, 1985).

In a further study (Trehub et al., 1987), we presented infants with an even more challenging task. They had already shown us that they could discriminate contour changes in the context of a fixed repeating melody or single standard. Now we asked them to discriminate contour changes in the context of five-note melodies that varied from one repetition to the next (Figure 1). The repeating melodies of one set had different component notes or pitches but a common contour (up-down). The contrasting set had melodies with the same component pitches as the standard set but reordered so as to generate a different contour (down-up-down). The infant's task was to ignore the local pitch changes within each set of patterns and to respond on the basis of the contrasting contour between sets. Infants were successful on this task, indicating that they could discriminate sets of melodies on the basis of contour alone and, moreover, that they could recognize similarities among discriminable melodies with common contour. In other words, they demonstrated auditory equivalence classification or

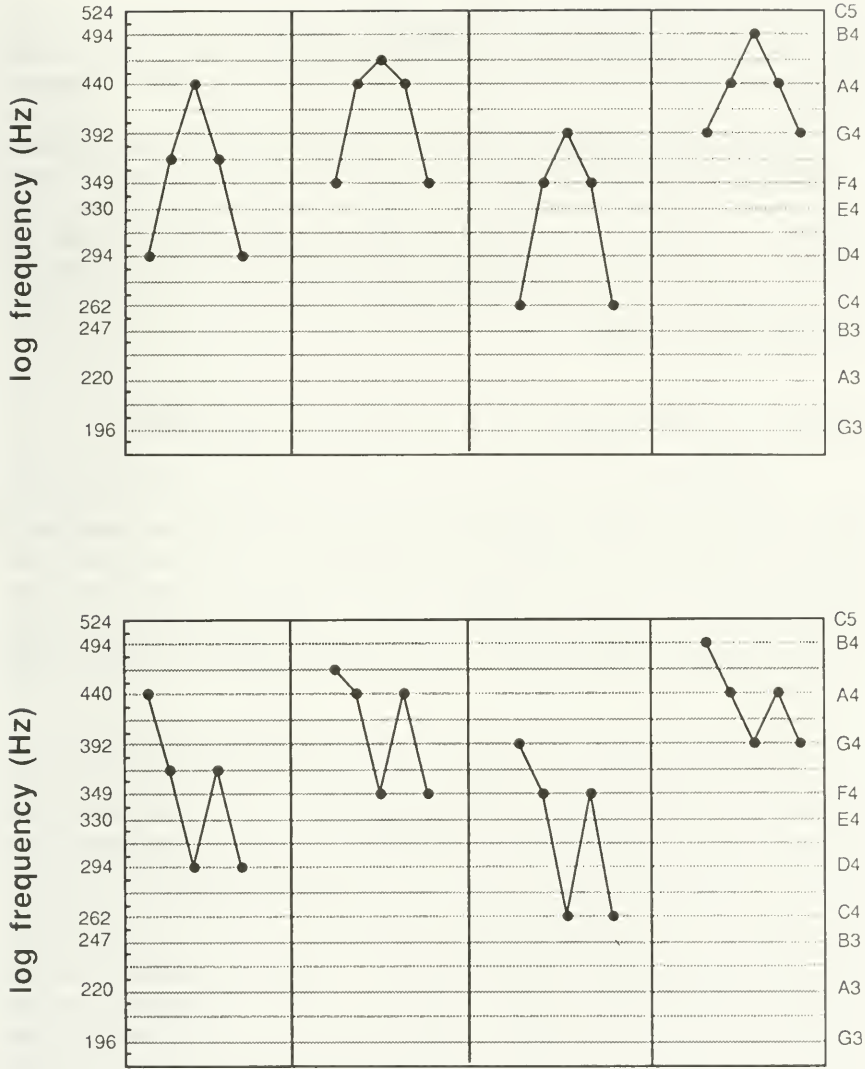


FIGURE 1. Sample melodies from Trehub et al. (1987). Upper panel: set of contour-preserving (variable interval) melodies. Lower panel: contrasting set with changed contour. Successive horizontal lines represent note names and associated numbers denote the relevant octave.

perceptual constancy for melodic contour. Of further interest is the fact that performance was unrelated to the age of infants (7-11 months) in this or any of our other investigations of melody perception.

