

ARTICLE WITH PEER COMMENTARY AND RESPONSE

Absolute pitch in infancy and adulthood: the role of tonal structure

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Abstract

Despite many similarities in infant and adult auditory processing, the literature suggests that two aspects of music perception, pitch processing and knowledge of tonal structure, change over development. The current experiments assess the use of absolute and relative pitch cues in a tone sequence statistical learning task containing tonal structure. The results suggest that infants preferentially process absolute pitch patterns in continuous tone sequences, supporting the hypothesis that absolute pitch is present in infancy, whereas adults tracked both absolute and relative pitch patterns. Infants and adults detected the tonal structure in the input, suggesting that humans are attuned to basic aspects of tonality early in life.

Introduction

Absolute pitch (AP) – the encoding of a pitch independent of its relation to other sounds – is generally considered to be an unusual ability, exhibited by a small subset of musicians (for review, see Takeuchi & Hulse, 1993). Instead, adult listeners tend to rely on relative pitch (RP) – changes in pitch between sounds, or intervals – to recognize and reproduce melodies. Adults do possess absolute pitch abilities that emerge under specific circumstances. For example, non-musicians can choose the absolute pitches which correctly begin highly familiar popular songs (Levitin, 1994), and consistently choose the same pitches for songs commonly heard in multiple keys (Halpern, 1989). These capacities also emerge in language processing and production among speakers of languages that use tones contrastively (Deutsch, Henthorn & Dolson, 1999). Outside of the context of highly familiar and rich auditory events, relative pitch is the primary mode of pitch perception for most adults (e.g. Takeuchi & Hulse, 1993). This is an adaptive state of affairs, as relative pitch enables the detection of invariance over transpositions in absolute pitch, and is thus more useful than absolute pitch in most circumstances.

It is often speculated that the roots of absolute pitch lie in childhood. For example, there is a negative correlation between the age of first music lessons and AP

accuracy (e.g. Miyazaki, 1988; Sergeant, 1969), and young children outperform older children in tasks designed to train AP labeling (Crozier, 1997). On this view, absolute pitch is the dominant mode of processing early in life, supplanted by the more useful ability to represent relative pitches. In a recent study, Saffran and Griepentrog (2001) directly tested the hypothesis that there is a developmental shift in pitch processing. Participants were exposed to a 3-min sequence of continuous tones (e.g. EC#FG#CGABC# . . .), and then tested to determine whether they had represented the tones with respect to their AP or RP patterns. Importantly, the tone sequences were atonal, and did not conform to any of the conventions of Western musical composition. The results suggest that while adults relied primarily on RP cues, 8-month-old infants tracked AP patterns. These results suggest a shift from an initial focus on absolute pitch to the eventual dominance of relative pitch. Absolute pitch may be a less mature perceptual capacity, eventually supplanted by RP during development (e.g. Trehub, Schellenberg & Hill, 1997).

While the Saffran and Griepentrog (2001) results suggest that infants and adults track different components of pitch given the same auditory stimuli, it is unclear whether their materials tapped the processes that underlie the perception of materials containing more pitch structure, such as music. Saffran and Griepentrog's (2001) stimuli were atonal, and included all of the 12

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scale tones in the Western octave. However, an important aspect of most music (and perhaps all music heard by infants) is tonality: conforming to a particular scale (or key, in Western music). As observed by Helmholtz (1885/1954, p. 5), 'Modern music has especially developed the principle of tonality, which connects all the tones in a piece of music by their relationship to one chief tone, called the tonic.' The absence of tonal structure could have led infants to process these materials in a non-musical fashion, memorizing individual pitch pairs rather than focusing on the 'melodies' carried by the relative pitches. If this is the case, then the introduction of tonal structure might lead infants to focus on RP patterns – the melodies in the tone stream – rather than AP patterns. Alternatively, if the detection of absolute pitch is a basic auditory learning process in infancy, then infants should continue to detect and use AP patterns even when the materials contain tonal structure.

