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Absolute Pitch in Infant Auditory Learning: Evidence for Developmental Reorganization

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To what extent do infants represent the absolute pitches of complex auditory stimuli? Two experiments with 8-month-old infants examined the use of absolute and relative pitch cues in a tone-sequence statistical learning task. The results suggest that, given unsegmented stimuli that do not conform to the rules of musical composition, infants are more likely to track patterns of absolute pitches than of relative pitches. A 3rd experiment tested adults with or without musical training on the same statistical learning tasks used in the infant experiments. Unlike the infants, adult listeners relied primarily on relative pitch cues. These results suggest a shift from an initial focus on absolute pitch to the eventual dominance of relative pitch, which, it is argued, is more useful for both music and speech processing.

When infants listen, what do they hear? Experimental evidence amassed over the past several decades suggests that the richness of the auditory world is handily exploited by infant listeners. Even the youngest listeners prefer certain auditory stimuli over others, such as their mother's voice (e.g., DeCasper & Fifer, 1980), their native language (e.g., Mehler et al., 1988), infant-directed speech (e.g., Cooper & Aslin, 1990), and familiar stories (e.g., DeCasper & Spence, 1986). Moreover, many of the mechanisms that underlie auditory discrimination and learning in adulthood are also present in infancy, such as categorical perception of speech and nonspeech contrasts (e.g., Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Jusczyk, Pisoni, Walley, & Murray, 1980) and processing advantages for consonant musical intervals (e.g., Schellenberg & Trehub, 1996).

Despite infants' auditory sophistication, there are a number of arenas in which they differ from their adult counterparts. Investigations of developmental change have primarily focused on experience-dependent shifts in auditory perception due to learning, particularly with regard to speech and music, the two auditory domains of most interest to infants. Perception of speech sounds differs as a function of native language experience for older infants and adults, but not for young infants (e.g., Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Werker & Tees, 1984). Similarly, 9-month-old infants prefer the prosodic and phonotactic patterns of their native language to foreign languages, whereas 6-month-olds do not (e.g., Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993). Infants' perception of musical harmony undergoes similar shifts as a function of experience with the native musical system (e.g., Lynch & Eilers, 1992; Trainor & Trehub, 1992).

The question to be addressed in this article is the extent to which there are developmental changes in the *types* of perceptual information detected by the mechanisms underlying auditory learning. That is, do infants and adults attend to different components of auditory events? In particular, this research addresses the relative status of two different types of pitch cues available in tone sequences: absolute pitch[1]—the encoding of a pitch independent of its relation to other sounds—and relative pitch—changes in pitch between sounds, or intervals, which are invariant over transpositions in absolute pitch (e.g., Takeuchi & Hulse, 1993). A brief melody like ADB contains not only these three absolute pitches but also two intervals: a descending perfect fifth between A and D, and an ascending major sixth between D and B. Intervals are relative: ADB and BEC♯ contain the same pair of intervals, despite their different absolute pitches.

Studies of infants' musical perception have typically found that whereas infants can use pitch cues in simple discrimination tasks, infants' discriminations are based primarily on melodic contour: the direction of pitch changes (e.g., Chang & Trehub, 1977; Trehub, Bull, & Thorpe, 1984; Trehub, Thorpe, & Morrongiello, 1987). However, studies that require infants to learn tone sequences suggest that they may be quite capable of representing absolute and/or relative pitches in complex sequential learning tasks. Saffran, Johnson, Aslin, and Newport (1999) contrasted two different sequence-learning tasks. Both tasks required infants to discover units via statistical learning: the process of detecting patterns of sounds on the basis of their probabilities of co-

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[1] The rare ability to accurately label pitches is also referred to as *absolute pitch* in the literature. Because the focus of this article is on pitch memory rather than on pitch labeling, we refer to pitch labeling ability as *perfect pitch* rather than as absolute pitch.

occurrence. In the first, infants were confronted by a continuous stream of syllables, made up of novel words (e.g., *golabu, patiku*), with no acoustic cues to word boundaries (e.g., *golabupatikubabupugolabubababupu . . .*). The infants were required to segment these words from the continuous speech stream by virtue of their statistical properties (see Saffran, Aslin, & Newport, 1996, for details of the linguistic stimuli). The second task was identical except that the stimuli were nonlinguistic: "words" consisted of sequences of tones from the octave above middle C (e.g., AFB, F♯A♯D), and the input consisted of a continuous stream of tones (e.g., AFBF♯A♯DEGD♯AFB). Infants acquired the sound sequences regardless of their linguistic or nonlinguistic status, successfully discriminating tested words[2] from part-words (sound sequences spanning a word boundary). Detection of melodic contour differences cannot explain the Saffran et al. (1999) tone-sequence segmentation results, as up–down patterns are not sufficient to specify four unique tone words. Instead, infants must have kept track of sequential patterns of absolute and/or relative pitch information during familiarization. Little, however, is known about the types of pitch cues represented and computed by infants in complex learning tasks.

Studies from the linguistic domain suggest some possible insights into the circumstances under which contour versus sequential cues predominate in infant learning tasks. Linguistic prosody, which is analogous to the melodic and rhythmic contours of music, is extremely salient to young language learners (e.g., Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Houston, & Newsome, 1999). However, given sequential learning tasks in which infants are confronted with unsegmented input without any prosodic cues, infants rapidly capitalize on the statistical properties of the input language: the sequential probabilities with which sounds are combined (e.g., Aslin, Saffran, & Newport, 1998; Saffran et al., 1996). For researchers interested in isolating the types of sequential, nonprosodic cues used by young learners, statistical learning tasks are an optimal domain. With respect to the study of pitch processing, we can use sequence-learning tasks to examine infants' use of pitch cues when prosodic information is uninformative and to tease apart the extent to which absolute and relative pitch information enter into infants' computations.

The available evidence suggests that both infants and adult nonmusicians have limited access to both absolute and relative pitch cues—but only under certain conditions. Although humans possess the neural hardware necessary for accurate and detailed pitch processing, including tonotopic frequency maps at multiple levels in the central nervous system (for review, see Weinberger, 1999), only a very small subset of adults possesses perfect pitch—that is, the ability to name the identity of notes without reference to an external standard. Similarly, adult nonmusicians are poor at processing interval information in novel musical stimuli (e.g., Burns & Ward, 1978; Siegel & Siegel, 1977).

Two factors affect the degree to which adult nonmusicians have access to absolute and relative pitch information. The first is familiarity. For example, nonmusicians are quite accurate at choosing the correct absolute pitches for overlearned tunes from popular music (Levitin, 1994) and are consistent from session to session in the pitch chosen for songs commonly heard in multiple keys (Halpern, 1989). Similarly, adult nonmusicians show evidence of categorical perception of interval information when given intervals from well-known songs as referents (e.g., labeling a perfect fourth as the "Here Comes the Bride" interval) but not in the absence of salient labels (Smith, Kemler Nelson, Grohskopf, & Appleton, 1994). The second factor is interference over time. Temporal delays filled with interpolated tones affect adults' ability to represent both pitches and intervals (for review, see Deutsch, 1999). Interestingly, interpolated materials that do not contain tonal information interfere only minimally with pitch memory (e.g., Deutsch, 1970), whereas strictly tonal materials and linguistic materials that also contain pitch information interfere equally (Semal, Demany, Ueda, & Halle, as described in Deutsch, 1999).