These studies, taken together, reveal that infants' perceptual processing of melodies (unfamiliar ones, of course) has much in common with adults' processing of unfamiliar melodies, with contour playing a critical role in both cases. Moreover, infants' relational approach to melody perception has relatively little in common with the local or absolute pitch strategy that predominates in the nonhuman species studied to date.

INFANT MELODY PERCEPTION: INTERVAL PROCESSING

Although it is generally the case that infants extract the contour and not the intervals of melodies, especially when the task is difficult (long retention intervals or variable melodies), there are some notable exceptions. In recent studies, we have shown that when the standard melody is a prototype or highly typical example of Western musical structure, infants seem to be capable of encoding intervallic relations, detecting changes as small as a semitone in a single note of a melody.

Some background information about Western tonal music may be necessary for clarifying this issue. Each octave (pitch ratio of 2:1) is divided into 12 equal intervals (semitones) that form the *chromatic* scale. Western tonal music is not based on this equal-interval chromatic scale but on the unequal-interval *diatonic* scale, which consists of seven notes from the chromatic scale. Designating the key or reference note of a melody implies an appropriate set of notes, specifically the seven notes of the relevant diatonic scale and those having the same position (or note name) in other octaves. Moreover, various notes and note sets within the diatonic scale are considered to have special structural and functional significance. For example, the *major triad* (consisting of the 1st, 5th and 7th position of the chromatic scale or 1st, 3rd and 5th position of the diatonic scale) is structurally central to Western music theory (Schenker, 1906/1954) and has unique mathematical properties (Balzano, 1982). Moreover, it occurs frequently in Western music (Roberts & Shaw, 1984; Simonton, 1984), has a stable mental representation (Krumhansl et al., 1982), and is considered a prototype of diatonic structure (Cuddy & Badertscher, 1987). Prototypical melodies, which are presumably internalized on the basis of extended exposure to the music of a culture, provide a perceptual frame of reference against which to evaluate current melodic input (Jones, 1981).

We explored infants' ability to detect a semitone change in the context of a simple, well-structured melody based on the major triad (Cohen, Thorpe, & Trehub, 1987). The standard or background set of melodies consisted of C E G E C and its transpositions; the comparison set consisted of C E G[#] E C and its transpositions. Thus the standard and comparison melodies involved a set of exemplars or variable repetitions (Cohen et al., 1987; Trehub et al., 1987) as opposed to a single exemplar of each (Trehub et al., 1984, 1985). Instead of the salient contour cues of the previous studies (Trehub et al., 1984; 1987), the comparison melodies in this study offered subtle interval cues, cues that infants tended to ignore. In this case, however, infants succeeded in detecting the change. In another condition, the background set of melodies was less well structured (C E G[#] E C and its transpositions) in the sense that one note (G[#]) was incorrect or outside the appropriate key (C major in this case); the comparison set consisted of C E G E C and its transpositions. Thus, infants now had to respond to a *good* comparison melody in the context of a *bad* standard; previously they had responded to the same *bad* melody in the context of the same *good* melody as standard. Infants failed to detect these changes, implying that subtle interval changes were apparent only when a *good* standard melody was available as a stable frame of reference.

This surprising finding of enhanced infant performance in the context of well-structured patterns is in line with enhanced adult performance for *good* melodic (Bharucha, 1984) and rhythmic (Bharucha & Pryor, 1986) materials. The implication is not that infants are absolutely unable to discriminate subtle changes to so-called *bad* melodies or to melodies that do not conform to cultural conventions. On the contrary, infants may be able to discriminate such changes when other task demands are minimized. For example, infants were able to detect a semitone change to the less well-structured melody when the background repetitions were identical rather than variable (Trehub, Cohen, Thorpe, & Morrongiello, 1986). In comparable situations with identical repetitions, Western infants have also demonstrated their ability to detect subtle changes to melodies based on a foreign (Javanese pelog) musical scale (Lynch, Eilers, Oller, & Urbano, 1990). In the latter case, it is unclear whether their performance was based on the *goodness* or integrity of the foreign pattern or on the minimal task demands (i.e., identical repetitions). In any case, the combination of a poorly structured pattern and difficult task is sufficient to degrade the discrimination performance of infant listeners.

