

## Pitch Perception in Young Infants

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Although many investigators assume that data showing infant discrimination of "frequency" indicate that infants also have pitch discrimination, it is not clear that infants can hear pitch, which is an abstract concept in which perception depends greatly on the overtones that accompany a fundamental frequency in nearly all naturally occurring sounds. Recent theories predict that organisms with little auditory experience might be unable to extract such a pitch from overtone complexes. To test this hypothesis, infants were habituated to a three-note melody. For some of the infants, the spectral composition of the individual notes varied from trial to trial while leaving the melody unchanged, whereas for others, the spectral composition was invariant. On the test trial, the melody was changed. Infants dishabituated to the change on the test trial only when the spectral composition of the tones was invariant. The presence of the fundamental frequency did not aid in recognition of the change in sequence. This suggests that the normal perception of pitch develops with experience and its mature form is not present in infants.

The literature that deals with, or relates to, early pitch perception is substantial. Appleton, Clifton, and Goldberg (1975) cite several studies concerned with the effects of various sound frequencies upon the infant. Low-frequency sounds soothe them, speech-band frequency sounds alert them, and high-frequency sounds distress them. Several studies (e.g., Eisenberg, 1969) point out the efficacy of wide-band sound in eliciting responses from newborns and older babies. Apart from these studies, most other research has not directly investigated psychophysical responses of infants to pitched sounds but has been concerned with understanding cognitive function. Some of this research (Horowitz, 1972; Kinney & Kagan, 1976; McCall & Melson, 1970; Melson & McCall, 1970) has demonstrated the infant's capacity to detect changes in tonal patterns

sometime during the 1st year through the use of habituation/dishabituation heart rate (HR) paradigms. In these paradigms, infants were familiarized to various auditory patterns, and HR dishabituation was observed when a melody changed (although it is not clear whether this discriminatory ability was due to a first-note discrepancy between the standard and novel patterns). Using the same technique, Chang and Trehub (1977) showed that infants before 6 months of age were sensitive to relative frequency; HR deceleration was found when a scrambled version of the habituated-to melody was presented, but *not* when a transposed version was presented. Finally, Kessen, Levine, and Wendrich (1979) found that 3- to 6-month-old infants possessed a rudimentary ability to imitate pitches sung or played to them.

In demonstrating adultlike frequency discrimination in even young infants, these studies have assumed that infants and adults perceive pitch in the same way. A brief survey of the psychoacoustic literature, however, indicates that there is some controversy over the actual nature of pitch perception and suggests that this assumption is perhaps not a safe one. Although knowledge about the status of early pitch perception is im-

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portant for the construction of stimuli in future studies of infant audition, the two types of theories contrasted in the acoustic literature very much resemble the heredity/environment controversies of developmental psychology and, thus, have major theoretical relevance to the field as well.

Most naturally occurring sounds possess a fundamental frequency (e.g., 200 Hz) and a series of overtones that cycle at integer multiples of the fundamental (e.g., 400 Hz, 600 Hz, 800 Hz, etc.). It is the presence and intensity of these overtones that contribute to the quality or timbre of the sound and provide the basis for discrimination among various sound sources. During the past century, much of the psychoacoustic research has demonstrated that pitch perception is mainly based on the presence of these overtones (Seebeck, 1841; Small, 1970; Wightman & Green, 1974), which indicates that our perception of pitch may not be disrupted even by the absence of the fundamental. For example, adults will usually adjust the pitch of a sine wave generator to 200 Hz to match a complex tone that contains only the over-

tones of 400 Hz, 600 Hz, 800 Hz, and 1000 Hz; in this case, the overtone complex "connotes" or "infers" a 200-Hz tone. Most of the traditional psychoacoustic explanations that have accounted for pitch perception where no fundamental is present (see Wightman & Green, 1974, for a review) suggest that the inferred, or "missing," fundamental is extracted by some peripheral or central analysis of the periodic components of the wave form. For example, these theories (known as "peak picker" or "fine structure" theories) note that a wave form composed of only the overtones of, for example, a 200-Hz fundamental actually cycles at a rate of 200 times a sec, thereby possessing some physical cue that might produce the perception of a 200-Hz tone. However, the validity of this type of explanation is questioned by the finding that the perception of pitch is relatively unaffected by manipulations that destroy this cyclicity, such as shifting the phase relationships of the wave form components (Wightman, 1973b).