The same two factors, familiarity and interference, also affect infants' abilities to perceive absolute and relative pitch information. With respect to familiarity, infants can detect absolute pitch changes in major triads but not in augmented triads (Trainor & Trehub, 1993b), which occur less often in Western music and are presumably less familiar to the infants (Cohen, Thorpe, & Trehub, 1987). As stimuli become more novel, contour cues predominate in discriminations, apparently wiping out any additional information provided by pitch cues (Trehub et al., 1987). Temporal interference also affects infants' perception: With very brief retention intervals (800 ms), infants can discriminate brief novel melodies on the basis of both absolute and relative pitches, but this ability diminishes as a function of temporal delays and the introduction of distractor tones, with contour cues remaining as the basis of discrimination (Chang & Trehub, 1977; Trehub et al., 1984).

Despite the apparent difficulty of representing pitch cues, it seems likely that infants in the Saffran et al. (1999) experiment were keeping track of sequences of either absolute or relative pitch sequences, since contour information was less informative. One indication that infants may be somewhat more capable in this regard comes from the literature on avian perception. Both absolute and relative pitch cues are important for conspecific song recognition in birds (e.g., MacDougall-Shackleton & Hulse, 1996). For example, black-capped chickadees, white-throated sparrows, and veeries maintain constant frequency ratios between notes in their songs and respond most readily to these intervals. Zebra finches can form categories on the basis of absolute pitch ranges, and they do so more accurately than humans (Njegovan, Ito, Mewhort, & Weisman, 1995). MacDougall-Shackleton and Hulse found that starlings can use both absolute and relative pitches in discrimination tasks. Interestingly, the starlings first attempted to solve the task using absolute pitches; when that strategy failed, they quickly learned to use relative pitch to solve the task.

One might argue that birds have a more pressing reason to attend to pitch than human infants, because song is the basis of avian communication. However, musical properties are also pertinent to the acquisition and processing of human languages. Relative pitches are clearly important in speech perception; the relative distances between formants (bands of energy characteristic of particular speech sounds) carry much of the acoustic information used for phoneme recognition, and distinctions between some consonants (e.g., /b/, /d/, and /g/) are carried by the initial rise and

[2] The term *word* is used throughout to denote a consistent pattern of sounds that has the formal statistical properties of a word: higher transitional probabilities between sounds internal to the word than across word boundaries. We do not intend to imply that music contains any analogous structures.

fall of particular formants. Pitch values themselves carry meaning in many languages; learners acquiring tone languages like Thai or Mandarin must be able to learn that words spoken at different pitches have different meanings. Under these circumstances, ignoring the pitches and contours with which words are spoken would seriously impair language acquisition and comprehension. Moreover, experimental evidence suggests that infants in early stages of language learning do maintain absolute pitch range in their representations of novel words: In a word segmentation task, 7½-month-olds were able to generalize across voices when the two speakers were of the same sex, but not when speakers were of different sexes, presumably due to the different frequency ranges of male and female voices (Houston, Jusczyk, & Tager, 1997). However, 10½-month-olds were able to generalize across speaker sex, suggesting that with development, infants can more readily ignore irrelevant absolute pitch cues in speech.

These findings raise the intriguing possibility that infants may begin life with the capacity to represent absolute pitches of auditory events but that this ability may diminish with experience. Absolute pitch processing is less computationally complex than relative pitch usage, which requires contrasting multiple absolute pitch levels, and thus may be a less mature perceptual capacity (see also Trehub, Schellenberg, & Hill, 1997). Infants may initially possess absolute pitch abilities that are subsequently overshadowed by relative pitch abilities, either as a function of maturation or due to experience with an auditory world in which relative pitch cues predominate. However, for those perceivers for whom absolute pitch cues retain importance, such as musicians who begin their musical training early, or speakers of tone languages, absolute pitch information may maintain some perceptual currency across development.

To address the issue of absolute and relative pitch in infants' perceptual learning, infants in Experiment 1 were confronted with a learning problem that could only be solved if the infants represented the absolute pitches of tones. If, instead, the infants tracked sequences of relative pitches, they could not succeed at distinguishing the tone words and part-words on the subsequent test, because the test items contained identical patterns of relative pitches. However, if infants can detect the statistical properties of sequences of absolute pitches, they should be able to discriminate between the words and the part-words. Replicating the results of Saffran et al.'s (1999) tone-sequence learning studies with these stimuli would strongly suggest that infants represent absolute pitches and that these pitch cues enter into the statistical learning process.

Experiment 1

In this study, infants were familiarized with a continuous sequence of tones, which served as a brief learning experience. Learning was then assessed by means of the preferential listening methodology (e.g., Kemler Nelson et al., 1995). Following familiarization, infants' listening preferences were assessed for tone words versus part-words (sequences of tones spanning word boundaries, which were heard during familiarization but which contained different statistical properties than the words). It is important to note that the tested tone words and part-words contained *identical* relative pitch sequences. The only information available for infants to discriminate words from part-words in these stimuli were absolute pitch sequences. If infants did not represent and remember the absolute pitches of the tones heard during familiarization, then no differences in listening times for words versus part-words should emerge during testing. But if infants were able to track the statistical co-occurrence of the absolute pitches of the tones, then a difference in listening times for the more familiar words versus part-words might be expected, as observed previously with linguistic (Aslin et al., 1998; Saffran et al., 1996) and nonlinguistic (Saffran et al., 1999) stimuli. Specifically, we expected longer listening times to the novel part-words than to the familiar words, a dishabituation effect observed in these prior experiments in which similar statistical segmentation tasks were used.

Method

Participants. Two groups of 10 full-term 8-month-old infants were tested (mean age = 8 months 1 week; range = 7 months 3 weeks to 8 months 2 weeks). Twenty additional infants were tested but not included in the analysis for the following reasons: fussiness (13), not looking at the side lights (3), taking more than 5 min to finish the test trials (2), looking times averaging less than 3 s to one or both sides (1), and parental interference (1). In this and the subsequent experiment, infants were free of ear infections at the time of testing, and no hearing deficits were reported. Local birth announcements were used to locate participants; parental consent was obtained prior to testing in accordance with the guidelines of the review committee of local human participants and the principles of ethical treatment established by the American Psychological Association.