In a further study (Trehub, Thorpe, & Trainor, 1990), we explored the generality of the finding of interval processing in the context of *good* melodies. The five-note melodies in Cohen et al. (1987) had been simple, symmetric, and limited to three different notes.

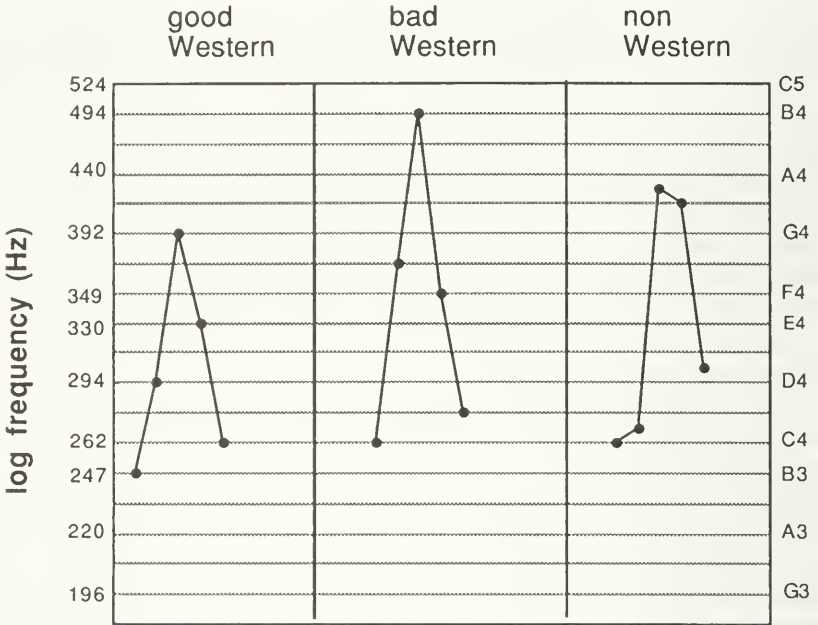


FIGURE 2. The *good* Western melody, *bad* Western melody, and non-Western melody from Trehub et al. (1990). Successive horizontal lines represent note names and associated numbers denote the relevant octave.

Would infants also exhibit differential processing of more complex melodies on the basis of their internal pitch structure? We generated three patterns with similar (rise-fall) contour and pitch range (Figure 2). The first melody (B₃ D₄ G₄ E₄ C₄ and its transpositions) was based on the major triad (the notes C E G) and could be considered *good* from the perspective of Western music theory (Piston, 1969; Schenker, 1906/1954) and psychoacoustics (i.e., simple integer ratios of adjacent notes, see Terhardt, 1978; Watkins, 1985). The second melody (C₄ F[#]₄ B₄ F₄ C[#]₄ and its transpositions) could be considered *bad* from a Western musical perspective in that its notes were drawn from the chromatic scale but not from any diatonic scale. Moreover, it contained two intervals that are considered to be highly dissonant (C₄ to F[#]₄; B₄ to F₄). The third melody could be considered *bad* as well as non-Western because its notes were not drawn from the chromatic scale. In fact, two of its intervals were smaller than a semitone but were still well within the frequency-resolving capability of infants (Olsho, Schoon, Sakai, Turpin, & Sperduto, 1982).

The infant's task was to detect a semitone change in the fourth position of each five-note melody. Since the three melodies had the same contour (up-down), note set size ($N = 5$), and timing (equal