Recent theories (e.g., Terhardt, 1974; Wightman, 1973a) have suggested that pitch

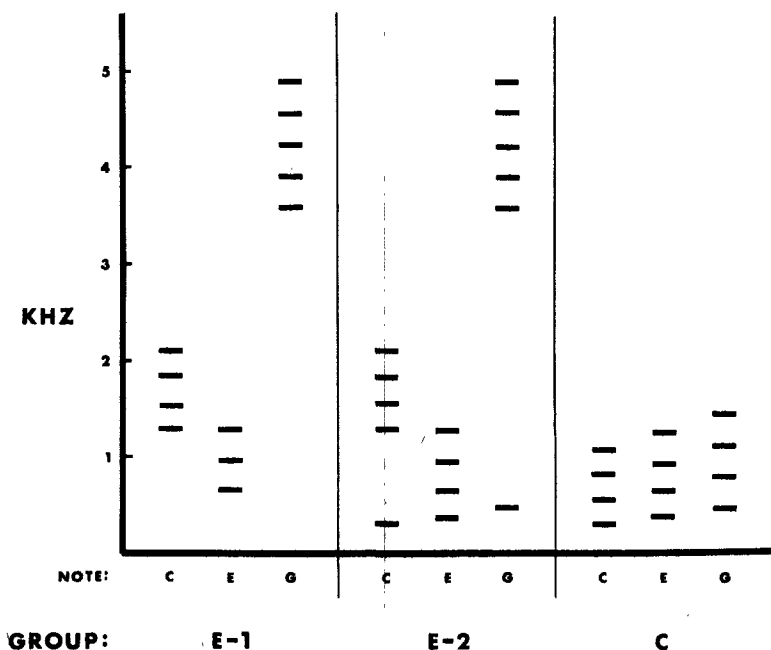


Figure 1. Spectrographic representation of a typical tone sequence presented to infants in respective experimental conditions. (C E G refer to the set of fundamentals.)

perception may be very much like other pattern recognition processes. In vision, certain features of a form may be modified or eliminated, and yet the form can still be recognized. Similarly, in speech perception, formants may be omitted without seriously impairing the recognition of a train of speech. In an analogous fashion, a particular pitch may be recognized because most of the spectral components usually associated with it are present. The absence of a particular component, such as the fundamental, may have little effect on the identification of that pitch. Since naturally occurring periodic sounds normally have energy at the fundamental and at a number of the overtones, it is possible that the association of spectral patterns with pitches develops through experience with normally occurring sounds. Normal pitch perception may develop only after a person has had considerable experience with a variety of periodic waveforms and is able to extract mutual characteristics. Adults may hear a pitch when the fundamental is absent, primarily because the fundamental is only *one* feature of a particular

pitch whose absence does not significantly detract from the other features that are still present.

To test this hypothesis, we examined infants' responses to spectrally variant and invariant sounds. (We selected infants because of their relative lack of auditory experience.) After habituating infants to a series of tones (which are perceived as consistent melodic patterns by adult listeners), we looked for response recovery when the melody was changed. In one condition, the tones were composed of spectral characteristics that were constantly varying; in another condition, only some of the characteristics were varied; and in another, spectral characteristics were kept constant. The traditional theories of pitch perception would predict that since the ability to extract a pitch from these wave forms is due to some naturally occurring stimulus analysis at the periphery or central levels, dishabituation should be evident in all three groups. Theories that propose some associative process in the development of this ability (Terhardt, 1974) predict that since the infants have insuffi-

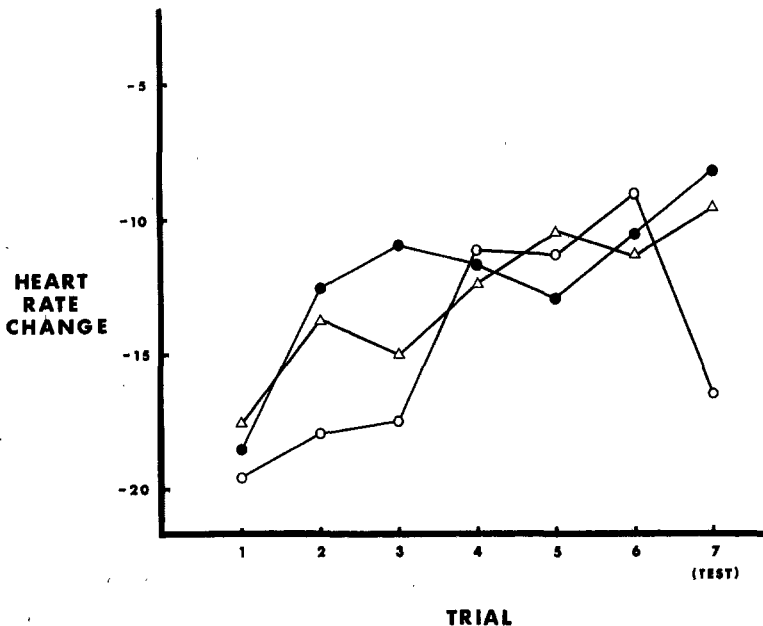


Figure 2. Habituation of the three infant groups to repeated presentation of tone sequence. (Dark circles represent Group E-1, triangles are Group E-2, and open circles denote the control condition (Group C). On the seventh (test) trial, dishabituation was observed only for Group C.)

cient experience with such sounds, they would not be able to extract a pitch when the spectral characteristics vary and, therefore, dishabituate only in the third condition.