Materials. Tone sequences were constructed out of the 12 chromatic pure tones of the octave starting at middle C, with the exception of A, which was drawn from the octave below middle C. Tones were generated using the sine-wave tone generator in CoolEdit on the personal computer; each tone was 0.33 s in duration. Two tone streams were constructed, each consisting of four tone words (see Table 1). In each condition, 45 tokens of each tone word were concatenated together in random order to create a 3-min tone stream, with the stipulation that the same tone word would never occur twice in a row. The tone words were not constructed in accordance with the rules of standard musical composition and did not resemble any paradigmatic melodic fragments (e.g., major and minor triads, or familiar three-tone sequences like the chimes of the NBC television network). As in the linguistic and tone sequence materials used in prior segmentation studies (Saffran et al., 1996, 1999), there were no acoustic markers of word boundaries. An orthographic representation of the tone stream is analogous to the following: G♯A♯F♯BF♯GADE . . . . The only consistent cues to the beginnings and ends of the tone words were the transitional probabilities between tones (calculated by determining how often each tone pair occurred in the tone stream and normalizing that frequency by dividing by the overall frequency of the first member of the pair), which were 1.0 between tones within words but .33 across word boundaries.[3]

Infants were tested by repeatedly presenting a single test item on each test trial and comparing the infants' responses to the two different types of items over a series of test trials. Each test item consisted of a three-tone sequence. The same four test items were used for all infants (see Table 1). Two of these test items were tone words, and the other two were tone

[3] Frequency of cooccurrence of absolute pitches was also available as a cue to word boundaries in these stimuli. We assumed, on the basis of the results of Aslin et al. (1998), that transitional probabilities rather than frequencies of co-occurrence are the statistics used in this task. However, any type of statistic computed over *pairs* of absolute pitches would serve as a cue for discriminating words from part-words in this task.

Table 1
Tone Words and Test Items for Experiment 1

Absolute pitches	Relative pitches
Condition 1	
G#A#F	M2 ↑ P4 ↓
CC#D#	M2 ↑ M2 ↑
BF#G	P4 ↓ m2 ↑
ADE	P4 ↑ M2 ↑
Condition 2	
DEB	M2 ↑ P5 ↑
F#GA	m2 ↑ m7 ↓
FCC#	P4 ↓ m2 ↑
D#G#A#	P4 ↑ M2 ↑
Test items	
BF#G	P4 ↓ m2 ↑
ADE	P4 ↑ M2 ↑
FCC#	P4 ↓ m2 ↑
D#G#A#	P4 ↑ M2 ↑

Note. Items are notated with respect to absolute pitch and relative pitch patterns. All pitches are taken from the octave starting at middle C except for A, which is taken from the octave below middle C.

part-words. A part-word consisted of a three-tone sequence spanning a word boundary, created by joining the final tone of one word to the first two tones of another word. Thus, the part-word sequences were heard during familiarization. However, their statistical properties differed from those of the words; tone pairs in part-words contained lower transitional probabilities (.33 and 1.0) than tone pairs in words (1.0 and 1.0). For infants in Condition 1, BF#G and ADE were words, and FCC# and D#G#A# were part-words, with the opposite pattern for infants in Condition 2. This between-subjects counterbalanced design ensured that any observed preference for words or part-words across the two conditions was due to learning and not to any inherent preference for certain tone sequences.

Crucially, the two words and the two part-words used during testing contained *identical* interval sequences. For example, consider Condition 1. The part-word created by conjoining the last tone of G#A#F with the first two tones of CC#D# is FCC#, and the part-word created by joining the last tone of CC#D# with the first two tones of G#A#F is D#G#A#. These two part-words, translated into intervals, consist of P4 ↓ m2 ↑ and P4 ↑ M2 ↑. These interval patterns are the same as the ones in the other two words in Condition 1, BF#G and ADE. Thus, the part-words created from the first two words contain the same interval sequence as the second two words but different absolute pitches. The same is true for Condition 2. The words thus differ from the part-words solely on the basis of the statistical properties of their absolute pitch patterns; relative pitch information was not available as a cue for the test discrimination. This pattern of cue availability is referred to below as the *absolute pitch contrast.*

Procedure. Each infant was tested individually while seated in a caregiver's lap in a sound-attenuated booth. An observer outside the booth monitored the infant's looking behavior on a closed-circuit TV system and coded the infant's behavior by using a button-box connected to the computer. This button-box was used to initiate trials and to enter the direction of the infant's head turns, which controlled the duration of each test trial. Both the caregiver and the observer listened to masking music over headphones to eliminate bias. Infants were randomly assigned to Condition 1 or Condition 2. At the beginning of the 3-min familiarization phase, the infant's gaze was first directed to a blinking light on the front wall in the testing booth. Then the sound sequence for one of the two tone streams was presented without interruption from two loudspeakers (one located on each of the two side walls in the booth). During this familiarization period, a blinking light above one of the two loudspeakers (randomly selected) was lit to keep the infants' interest and extinguished dependent on the infant's looking behavior. When this blinking side light was extinguished, the central blinking light was illuminated until the infant's gaze returned to center, and another blinking side light was presented to elicit the infant's gaze. During this entire familiarization phase there was no contingency between lights and sound, which played continuously. Immediately after familiarization, 12 test trials were presented (3 trials for each of the four test items, presented in random order). Six of these trials were tone words and 6 were tone part-words. Each test trial began with the blinking light on the front wall. When the observer signaled the computer that the infant was fixating this central light, one of the lights on the two side walls began to blink, and the central light was extinguished. When the observer judged that the infant had made a head turn of at least 30° in the direction of the blinking side light, a button press signaled to the computer that one of the test items should be presented from the loudspeaker adjacent to the blinking light. This test item was repeated with a 500-ms interstimulus interval until the observer coded the infant's head turn as deviating away from the blinking light for 2 consecutive s, with a maximum of 15 repetitions per trial. When this look-away criterion was met, the computer extinguished the blinking side light, turned off the test stimulus, and turned on the central blinking light to begin another test trial. The computer accumulated total looking time to each of the two test words and two part-words.

Results and Discussion

Looking times for words and part-words were averaged across the two exposure conditions because no differences were observed between Conditions 1 and 2, $t(18) = 0.06$, *ns*. Infants showed a significant difference in listening times to the two types of test items (part-words vs. words), $t(19) = 2.28$, $p < .05$. Listening times to part-words ($M = 8.58$ s, $SE = 0.53$) exceeded listening times to words ($M = 7.54$ s, $SE = 0.75$), the same novelty preference pattern found in prior studies using speech and tone segmentation stimuli (Saffran et al., 1996, 1999). This difference demonstrates that infants can distinguish sequences that form words from sequences that span word boundaries, even when those sequences consist of the same patterns of relative pitches. To do so, infants must have maintained information about the absolute pitch sequences heard during familiarization.