For tonality to affect infant music perception, infants must know the difference between atonal and tonal music. However, the extent of infants' knowledge of Western tonal structure remains unclear. Infants under a year of age appear to represent some Western scale structures, detecting changes to prototypical patterns like major triads more readily than uncommon patterns like augmented triads (e.g. Trainor & Trehub, 1993b; Cohen, Thorpe & Trehub, 1987). However, these data are believed to reflect existing biological predispositions to preferentially process consonant intervals over dissonant intervals, rather than acquired knowledge of tonal structure (Schellenberg & Trehub, 1996; Trainor & Heinmiller, 1998; Trainor & Trehub, 1993a, 1993b; Zentner & Kagan, 1996). Indeed, most studies suggest that the influence of Western tonal structure on perception is minimal during the first year of life, with an extended developmental trajectory throughout late infancy and childhood (e.g. Krumhansl & Keil, 1982; Lynch & Eilers, 1992; Lynch, Eilers, Oller, Urbano & Wilson, 1990; Morrongiello & Roes, 1990; Trainor & Trehub, 1992; Trehub *et al.*, 1997).

The current experiments were designed to address three questions. First, do infants continue to represent absolute pitches when the tone sequences are tonal, rather than atonal? Second, does the introduction of tonal structure have any impact on infant perception? Third, does tonal structure affect the use of pitch cues by adult non-musicians? To address these questions, we exposed infants and adults to a continuous sequence of tones, organized into three-tone sequences by virtue of their statistical properties. The question of interest was which pitch cues entered into listeners' computations: did listeners track the probabilities with which absolute

itches followed one another, or the probabilities with which relative pitches followed one another? Importantly, the materials were tonal rather than atonal, conforming to the key of C major. Participants were then tested to determine which types of pitch cues were tracked. Comparison of these results with data from Saffran and Griepentrog's (2001) atonal task will allow us to assess the degree to which tonality impacts on pitch processing and learning by infants and adults.

Experiment 1

Using the head-turn preference procedure (e.g. Kemler Nelson, Jusczyk, Mandel, Myers, Turk & Gerken, 1995), infants were familiarized with a 3-min tone sequence, made up of four three-tone sequences – referred to below as 'tone words' – in random order. We then assessed infant listening preferences for tone words versus 'part-words' (sequences of tones spanning tone word boundaries, which occurred with lower probabilities than the words during familiarization). Importantly, the tested tone words and part-words contained *identical* RP sequences; only AP information was available to distinguish words from part-words. If infants were unable to represent and remember the absolute pitches heard during familiarization, no differences in listening times for words versus part-words should emerge.

Method

Participants

Two groups of eight 8-month-old infants were tested (mean age 8 months: 0 weeks; range 7:3 to 8:2). Fourteen additional infants were not included in the analysis due to: fussiness (5), test duration exceeded 5 min (3), looking times averaging less than 3 sec to one or both sides (4), and parental interference (2). Parental consent was obtained prior to testing.

Materials

Tone sequences were constructed using the C major scale for the octave beginning at middle C. Each tone was .33 sec in duration, generated using the sine-wave tone generator in CoolEdit on the PC. Two tone streams were constructed, each consisting of four tone words (see Table 1). In each condition, 45 tokens of each tone word were combined in random order to create a 3-minute tone stream; no silences or other acoustic cues marked tone word boundaries (e.g. EDCGFGCDAC*FGCDAEDC . . .).

Table 1 Tone words and test items for Experiment 1

	Absolute pitches	Relative pitches
<i>Condition One</i>	E D C	M2↓M2↓
	C* F G	P5↓M2↑
	C D A	M2↑ P5↑
	G F G	M2↓ M2↑
<i>Condition Two</i>	A G F	M2↓M2↓
	G C D	P5↓M2↑
	F G E	M2↑ m3↓
	D C C*	M2↓O↑
<i>Test Items</i>	E D C	M2↓M2↓
	C* F G	P5↓M2↑
	A G F	M2↓M2↓
	G C D	P5↓M2↑

Note: Experiment 1 items notated with respect to absolute pitch and relative pitch patterns. All pitches are from the octave above middle C (C* = one octave above middle C).

On each test trial, infants heard repetitions of a single test item, consisting 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, while the other two were tone part-words (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). While the part-word sequences were heard during familiarization, their component pitch pairs occurred with lower probabilities than the words. For infants in Condition One, E D C and C* F G were words and A G F and G C D were part-words, with the opposite pattern for infants in Condition Two, providing counterbalancing of the test items. Crucially, the tested words and part-words contained *identical* RP sequences. The words thus differed from the part-words only in absolute pitch; relative pitch information was not available as a cue for the test discrimination. This pattern of cue availability is referred to below as the AP contrast.