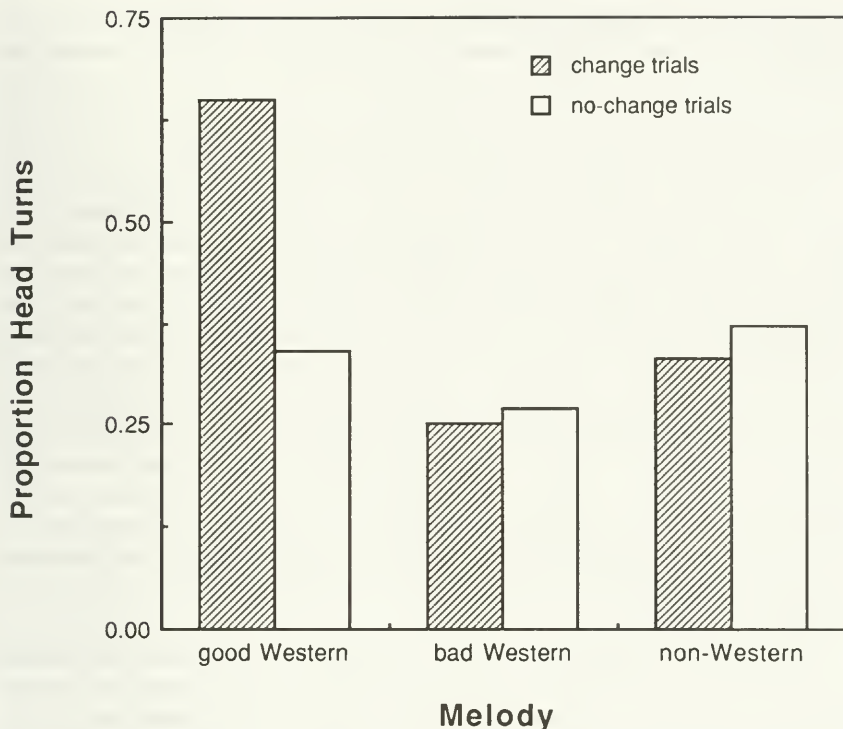


FIGURE 3. Average proportion of head turns on change trials and no-change (control) trials for each melody.

spacing between notes), any differences in performance would be due to differences in the melodic or pitch structure of such melodies. If diatonic structure is salient for infant listeners by virtue of pattern processing predispositions or experiential factors, then there should be facilitation for the *good* melody. If chromatic or semitone structure is relevant to infant perception, then infants should perform better on the two Western melodies than on the non-Western melody. In fact, infants responded to the semitone change only in the context of the *good* Western melody (Figure 3), suggesting that diatonic structure in general or major triadic structure in particular embodies some performance-enhancing properties, as yet undefined. There are further implications of these findings of interval processing in the context of prototypical or diatonic melodies. Specifically, the findings raise questions about adults' interval-processing strategy in the case of so-called *familiar* melodies. Is the interval-processing strategy engaged by the familiarity of the melody, as presumed, or is it engaged by special structural features of the melody? In most research on melody perception, *familiar* melodic structures and *good* melodic structures

have been confounded. In fact, it is difficult to unconfound them unless *good* (i.e., prototypical) patterns from foreign cultures are used as stimuli.

ADULT-INFANT DIFFERENCES: EXPERIENTIAL EFFECTS

The picture that seems to be emerging is that, like their adult counterparts, human infants exhibit enhanced processing for *good* auditory patterns, although the defining features of *good* patterns remain to be determined. Although perceptual predispositions, and perhaps exposure, play a role in the converging strategies of infants and adults, it is likely that musical acculturation would generate some strategic changes in auditory pattern processing. For example, our musical culture defines not only the *goodness* or acceptability of a sequence of notes but also the acceptability of various changes to that sequence. Given a *good* melodic context, subsequent changes could preserve its inherent structure or violate that structure. Presumably, structure-violating changes would be jarring, at least for experienced listeners, and, therefore, should be more noticeable than structure-conserving changes.

Recently, we examined the ability of 8- to 9-month-olds and adults to detect changes to a *good* or well-structured melody (Trainor & Trehub, in press). The standard or background melody was a sequence of 10 notes that embodied typical elements of Western melodic structure. In one condition, a note was changed by four semitones such that the resulting pattern was optimally consistent with the original melodic structure (diatonic change). In another, the note was changed by one semitone only but the change violated the structural conventions of Western music (nondiatic change). The standard and comparison melodies were presented in transposition so that the discrimination could be accomplished only on the basis of relative as opposed to absolute pitch cues. Would listeners respond to the larger pitch difference, ignoring the musical structure, or would they respond to the structural change, ignoring the degree of pitch difference? One would expect musically naive listeners such as infants to find the diatonic change more salient (i.e., greater pitch difference but similar structure) and experienced listeners to find the nondiatic change more salient (i.e., structural discrepancy but smaller pitch difference).