Could other types of musical information known to be compelling to infant listeners account for these results? Prior research suggests three components of music that are particularly compelling to infant listeners: rhythm, intonational contour, and preferences for consonant intervals (for an overview, see Trehub et al., 1997). Rhythmic information is irrelevant to the task faced by infants in this study. Moreover, the tested words and part-words were matched for interval sequences and thus necessarily contained the same intonation contours and interval types. Clearly, the present stimuli were quite impoverished with respect to their musical content; future studies will assess the degree to which absolute pitch continues to play a role in infant auditory perception given more musical stimuli. For example, the lack of tonality in these stimuli—the fact that they did not conform to a key—may have forced listeners to maintain more specific information about the tones than would be necessary when the material can be integrated into a tonal framework. Nevertheless, these data suggest that at least under certain conditions, infants have access to absolute pitch information and can use absolute pitch cues in the computations entailed in statistical learning tasks.

Although these results support the hypothesis that infants represent and remember sequences of absolute pitches, it is possible that infants were detecting patterns of relative pitches as well. To use relative pitch information in this statistical learning task, infants would be required to distinguish the most consistent interval pairings (words) from interval pairings that occurred less often (part-words). The next study more directly assessed the role played by relative pitch in infants' tone-sequence segmentation by creating a test situation in which relative pitch pairs (referred to as *RP pairs*) served as better cues for discriminating words from part-words than absolute pitch pairs (referred to as *AP pairs*).

Experiment 2

The ideal design counterpart to Experiment 1 would flip the roles of absolute and relative pitch, such that test items would contain identical absolute pitch patterns, maintaining relative pitch as a cue for discriminating words from part-words. However, it is impossible to equate absolute pitches without concurrently equating relative pitches. Instead, in Experiment 2 we used part-word test items created from familiar AP pairs combined to create novel interval pairs. The goal of this manipulation was to generate a test contrast in which discrimination was possible on the basis of the relative familiarity of the RP pairs—but not the AP pairs—in tested words and part-words. As shown in Table 2, AP pair statistics were the only available cues for discrimination in Experiment 1, and RP pair statistics were the only available cues for discrimination in Experiment 2.

Method

Participants. Two groups of 10 full-term, 8-month-old infants were tested (mean age = 8 months 0 weeks; range = 7 months 3 weeks to 8 months 2 weeks). Twenty-three additional infants were tested but not included in the analysis for the following reasons: fussiness (16), two or more trials out of view (2), looking times less than 3 s to one or both sides (2), parental interference (2), or not looking at the side lights (1).

Materials. As in Experiment 1, two counterbalanced tone streams were constructed, each consisting of four tone words (see Table 3). Similarly, the test consisted of two words and two part-words. However, unlike the part-words tested in Experiment 1, the part-words tested in Experiment 2 consisted of parts of two words rather than a sequence spanning a word boundary. The same four test items were used for all infants (see Table 3). For infants in Condition 1, A♯D♯G and F♯DA were words, and G♯A♯D♯ and C♯F♯D were part-words, with the opposite pattern for infants in Condition 2. The part-words contained familiar AP pairs but novel RP pairs. For example, one of the part-word test items for Condition 1 was G♯A♯D♯. The tone sequence G♯A♯ was familiar to the infants from Condition 1, as was the tone sequence A♯D♯. However, the relative pitch sequence in this test item (M2 ↑ P5 ↓) was novel; the infants in Condition 1 did not hear this combination of relative pitches during familiarization. Thus, the part-words contained novel RP pairs but familiar AP pairs. The statistical properties of the test items relative to the exposure corpus are shown in Table 4. Transitional probabilities between relative pitches, but not between successive absolute pitches, were available as a cue to discriminate words from part-words. This pattern of cue availability is referred as the *RP contrast.*

Procedure. The procedure was identical to that of Experiment 1.

Table 3
Tone Words and Test Items for Experiment 2

Absolute pitches	Relative pitches
Condition 1	
A♯D♯G	P5 ↓ M3 ↑
F♯DA	M3 ↓ P5 ↑
G♯A♯F	M2 ↑ P4 ↓
C♯F♯E	P4 ↑ M2 ↓
Condition 2	
G♯A♯D♯	M2 ↑ P5 ↓
C♯F♯D	P4 ↑ M3 ↓
D♯GF	M3 ↑ M2 ↓
DAE	P5 ↑ P4 ↓
Test items	
A♯D♯G	P5 ↓ M3 ↑
F♯DA	M3 ↓ P5 ↑
G♯A♯D♯	M2 ↑ P5 ↓
C♯F♯D	P4 ↑ M3 ↓

Note. Items are notated with respect to absolute pitch and relative pitch patterns. All pitches are taken from the octave above middle C.

Results and Discussion

Looking times for words and part-words were averaged across the two exposure conditions because no differences were observed between Conditions 1 and 2, $t(18) = 0.76$, *ns*. Listening times to the two types of test items (part-words vs. words) were not significantly different, $t(19) = 0.56$, *ns* (part-words: $M = 7.56$ s, $SE = 0.55$; words: $M = 7.26$ s, $SE = 0.51$).

Table 2
Item Statistics: Experiments 1 and 2

Item statistics	Experiment 1	Experiment 2
Individual AP frequencies	No	No
Individual RP frequencies	No	No
AP pair statistics	Yes	No
RP pair statistics	No	Yes

Note. Types of information available for distinguishing tested words from part-words in Experiment 1 (absolute pitch [AP] contrast) and Experiment 2 (relative pitch [RP] contrast). Note that in neither experiment do the frequencies of individual tones or intervals distinguish words from part-words.

Table 4
Statistical Properties of Experiment 2 Test Items

Item	Transitional probabilities: Absolute pitch pairs	Transitional probabilities: Relative pitch pair
Words	1.0, .5	1.0[a]
Part-words	1.0, .5	0

Note. Transitional probabilities and pairwise frequencies were computed with respect to absolute pitch and relative pitch pairs.
[a] One of the words contained a transitional probability of .75 rather than 1.0, because one of its component intervals also occurred spanning a word boundary.

Despite the similarities between Experiments 1 and 2, infants succeeded at discriminating words from part-words only for the contrasts based on absolute pitch (hereafter referred to as the *AP contrasts*) tested in Experiment 1; the RP-based contrasts tested in Experiment 2 were not discriminated (see Figure 1). This null result does not rule out the possibility that infants can detect and use relative pitch information in tone-sequence learning. One reason that infants may not have succeeded in this task is that this particular test contrast was difficult for reasons independent of relative pitch detection. A second possibility is that the atonal structure of the exposure stimuli diminished the prominence of the relative pitch cues; the types of melodic structures carried by relative pitches may have been obscured by the lack of musical structure in these stimuli. Certainly, the literature suggests that at least for discriminations relying on brief memory intervals (<1 s), 8-month-old infants are able to capitalize on relative pitch cues (Trehub et al., 1984). Moreover, in order for an infant to acquire information about melodies beyond overall pitch contour, relative pitch cues are essential. By this age, infants are able to remember significant portions of complex pieces of music, even after retention delays of 2 weeks (Saffran, Loman, & Robertson, 2000). Future research (Saffran, 2000) will address the relative roles of different types of pitch cues in the acquisition and retention of tone sequences that adhere to the rules of Western tonal structure and contain additional musically relevant cues. The current results suggest that given a tone-segmentation task such as the one used by Saffran et al. (1999), in which both absolute and relative pitch cues were available for discriminating words from part-words, 8-month-old infants rely more heavily on absolute pitch cues.