Procedure

Infants were 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 using a button-box connected to the computer. The 3-min sound sequence for one of the two tone streams was presented without interruption. Twelve test trials were then presented (three trials for each of the four test items, in random order). Six trials were tone words and six 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 extin-

guished. When the observer judged that the infant had made a head turn of at least 30 deg 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 sec. When this criterion was met, the computer extinguished the blinking 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

Infants showed a significant difference in listening times to words (6.93 sec, SE = 0.40 sec) versus part-words (5.96 sec, SE = 0.29 sec): $t(15) = 2.50$, $p < 0.05$ (see Figure 1). For this difference to emerge, infants must have represented the AP sequences heard during familiarization. Twelve of the 16 infants listened longer to words than part-words. This is the opposite direction of preference from the novelty preference for part-words found by Saffran and Griepentrog (2001, Exp. 1). An ANOVA comparing the current results to Saffran and Griepentrog's results revealed a significant main effect of experiment (tonal versus atonal) [$F(1, 34) = 4.99$, $p < 0.05$], with longer listening times overall for the atonal stimuli. The main effect of item (word versus part-word) was not significant [$F(1, 34) = 0.005$, n.s.]. However, the interaction between experiment and item was significant [$F(1, 34) = 10.68$, $p < 0.01$]. This interaction indicates that tonality affected preferential listening: infants exposed to atonal stimuli listened longer to the relatively novel part-words, whereas infants exposed to tonal stimuli listened longer to words.¹

The significant difference in listening times for words and part-words suggests that infants continue to track absolute pitches when tone sequences contain tonal structure, in this case the key of C major. One possible objection is that although the pitches used in this experiment were chosen to conform to C major, the materials may have lacked sufficient structure with regard to a tonal center to afford the induction of C major. Krumhansl and Kessler (1982) developed profiles for major and minor keys based on listener ratings of the fit

¹ It is unlikely that the flip in preference is due to the relative ease of processing consonant intervals (e.g. Schellenberg & Trehub, 1996), which are more prevalent in the tonal stimuli than the atonal stimuli. Typically, stimuli which are easier to learn elicit novelty preferences due to a more rapid habituation process (e.g. Hunter & Ames, 1988); this is the opposite of the current findings.

between individual probe tones and a preceding tonal context. These profiles are widely used to assess the strength with which particular pitches contribute to the induction of a particular key. The process of organizing pitches according to their tonal hierarchy is partially based on frequency of occurrence; the most important pitches signifying a key (tonic, dominant) are also the most frequently presented pitches in Western tonal music (e.g. Krumhansl, 1990). We thus assessed the degree to which our materials fit the profile for C major by comparing the Krumhansl and Kessler (1982, data from their Figure 2) pitch rating profiles for C major to the frequency of occurrence of each pitch in the current stimuli, as well as to Saffran and Griepentrog's (2001) atonal stimuli. The correlations suggest that the current stimuli closely fit the C major profile [R -squared = 0.85, $F(1, 10) = 55.29$, $p < 0.0001$] whereas the atonal stimuli do not [R -squared = 0.07, $F(1, 10) = 0.76$, n.s.]²

While the introduction of tonality did not interfere with infants' ability to track absolute pitches, the direction of preference suggests that infants may be sensitive to tonality. The only difference between this study and Saffran and Griepentrog (2001, Exp. 1) was the introduction of tonal structure. The resulting familiarity preference differs from the novelty preference observed with atonal stimuli, a dishabituation-like effect consistent with a number of prior studies using similar familiarization protocols (e.g. Aslin, Saffran & Newport, 1998; Echols, Crowhurst & Childers, 1997; Marcus, Vijayan, Bandi Rao & Vishton, 1999; Saffran, Aslin & Newport, 1996; Saffran, Johnson, Aslin & Newport, 1999).

We hypothesize that the introduction of tonality altered infants' processing. In particular, we suggest that infants applied rudimentary knowledge of Western tonal structure to these materials. Prior knowledge is known to influence infant preferential listening: infants consistently prefer to listen to the sound patterns of their native language, and to linguistic materials interrupted at structurally relevant junctures (for an overview, see Jusczyk, 1997). Musical stimuli segmented at structurally relevant boundaries (e.g. Jusczyk & Krumhansl, 1993; Krumhansl & Jusczyk, 1990), or played in the musical contexts in which they were originally learned (Saffran, Loman & Robertson, 2000), are also preferred by infant listeners. Most relevant to the current results, infants show a familiarity preference for linguistic words over part-words in statistical learning tasks when the 'words' initially heard in a continuous sequence of syllables are later embedded in a familiar English sentence (Saffran,

2001). Infants appear to attempt to integrate the auditory materials presented in lab tasks with their prior domain-relevant knowledge. On this view, the current stimuli were integrated with infants' prior knowledge of Western tonal structure, leading infants to acquire statistically defined 'melodies' (a.k.a. the tone words). When the melodies were broken, as in the test part-words, infants were less interested in listening. Because Saffran and Griepentrog's (2001) atonal materials were not integrated into the infant's knowledge of musical structure, prior knowledge did not affect performance, and the standard dishabituation response emerged.