In fact, adults with no formal music training but the usual incidental experience readily detected the smaller nondiatic change but failed to detect the larger diatonic change. By contrast, infants detected both changes equally well. Thus, although infants detected the change in relative pitch (i.e., interval change) from standard to comparison melody, the size of the pitch change was irrelevant to

their performance. What is particularly notable, however, is that the level of infant performance on the diatonic change was significantly better than that of adults. This does not reflect special skill on the part of infants but rather special difficulty on the part of adults. Indeed, adults' difficulty detecting the diatonic change in the context of a task designed for infants, a task involving numerous repetitions of the standard melody, underlines the profound processing changes that arise from musical acculturation.

In short, the suggestion that emerges from these findings is that musical acculturation builds on relational processing predispositions that are evident in early life, leading to the perceptual enhancement of culturally relevant information about musical structure at the expense of culturally neutral information about pitch distance. Furthermore, infants' ability to discriminate melodic changes that are not apparent to adult listeners parallels their facility with some foreign language discriminations that pose difficulties for adults (Trehub, 1976; Werker & Lalonde, 1988; Werker & Tees, 1984). In other words, acculturation may involve some refocusing of attention such that certain acoustic differences that are distinguishable but do not signal meaningful consequences (e.g., *l* and *r* for Japanese speakers) may be ignored by experienced listeners in favor of other distinctions that signal more meaningful consequences.

One challenge for future research is to specify the features that define *good* melodies for infant listeners and the age-related changes in these features. Some of these features are likely to capitalize on human pattern processing predispositions (i.e., innate or readily acquired) and others on experience. It may be relevant that all of the melodic processing tasks in which infants applied an interval-processing strategy involved the musical interval of a perfect fifth (seven semitones) or the simple integer ratio of 3:2 (Trehub & Trainor, in press). This frequency ratio is present in complex sounds in the natural environment, including speech sounds. If *good form* in general is critical to enhanced processing, diatonic structure being one of many possible instantiations of *good form*, then infants should show comparable enhanced processing for prototypical melodies from foreign musical cultures. Presumably, musical cultures the world over should favor patterns that are congenial to natural perceptual abilities, preferences, and perceptual learning. If exposure, however limited and unsystematic, is critical, then infants from our culture should perform more poorly on *good* foreign melodies than on *good* Western melodies, as is the case for adults (Castellano, Bharucha, & Krumhansl, 1984). There is some precedent for experiential effects in early life, as seen in enhanced processing for mother's over stranger's voice in the neonatal period (DeCasper & Fifer, 1980) and for native over foreign speech sound categories by 10 months of age (Best, Mc-

Roberts, & Sithole, 1988; Werker & Lalonde, 1988; Werker & Tees, 1984). On the other hand, it is probably no accident that the speech sounds of different languages have considerable overlap, their selection being influenced by relative discriminability or ease of processing (Comrie, 1981).

POSSIBLE SIGNIFICANCE OF RELATIONAL PITCH PROCESSING IN INFANCY

What possible functions are served by these relational pitch processing strategies in early life? One such function may be related to the fact that human caregivers reserve a unique vocal register for interactions with their young, a register known variously as *babytalk*, *motherese*, or *infant-directed speech* (for reviews see Ferguson, 1964; Fernald, 1984; Papoušek, Papoušek, & Bornstein, 1985). The acoustic properties of this register seem to be finely tuned to infants' pattern processing skills and dispositions (Trehub, 1990; Trehub & Trainor, 1990), in the sense that they exhibit a number of music-like features (Fernald, in press; Papoušek & Papoušek, 1981).

Although infant-directed speech differs from adult-directed speech in its higher fundamental frequency (i.e., pitch), increased pitch range, slower tempo, reduced utterance length, and simpler pitch contours (Fernald & Simon, 1984; Papoušek & Papoušek, 1981; Stern, Spieker, Barnett, & MacKain, 1983), it is the pitch contours that are most prominent and distinctive. These contours are relatively few in number, each being used repeatedly with variable content (Stern, Spieker, & MacKain, 1982). Moreover, specific contours (rising, falling, bell-shaped) are associated with distinctive caretaking contexts (Ferrier, 1985; Papoušek et al., 1985; Stern et al., 1982) so that pitch contour emerges as the essence of caregiver communications (Fernald, 1989, in press; Trehub, 1990).