To what extent might the same pattern of results be expected across development and across different degrees of musical experience? Adult listeners are typically more attuned to relative than to absolute pitch during musical listening experiences (e.g., Attneave & Olson, 1971; Dowling & Fujitani, 1971; White, 1960)—it is this bias which allows one to recognize that, for example, the sequences CCGGAAG and GGDDEED are the same melody ("Twinkle Twinkle Little Star"). The same is true for musicians, the vast majority of whom do not possess perfect pitch (e.g., Takeuchi & Hulse, 1993).

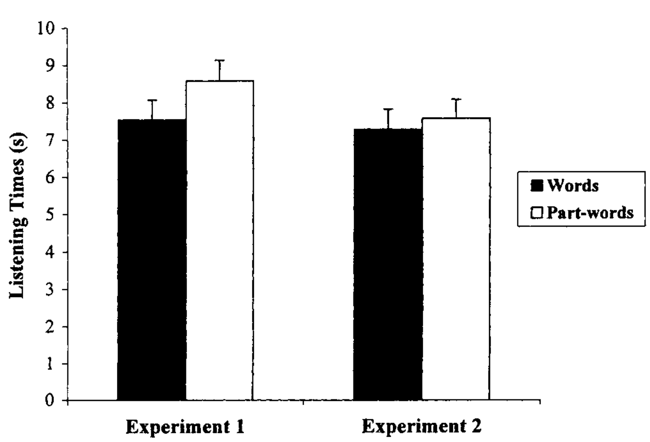

Figure 1. Mean infant listening times from Experiment 1 (absolute pitch contrast) and Experiment 2 (relative pitch contrast).

To assess the effects of development and experience on the processing of pitch in novel tone sequences, in Experiment 3 we replicated Experiments 1 and 2 with two groups of adult participants (nonmusicians and musicians). Although the methods used to assess the outcome of learning are different from those used with infants (forced-choice judgments as opposed to preferential listening measures), we can contrast the overall pattern of test performance obtained with infants (successful discrimination based on absolute pitch in Experiment 1, no discrimination based on relative pitch in Experiment 2) with adult performance. On the basis of the prior literature, we predicted that adults would show the opposite pattern of results from the infants: Better performance on the RP contrast from Experiment 2 than on the AP contrast from Experiment 1. With respect to the effects of musical experience on performance, we anticipated that the musicians would generally outperform the nonmusicians. Whether the musicians would show a pattern of relying on absolute pitch cues, as was observed with the infants, was unclear; musicians possess better pitch memory than nonmusicians do (e.g., Bartlett & Dowling, 1980; Cuddy & Cohen, 1976) but are much more likely to develop the ability to identify relative pitches than absolute pitches (e.g., Burns, 1999). In addition, if adults succeed on the RP contrast from Experiment 2, one may be somewhat more confident that infants did not fail to discriminate the RP contrast because this test was inherently more difficult than the AP contrast from Experiment 1. Differential patterns of adult and infant successes and failures would suggest an interaction between inherent task difficulty and the nature of the learning processes brought to bear on the task (in this case, as a function of age). From this viewpoint, the structure of the learner and the structure of the task are both central factors in determining the outcome of learning.

Experiment 3

Method

Participants. One hundred and twenty students at the University of Wisconsin—Madison participated in this experiment for course extra credit. All reported having normal hearing. Sixty participants were identified as nonmusicians (did not self-identify as a musician and had not played an instrument, sung in choruses, or studied music theory since the seventh grade). The other 60 participants were identified as musicians (self-identified as musicians and played an instrument or sang in a choir until at least the age of 16; mean age of beginning music lessons was 8 years 6 months). Five of the musicians reported having perfect pitch. Each participant was randomly assigned to hear the stimuli from either Condition 1 or Condition 2 from Experiment 1 or Experiment 2.

Materials. The 3-min tone sequences used in Experiment 1 (AP contrast: Conditions 1 and 2) and Experiment 2 (RP contrast: Conditions 1 and 2) served as exposure stimuli for this experiment. AP Conditions 1 and 2 refer to the two streams of tones from Experiment 1, in which absolute but not relative pitch pairs distinguished words from part-words; RP Conditions 1 and 2 refer to the two counterbalanced tone streams from Experiment 2, in which the familiarity of relative but not absolute pitch pairs distinguished words from part-words.

To assess learning, we constructed two 16-item two-alternative forced-choice tests. The AP contrast test included the four three-tone sequences (two words and two part-words) used as test items in Experiment 1; the RP contrast test included the four three-tone sequences (two words and two part-words) used as test items in Experiment 2. Each test item consisted of a word paired with a part-word. On both the AP and RP tests, the counterbalancing of Conditions 1 and 2 meant that the items that were words for participants in Condition 1 were part-words for participants in Condition 2, and vice versa. The two three-tone sequences presented on each trial were separated by a 0.75-s pause, with an intertrial interval of 5 s. Learners in the AP condition received the AP test; learners in the RP condition received the RP test.

Apparatus. The study was conducted in a small sound-attenuated room. A Sony minidisk deck and speakers were used to present the tone stream and the test.

Procedure. Participants were instructed that they would hear a tape of continuous tones with a subsequent test, but they were not told that the tape contained units of any sort. Participants were randomly assigned to the AP or RP contrast condition, and within each condition they were assigned to either Condition 1 or 2. After listening to the 3-min tone stream, participants in the AP condition received the AP test; participants in the RP condition received the RP test. Participants were instructed to indicate the most familiar tone sequence on each trial by circling either 1 or 2 on their answer sheet, corresponding to whether the familiar sequence was played first or second on that trial. All participants were tested individually.

Results and Discussion

The first set of analyses asked whether learners successfully discriminated words from part-words, as measured by above-chance performance (see Figure 2). Nonmusicians in the AP condition did not perform significantly better than would be expected by chance, $t(29) = 1.34$, *ns*. Nonmusicians in the RP condition performed significantly better than would be expected by chance, $t(29) = 2.44$, $p < .05$. Musicians performed significantly better than chance in both the AP, $t(29) = 2.35$, $p < .05$, and RP, $t(29) = 4.85$, $p < .0001$, conditions. To assess the contributions of musical experience and the AP versus RP contrast, we submitted the data to a two-factor analysis of variance (ANOVA) including musical experience (musicians vs. nonmusicians) and condition (AP vs. RP). The analysis revealed a trend toward significant effects of musical experience, $F(1, 116) = 3.38$, $p < .07$. There was also a trend for better performance in the RP than the AP condition, $F(1, 116) = 3.88$, $p < .06$; the interaction was not significant, $F(1, 116) = 0.35$.