Regardless of the roots of the familiarity preference, this experiment yielded two important results: infants continue to track absolute pitches even when the materials contain tonal structure, and infants show a different pattern of listening preferences when the input contains tonal structure. What remains unknown is the role of relative pitch processing in this learning process. While relative pitch patterns cannot have served as the basis for the successful test discrimination, it is possible that infants were engaged in tracking relative pitches along with absolute pitches during the learning process. Infants are highly attuned to melodic contour – the shape of melodies – in which relative pitch plays an important role (for review, see Trehub *et al.*, 1997). In addition, several studies have demonstrated that infants are able to detect mistunings in melodies that have been played repeatedly in transposition (ruling out absolute pitch as the grounds for discrimination), suggesting that infants do attend to relative pitch distance (e.g. Lynch & Eilers, 1992; Trainor & Trehub, 1992, 1993a). Although infants in Saffran and Griepentrog (2001, Exp. 2) did not appear to track relative pitch patterns given atonal tone sequences, it is possible that the introduction of tonal structure may increase attention to melodic structure, supporting representations of intervals. To address this question, Experiment 2 assessed infants' ability to track patterns of relative pitches in tonal materials.

Experiment 2

Method

Participants

Two groups of ten 8-month-old infants were tested (mean age 8 months: 1 week; range 7:3 to 8:2). Eight additional infants were not included in the analysis due to: fussiness (7), and looking times averaging less than 3 sec to one or both sides (1). Parental consent was obtained prior to testing.

² Because these stimuli consist of a flat distribution of all the pitches in the octave, they are not a good fit to any key, thus their atonal designation.

Table 2 Tone words and test items for Experiment 2

	Absolute pitches	Relative pitches
<i>Condition One</i>	E D C	M2↓M2↓
	C* F G	P5↓M2↑
	C E F	M3↑ m2↑
	G C* D	P4↑ m7↓
<i>Condition Two</i>	C E D	M3↑ M2↓
	G C* F	P4↑ P5↓
	C* D C	m7↓M2↓
	E F G	m2↑ M2↑
<i>Test items</i>	E D C	M2↓M2↓
	C* F G	P5↓M2↑
	C E D	M3↑ M2↓
	G C* F	P4↑ P5↓

Note: Experiment 2 items notated with respect to absolute pitch and relative pitch patterns. All pitches are taken from the octave above middle C (C* = one octave above middle C).

Materials

As in Experiment 1, we constructed two counterbalanced tone streams drawing pitches from the C major scale, each consisting of four tone words, with the same four test items for all infants (see Table 2). The tested part-words contained familiar AP pairs, but novel RP pairs (unlike Experiment 1, the part-words consisted of parts of two words, rather than a sequence spanning a word boundary). For example, one of the part-word test items for Condition One was CED. The tone sequence CE was familiar to the infants from Condition One, as was the tone sequence ED. However, the RP sequence in this test item (M3↑ M2↓) was novel; the infants in Condition One did not hear this combination of relative pitches during familiarization. In terms of the statistical properties of these materials, the words and part-words contained identical transitional probabilities between absolute pitches (all 0.5), but different transitional probabilities between relative pitches (word average: 0.93; part-word average: 0). This pattern of cue availability for the part-words, in which AP pairs were familiar but RP pairs were novel, is referred to below as the RP contrast.

Procedure

The procedure was identical to Experiment 1.

Results and discussion

Infants did not show significantly different listening times for words (7.12 sec, SE = 0.40) versus part-words (7.35 sec, SE = 0.67): $t(19) = 0.37$, n.s. Nine of the 20 infants tested listened longer to the words. Infants succeeded at discriminating words from part-words only for the AP-based contrasts tested in Experiment 1; the results from

Experiment 2 provide no evidence that infants were able to use relative pitch in their discriminations.