Infant-directed speech seems to be highly effective in modulating attention, arousal, and affect in preverbal infants. When given a choice of infant-directed or adult-directed speech, 4-month-olds attend selectively to the former (Fernald, 1985; Werker & McLeod, 1989), with the pitch patterning or contour being primarily responsible for this preference (Fernald & Kuhl, 1987). It is also the case that exposure to infant-directed utterances of approval heightens positive affect compared to adult-directed utterances (Werker & McLeod, 1989) or to infant-directed utterances of disapproval, even when the language is unfamiliar to infants (Fernald, in press).

There are interindividual and intercultural differences in specific parameters of infant-directed speech such as the absolute pitch level and pitch range (Fernald et al., 1989). These differences reflect,

among other things, the caregiver's vocal tract size (and corresponding fundamental frequency differences), variations in cultural display rules, which encourage or inhibit vocal expressiveness (Fernald et al., 1989), and the caregiver's emotional state (Bettes, 1988; Stern et al., 1982). Nevertheless, the apparent universality of caregiving pitch contours (Fernald et al., 1989; Grieser & Kuhl, 1988; Papoušek & Papoušek, in press) together with their clear efficacy (Fernald, 1985; Werker & McLeod, 1989) suggests a biological basis for the production of such signals, on the one hand, and for infant melodic receptivity, on the other. Later in infancy, pitch contour processing may facilitate the process of language acquisition by directing attention to word, phrase, and clause boundaries (Kemler Nelson, Hirsh-Pasek, Jusczyk, & Wright Cassidy, 1989; Morgan, Meier, & Newport, 1987).

Although a unique vocal register for caregiving is generally viewed as an exclusively human adaptation, some research with non-human primates suggests that this might not be the case (Baldwin, 1969; Biben, Symmes, & Bernhards, 1989; Dumond, 1968). Biben et al. (1989) have described a class of squirrel monkey calls that is exclusively infant-directed. In contrast to other (adult-directed) calls, these caregiver signals are characterized by distinctive fundamental frequency (lower), rich harmonic structure, clear tonal quality, and rapid modulations of frequency and amplitude. Moreover, Biben et al. have identified three types of calls in distinct caregiving contexts: (1) maternal calls during dorsal contact or nursing, (2) inspection calls by aunts (female nonmothers) during dorsal contact or nursing, and (3) retrieval. The finding of unique infant-directed vocalizations in squirrel monkeys suggests the possibility of their presence in other nonhuman species. Further progress in elucidating the motivational basis of caregiver signals in nonhuman species may help clarify the biological basis and functional significance of music-like caregiving signals for human infants.

Whereas contour-processing strategies in human infants are of obvious relevance to the reception of infant-directed speech, the function of interval-processing strategies is much less clear. Just as interval processing may be limited to *good* or well-structured melodies in the case of infants (Cohen et al, 1987; Trehub et al., 1990) and to *familiar* or highly overlearned melodies in the case of adults (Attneave & Olson, 1971), so this strategy may be reserved for infants' identification of individual speakers such as their primary caretaker.

Although there is evidence that very young infants can recognize their mother's voice (DeCasper & Fifer, 1980; Mehler, Bertoncini, Barrière, & Jassik-Gerschenfeld, 1978), the basis for such recognition is unknown. Perhaps it is relevant that studies reporting maternal voice recognition have presented extended speech sequences as opposed to single sounds so that the extraction of pitch contours and

interval patterns (i.e., specific melodies) would have been possible. Nevertheless, descriptions of the pitch patterning of maternal speech have focused largely on pitch level, pitch range, and contour, with no identification of interval patterns or actual tunes. It is possible, then, that caregivers have distinctive interval patterns or tunes over and above their species-typical contours so that infants could learn to recognize their mother's unique vocal signature or tunes, just as they quickly learn to recognize her unique olfactory signature or smells (Cernoch & Porter, 1985; Macfarlane, 1975). In a variety of species, infants readily learn to differentiate salient stimuli that are associated with maternal care (Alberts, 1981). Perhaps human infants' precocious perception of contour and intervals will ultimately be linked to their role in fostering optimal emotional states and reciprocal attachment in caregiver and infant. Could there be parallels between human infants' perception of pitch contour and songbirds' recognition of conspecific neighbors and between human infants' perception of intervals and songbirds' recognition of individuals?

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