In a second set of analyses, we examined the data after excluding the 5 participants who reported having perfect pitch (3 in the AP condition, 2 in the RP condition), as possession of perfect pitch is not representative even of the musically trained population (e.g., Takeuchi & Hulse, 1993). When individuals reporting perfect pitch were excluded, the musician group's performance in the AP condition no longer exceeded chance, $t(26) = 1.89$, $p < .07$. However, the musician group's performance in the RP condition continued to exceed chance, $t(27) = 4.35$, $p < .001$. The ANOVA including musical experience (musicians vs. nonmusicians) and condition (AP vs. RP) now showed a significant effect of AP versus RP contrast, $F(1, 111) = 4.33$, $p < .05$; neither the effect of musical experience, $F(1, 111) = 2.48$, *ns*, nor the interaction, $F(1, 111) = .54$, *ns*, was significant.

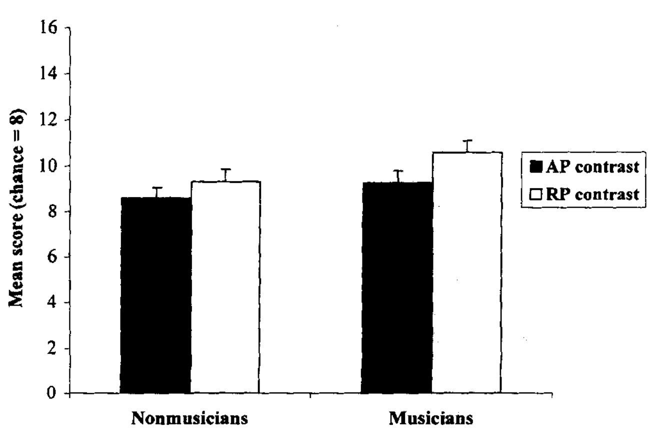

Figure 2. Adult nonmusician and musician forced-choice responses in Experiment 3 on the absolute pitch (AP) contrast (stimuli from Experiment 1) and relative pitch (RP) contrast (stimuli from Experiment 2).

These results suggest that adult and infant perceivers do not show the same pattern of learning performance given an identical set of tone sequence stimuli as input. Although infants successfully discriminated words and part-words on the basis of absolute pitch cues in Experiment 1, adult nonmusicians and musicians without perfect pitch failed to do so on the same set of stimuli (the AP condition). Conversely, both groups of adults in the RP condition were able to discriminate the test stimuli on the basis of relative pitch, but infant perceivers were unable to do so in Experiment 2. These cross-age comparisons suggest that neither contrast is inherently more difficult than the other; instead, something about the perceptual mechanisms brought to the task facilitates different aspects of learning at different ages.

To explicitly test for different patterns of performance as a function of age, we compared infants' and adults' performance on the AP and RP contrasts by translating the raw data into *z* scores and performing an ANOVA with age (infant vs. adult) and test contrast (AP contrast vs. RP contrast) as between-subjects factors. Infant *z* scores were computed for the AP and RP contrasts separately by subtracting the listening times for words from the listening times for part-words for each participant and dividing the difference by the standard deviation of the difference scores. Similarly, adult *z* scores were computed separately for each of the four groups of participants (musicians and nonmusicians in the AP and RP conditions) by subtracting the number of trials on which part-words were chosen from the number of trials on which words were chosen[4] and dividing the difference by the standard deviation of the difference scores. The ANOVA revealed no significant main effects of age or test contrast, $Fs(1, 156) = 1.16$ and 0.05, respectively, *ns*. However, the interaction was significant, $F(1, 156) = 4.07$, $p < .05$. This result indicates that adults and infants based their discriminations on different types of pitch information. As shown in Figure 3, infants evidenced superior performance on the contrast requiring absolute pitch, whereas adults performed best on the contrast requiring relative pitch. A subsequent analysis excluding the 5 adult participants who reported perfect pitch revealed the same pattern of results.

[4] For infants, word times were subtracted from part-word times because preferences for part-words are taken as a measure of dishabituation—an index of learning—based on prior research using similar procedures (e.g., Aslin et al., 1998; Saffran et al., 1996, 1999). For adults, part-words chosen were subtracted from words chosen because successful performance was measured by above-chance choice of words over part-words.

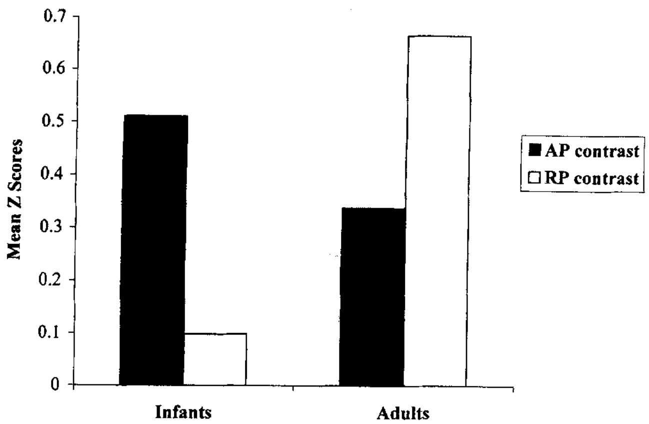

Figure 3. *Z* scores for infant and adult performance on the stimuli from the absolute pitch (AP) contrast (stimuli from Experiment 1) and relative pitch (RP) contrast (stimuli from Experiment 2).

General Discussion

Contrasts between infant and adult learners suggest a developmental shift in the use of pitch cues in a tone sequence statistical learning task. In Experiment 1, 8-month-old infants discriminated tested tone words and part-words that contained identical patterns of relative pitches. Absolute pitch patterns were the only remaining cues available to support successful discrimination. In Experiment 2, infants were unable to perform an analogous discrimination based on patterns of relative pitches. These findings suggest that infants can track absolute pitch patterns, at least given nonmusical, unsegmented sequences of tones as input; the use of this ability given input with more musical structure will be the object of future research.

The results from adult participants in Experiment 3 suggest that adult listeners use different perceptual primitives in learning the same tone sequences. Adults without musical training showed chance performance in choosing between the same words and part-words used in Experiment 1 (AP contrast) but performed significantly better than chance on the discrimination tested in Experiment 2 (RP contrast); when participants with perfect pitch were excluded, adults with musical training showed the same pattern of results as nonmusicians. This is the opposite pattern of results from that obtained from the data of the infants.

When both types of pitch cues are available, adults—unlike infants—preferentially capitalize on relative pitch patterns. These findings are interesting given that adults *do* have the capacity to represent absolute pitches for highly familiar music (e.g., Halpern, 1989; Levitin, 1994). Moreover, research on the perception of pitch paradoxes suggests that the perception of ambiguous tone sequences (such as tone pairs that are a tritone, or a half-octave, apart) is influenced not only by pitch class—suggesting that adults retain at least partial absolute pitch abilities—but also by the pitch ranges characteristic of the perceiver's speaking voice and linguistic community—suggesting that pitch processing is affected by a learning process encompassing both spoken and musical experiences (e.g., Deutsch, 1986, 1991, 1992; Deutsch, North, & Ray, 1990). The current results should not be taken as evidence that adults do not retain residual absolute pitch abilities or that infants do not possess relative pitch abilities. Instead, the patterns of results from the infants and adults suggest that different types of pitch information attain priority in tone-sequence computations at different ages, given unsegmented, unmusical tone streams. Other features of the task may have influenced adult performance, such as perceived task demands; adult listeners might have assumed, in the absence of any instructions to the contrary, that their task was to learn and remember melodic (relative pitch) patterns. Had adults received task instructions to attend to absolute pitch information, they might have more readily done so; however, this sort of task manipulation would render comparisons between the infants and the adults even more difficult.