## Method

### *Subjects*

Forty-five 4-month-olds ( $M = 123$  days, range = 113–127 days), recruited by mail and telephone predominantly from the middle-class suburbs of Buffalo, New York, were successfully tested. Infants were randomly assigned to one of three groups, and each group ( $n = 15$ ) had an approximately equal number of males and females. Fourteen of an original sample of 59 infants were excluded from the study because of fussing or crying.

### *Apparatus and Stimuli*

Three sets of auditory stimuli were synthesized with a SWTPC 6800 computer. Each set consisted of six acoustic complexes, connoting the set of fundamentals C-E-G (262 Hz, 329 Hz, & 392 Hz, respectively), and a seventh presentation in which the melodic pattern was changed to E-C-G. For condition E-1, tones were composed of different combinations of one of the following sets of overtones: 2-4, 5-8, or 9-13. For the condition E-2, the same tones were used, with the addition of the fundamental to the wave form. In both of these conditions, each note of the three-note sequence was composed of a different set of overtones within each trial. Each trial, however, contained a different permutation of overtones to connote the tone sequences. For example, the first trial consisted of five repetitions of the note sequence C-E-G, with the C note composed of overtones 5-8, the E note composed of overtones 2-4, and the G note composed of overtones 9-13. On the second trial the C, E, and G tones were composed of overtones 9-13, 5-8, and 2-4, respectively. The sets of overtones were counterbalanced across notes. The lower harmonics (overtones 3, 4, and 5) associated with the fundamental tended to produce the strongest perception of pitch. To partially correct for possible differences in pitch strength in cases where tones were composed of only higher harmonics, we used a greater number of overtones (stimuli constructed of harmonics 2-4 consisted of 3 overtones, stimuli with harmonics at 5-8 contained 4, and stimuli with harmonics 9-13 possessed 5). Overtones were combined in random phase and equal amplitude relative to one another and the fundamental frequency (when present). The tones had linear rise and fall times of 50 msec.

The subsequent trials in the habituation sequence continued in the same fashion, with the tones being composed of a different permutation of the sets of overtones but with no set of overtones being used on two different notes in the same trial. Only in the control condition (C), the spectral compositions of the tones used in the melodic pattern were held invariant; these were composed of the fundamental and the next three overtones. Although the tonal pattern changed from C-E-G to E-

C-G during the test trial, the tones composing the changed pattern were constructed in a manner consistent with those stimuli previously presented in that condition. Several of the adults who were asked to identify the place of melodic change on stimulus tapes were able to do so correctly, even when the pitches were composed of different sets of overtones, as they were for groups E-1 and E-2. A spectrographic representation of a typical tone sequence from each of the three conditions is shown in Figure 1.

The sounds were recorded on a TEAC A-3340S reel-to-reel recorder and presented at a mean intensity of 70 dB (SPL) through an ADS 200 speaker located directly in front of the infant.

### *Procedure*

Each trial (habituation and test) consisted of a 20- to 30-sec prestimulus interval, in which baseline heart rate was recorded, followed by a 12-sec stimulus-presentation period. Within this 12-sec stimulus period, five repetitions of the three-note sequence were presented to the infant. Each note within a sequence was 1 sec long, and there was a 1 sec intersequence interval. There were six habituation trials in which the repeating note sequence C-E-G was presented. The seventh trial was a dishabituation trial in which the sequence E-C-G was presented. The HR decelerations were scored by comparing the longest three interbeat intervals during each trial with the average of the five prestimulus interbeat intervals.

## Results

As seen in Figure 2, each of the groups initially showed strong HR decelerations to the tone sequence presentations, which decreased with subsequent presentations. Despite the fact that Groups E-1 and E-2 received stimulus presentations of constantly varying spectral characteristics and Group C did not, analyses of decelerations, as described above, showed no differences among the three groups in the rate of habituation. On the test trial, only infants in the control condition (C) indicated recognition of the change by significant response recovery. An analysis of variance on Trials 6 and 7 shows a significant *Trials*  $\times$  *Conditions* interaction,  $F(2, 42) = 3.22, p = .05$ .

## Discussion

The infants in the two experimental conditions apparently did not extract pitch from the combinations of overtones, as adults normally do, and were, therefore, unable to hear the change on the test trial. This suggests,

at minimum, that pitch perception, as demonstrated by adult listeners, is not present early in life. Furthermore, the results support the possibility that the perception of pitch develops through experience with periodic sounds that normally have both fundamental and overtones.

Although these findings do not directly contradict or disconfirm any of the previously cited research on infant audition, they do provide important insight about the development of this perceptual capacity. In addition, future researchers who study perceptually naive organisms should carefully consider the assumptions made with respect to stimulus construction and presentation. The inability of infants to extract a pitch from acoustic complexes, which strongly connote such a perception in adults, raises the question of whether infants fuse the presentation of several wave forms that are added together to produce a unitary auditory experience. Although research on infant vision has shown that the "bloom" of the "blooming, buzzing confusion" may not exist, these results indicate that at 4 months of age, much of the "buzz" might still linger on.

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