Is it valid to compare performance of adults and infants on these tasks? Certainly, the methods and measurements are very different: Infants performed a preferential listening task, in which learning was gauged by measuring differences in listening times for tone words and part-words, whereas adults performed a forced-choice judgment, choosing between words and part-words on each trial. The adults' task did not solely measure discrimination between words and part-words as a function of learning; we predicted a particular direction of discrimination—namely, that words would be chosen more often than part-words, with performance exceeding chance. It is important to note, however, that the same type of prediction was generated for the infants. On the basis of prior research (Aslin et al., 1998; Saffran et al., 1996, 1999), we expected that infants would show a novelty preference for the part-words. This was the direction of preference observed in Experiment 1. Thus, when discrimination was observed, it was in the predicted direction for both age groups. The conclusion that infants and adults showed different patterns of successful and failed discrimination was supported by the significant interaction between age and performance across these tasks.

These results raise a number of interesting issues concerning the infant's initial state and the processes influencing the observed developmental shift in pitch-cue precedence. That is, if infants enter the world with reasonable absolute pitch memory skills, why are those abilities typically overtaken by relative pitch representations, at least for unfamiliar stimuli? This issue is loosely analogous to the nonnative-to-native shift in infant speech perception: Infants can initially perceive distinctions between phonemes that are not contrastive in their native language, but by the end of the first year, perception is tuned to discriminate only native language contrasts.

Several speculations regarding the shift in the relative weighting of absolute and relative pitch information over development are offered elsewhere in the literature, often motivated by the observation that it is easier to acquire perfect pitch labeling in childhood than in adulthood (for review, see Takeuchi & Hulse, 1993). Trehub et al. (1997), noting that nonhuman animals tend to respond primarily to absolute pitch, suggest a maturational account whereby relational pitch processing supercedes the less mature strategy of absolute pitch processing. The shift might also be due to a developmental change in focus from absolute to relative features in representational systems more generally (Takeuchi & Hulse, 1993). The use of pitch in speech perception may also affect music perception; Terhardt (1974) suggested that processing speech leads the auditory system to acquire the specific pitch relations between the harmonics in speech sounds, which in turn become the intervals found in music.

Here we explore a related explanation focused on categorization, which derives from what is currently known about infant tone and speech perception. The literature reviewed in the introduction suggests that infant perceivers are most capable of categorizing brief novel tone sequences based on their melodic contour: patterns of upward and downward motion. This reliance on contour is particularly pronounced when the discrimination task is made difficult by interpolating additional tones during the retention interval (Trehub et al., 1984). Detection of contour requires at least a rough-grained type of relative pitch, as detection of direction requires the comparison of two pitches and assessment of their relative height. However, categorization of melodies by their contour direction alone would render groupings that are too general to adequately capture the music in the infants' environment: ↑ ↓ ↓ ↑ ↓ is a pattern that could characterize any number of tunes.

The same argument can be made with respect to first language acquisition. Infants are initially attuned primarily to linguistic prosody (the pitch contours and rhythmic patterns of a language), as is evidenced by the neonate's capacity to use prosody to discriminate novel and familiar stories (DeCasper & Spence, 1986) and languages (Mehler et al., 1988). This rough-grained information, however, is not sufficient for the acquisition of native speech and lexical categories, which requires knowledge about individual sound segments and their concatenation. Thus, despite the salience of prosody, the infant must swiftly add finer-grained linguistic information to discern the relevant categories of the input language. It appears that infants do so quite readily: For example, 3-month-olds can group instances of vowels that vary in contour into a single category (e.g., Kuhl & Miller, 1982).

The current results, however, suggest that infants can track extremely fine-grained information regarding the pitches of sounds in the input. Unlike categorizing via contour patterns, which generates overly general categories relative to the structure of the auditory environment, categorizing via absolute pitch patterns would lead to overly specific categories. Infants limited to grouping melodies by absolute pitches would never discover that the songs they hear are the same when sung in different keys or that words spoken at different fundamental frequencies are the same. Thus, absolute pitch information could lead infants to generate overly specific categories of sounds, which would leave little room for generalization. Turning again to the analogy with speech, one sees that infants can learn to ignore the perceived absolute pitch of vowels spoken by males and females, categorizing according to vowel identity rather than speaker sex (e.g., Kuhl, 1979, 1983). However, in more demanding tasks such as segmenting words from fluent speech, switching speaker sex between exposure and test interferes with recognition performance in 7½-month-old infants, though not 10½-month-olds (Houston et al., 1997).

It is possible that the conflict between the rough-grained categories that emerge from attending primarily to melodic contour and the fine-grained categories that result from grouping according to absolute pitch patterns may resolve itself over development by enhancement of contour information to include the *distance* of contour changes, with a resulting diminution of absolute pitch representations. On the basis of contour information, the perceptual learning process would cluster together melodies which share the ↑ ↑ contour such as CEG, CFG, and DF#A. However, if infants are able to detect not just direction of contour but also distance of contour (the degree of the excursion from one pitch to the next), then the perceptual learning process might cluster CEG and DF#A together more closely because they share the same distance between notes, with CFG slightly more distant. Encoding distance is tantamount to the beginnings of relative pitch perception. Infants may begin by encoding only direction, with distance emerging with additional experience with melodic input. Indirect evidence suggesting that distance of contour does not initially affect infant discrimination performance comes from a study by Thorpe (1986, cited in Trehub, 1987), who found that 7- to 10-month-old infants' performance on a contour discrimination task was not affected by the magnitude of the pitch change.

Why, if infants do not initially process contour distance, would they eventually begin to do so? One possibility comes from research suggesting that musical intervals that consist of simple frequency ratios, such as octaves and perfect fifths, afford inherent processing advantages to infant listeners (e.g., Schellenberg & Trehub, 1996; Trainor & Trehub, 1993a, 1993b). Similarly, infants prefer consonant intervals to dissonant intervals (Trainor & Heinmiller, 1998; Zentner & Kagan, 1996). These findings, which indicate that not all intervals are created equal with respect to infant perception, suggest that early processing biases may implicitly guide infant perceivers to begin to track the distance between notes. The vowel perception findings described previously also suggest that infants may be engaged in learning to ignore overall contour and absolute pitch information in favor of the relative distances between formants, configurational cues which specify vowel identity.

According to this type of account, the perceptual learning process would push the infant toward ignoring absolute pitch information. Continuing with the example above, when contour distance is included in the categorization metric, CEG and DF#A are clustered together more tightly in the ↑ ↑ contour category than either is clustered with CFG. It is important to note that this grouping occurs despite the fact that CEG shares two pitches with CFG but none with DF#A. Categorization at this grain ignores absolute pitch information and might lead the perceptual learning system to weight absolute cues less than relative cues. An additional result is the derivation of a more optimal number of categories for representation of melodies. Contour direction permits only three categories: up, down, and same. Absolute pitch, in the absence of labels, generates any number of categories. Contour direction plus distance renders a smaller number of categories, because the same distances recur across transpositions. Processing at this grain may be an optimal solution to the conflicting demands inherent in categorization: ensuring within-category similarity while promoting generalization to novel category members.

Change in the degree to which infants encode relative as opposed to absolute pitch patterns may suggest an explanation for findings that demonstrate age-related shifts in infants' perception of native and nonnative harmonic structure. Such shifts are generally taken as a function of exposure to the native musical system. For example, although 12-month-olds detect interval changes in diatonic patterns (those conforming to a major or minor scale) more readily than interval changes in nondiatonic patterns (atypical in Western tonal music), 6-month-olds detect changes in both patterns equally well (Lynch & Eilers, 1992). Similarly, 8-month-olds are equally adept at detecting melodic changes that are consistent or inconsistent with diatonic structure, whereas adults are not (Trainor & Trehub, 1992). These findings are taken to suggest that 6- and 8-month-olds are not yet acculturated to Western tonal structure. However, at this point, infants have heard a great deal of music that is ideally tailored to diatonic structure in the form of children's play songs, lullabies, television and radio jingles, and so forth. Infant-directed music should, in principle, provide excellent input for the induction of native tonal structure. Rather than lack of exposure, then, it is possible that 6–8-month-olds' lack of experience-dependent learning as measured in these prior studies is due to infants' not yet tracking relative pitch relations in the music in their environments. Contour direction and absolute pitch cues are not informative about the structure of harmony in the native musical system. As contour distance attains more weight in infants' perceptual computations, the incidence and relationships between different types of intervals will become detectable, with subsequent influence on the representation and processing of harmonic structure.

Prior discussions of the genesis of perfect pitch (the rare ability to accurately label pitches, which requires absolute pitch) have focused on an early learning hypothesis, akin to the critical period for language development, whereby early musical experience facilitates the acquisition of perfect pitch[5] (e.g., Takeuchi & Hulse, 1993). There is a negative correlation between age of first music lessons and perfect pitch accuracy (e.g., Miyazaki, 1988; Sergeant, 1969), and young children perform better than older children in tasks designed to train absolute pitch labeling (Crozier, 1997). At one level, the early learning hypothesis is compatible with our results: Infants initially possess the capacity to represent the absolute pitches of sound sequences, with a diminution in this ability over development. However, the relationship between pitch memory, as tested in the current study, and pitch labeling, which is the other component of perfect pitch, remains unclear. Even adults who are nonmusicians retain some residual ability to represent the absolute pitches of highly familiar melodies (e.g., Halpern, 1989; Levitin, 1994). Thus, the relationship between the type of pitch memory observed in our infants and the type of pitch memory found in musicians with perfect pitch may be quite different. The capacity observed in the current work may be more closely related to residual absolute pitch abilities in adult nonmusicians (e.g., Deutsch, 1992).

Although the early learning view may be an apt characterization of the acquisition of the labeling component of perfect pitch, the perceptual abilities tested here may be more adequately characterized by an *unlearning* view of absolute pitch: perceptual learning leads to a primary focus on the distance between frequencies rather than the frequencies themselves. The unlearning hypothesis suggests that certain types of experiences may lead learners to maintain absolute pitch abilities. Findings that people who are congenitally blind (Welsch, 1988) and that people with autism (e.g., Heaton, Hermelin, & Pring, 1998; Mottron, Peretz, Belleville, & Rouleau, 1999) show better absolute pitch memory than the general population suggest that attending to different aspects of the environment may affect the degree to which absolute pitch is unlearned.

Another type of experience hypothesized to affect pitch perception is the use of tone languages like Mandarin and Thai, in which pitch levels and contour determine word meaning along with phonetic content. Deutsch, Henthorn, and Dolson (1999) found that speakers of tone languages represent individual words at precise pitch levels. These findings suggest that certain types of linguistic experiences affect pitch memory, at least for overlearned and regularly produced linguistic stimuli. In order to ask whether the use of a tone language would lead to more infant-like performance on tone segmentation—namely, a bias to focus on absolute pitches—we tested a sample of 23 native speakers of Mandarin[6] on the AP condition from Experiment 3. The group did not exceed chance on this task, much like the nonmusicians from Experiment 3: $t(22) = -0.41$, *ns*.

Why did Mandarin speakers perform like English speakers, given that their native language requires them to accurately represent tone levels? One possibility is that the characteristics of this sample rendered English-like performance.[7] Although the native language of these participants was Mandarin, they all use English daily as students in the United States, and the task instructions were delivered in English. In addition, many of these speakers use several Chinese dialects, which increases the likelihood that they have a flexible tonal template. Alternatively, the pitch abilities possessed by tone language speakers may be compartmentalized for native language production or processing. Our tone stimuli, unlike input derived from tone languages like Mandarin, contained no phonetic content. Interestingly, speakers of nontonal languages engaged in pitch-processing tasks when phonetic content is available show right hemisphere activation—as opposed to the left hemisphere activation resulting from phonetic-processing tasks using the same stimuli (Zatorre, Evans, Meyer, & Gjedde, 1992). The relation between domain-general absolute pitch ability and linguistic tasks may be most relevant far earlier in life: Without the ability to track the pitches of words in the input, infants would not be able to acquire tone languages to begin with or even to notice that tone is relevant in their input language. Thus, it is possible that some of the same learning mechanisms subserve linguistic and tone learning tasks, with distinctions between linguistic and nonlinguistic processing emerging once learners have acquired basic knowledge about the structures in each domain (see also Saffran et al., 1999).

In conclusion, infants, like many songbirds, can represent the absolute pitches of tone sequences and can do so given complex and unsegmented input. Whereas adults maintain residual absolute pitch memory abilities, adult perception is dominated by detection of relative pitch patterns. Although absolute pitch can be a useful and desirable musical skill, the ascension of relative pitch represents a positive development; without the capacity to represent and maintain the intervals between notes, musical structure (and, indeed, much of phonetic structure) would remain elusive to listeners.

[5] This observation was borne out in our data as well; the 5 adults who reported having perfect pitch began music lessons at a mean age of 4 years 8 months, whereas the rest of our participants began at 9 years 4 months.

[6] Participants were undergraduate and graduate students at the University of Wisconsin—Madison, who participated for payment of $3. All gave their informed consent.

[7] We thank an anonymous reviewer for this suggestion.

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