If infants are able to use absolute pitch patterns, as demonstrated in Experiment 1, why did they not use the differences in absolute pitches to discriminate words from part-words in Experiment 2? The current design ensures that the transitional probabilities between absolute pitches in the part-words equal the transitional probabilities between absolute pitches in the words (all 0.5). As responses in this methodology rest on relative familiarity/novelty, the results suggest that the equating of absolute-pitch pair familiarity across test items removed absolute pitch as a cue – this is the case even if the words are processed as melodies, as suggested in the discussion of Experiment 1. Words and part-words differed far more with respect to relative pitch pair probabilities (0.93 versus 0), a difference which failed to lead to discrimination.

This null result does not rule out the possibility that infants can detect and use relative pitch information in tone sequence learning. Indeed, the literature suggests that infants do have access to relative pitch information given certain types of discrimination tasks (for review, see Trehub *et al.*, 1997). For example, 8-month-old infants are able to capitalize on relative pitch cues given discrimination tasks over brief (< 1 sec) retention intervals (Trehub, Bull & Thorpe, 1984), and attend to the differences between consonant and dissonant intervals (e.g. Schellenberg & Trehub, 1996; Trainor & Heinmiller, 1998; Trainor & Trehub, 1993a, 1993b; Zentner & Kagan, 1996). The task used here, however, failed to elicit RP-based discrimination of words from part-words, despite the fact that infants successfully discriminated the test items when AP cues were available in Experiment 1. While infants presumably have access to some RP cues, they appear to depend more heavily on AP cues given a lengthy and complex tone sequence as input.³ Increasing the musicality of the materials by adding other musical cues, or using more naturally generated tones, may enhance attention to relative pitches.

Unlike infants, adults typically rely on relative pitch, particularly given novel materials (Attneave & Olson, 1971; Dowling & Fujitani, 1971; White, 1960). Consistent with the literature, Saffran and Griepentrog (2001, Exp. 3) found that adults performed the atonal pitch sequence learning task using RP cues, but not AP cues – the opposite pattern of performance from infants, suggesting a developmental shift in pitch processing. However, adults do represent absolute pitches for certain

³ Other types of cues such as intonation contour and rhythm are known to be highly salient to infants (e.g. Trehub *et al.*, 1997), but were not available as good cues for learning in the current experiments.

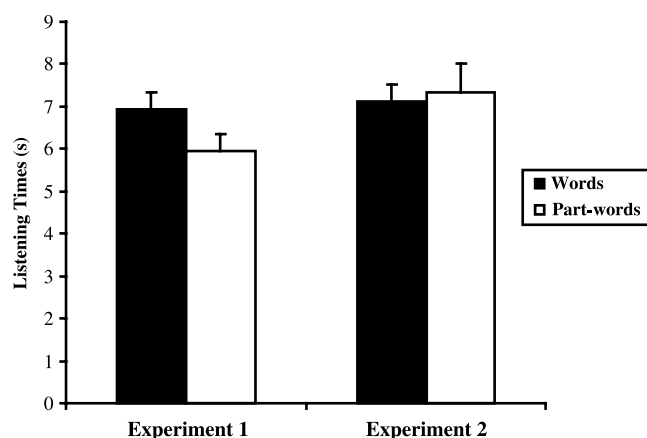


Figure 1 Mean infant listening times from Experiment 1 (AP contrast) and Experiment 2 (RP contrast).

types of materials, such as highly familiar songs (e.g. Halpern, 1989; Levitin, 1994). Perhaps the adults tested by Saffran and Griepentrog (2001) failed to track absolute pitches because they were unfamiliar with atonal materials, rendering absolute pitches more difficult to represent. Indeed, the literature suggests that tonal structure facilitates memory; adults and grade-school-aged children are less accurate in encoding and representing novel atonal melodies than tonal melodies (e.g. Cuddy, Cohen & Miller, 1979; Krumhansl, 1979; Morrongoiello & Roes, 1990). Experiment 3 addresses the hypothesis that given more familiar materials, such as those drawn from the key of C major, adult non-musicians will track and represent AP cues. Since adults were able to track RP cues given Saffran and Griepentrog's (2001) atonal stimuli, we expected that they would continue to do so given tonal stimuli. To test these hypotheses, Experiment 3 replicated Experiments 1 (AP contrast) and 2 (RP contrast) with adult non-musicians.

Experiment 3

Method

Participants

Forty students at the University of Wisconsin-Madison participated for course extra credit. All reported normal hearing, and were non-musicians (did not self-identify as a musician, and had not played an instrument, sung in choruses or studied music theory since the seventh grade). Each participant was randomly assigned to hear the stimuli from either Condition One or Condition Two from Experiment 1 or Experiment 2.

Materials

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

Learning was assessed via two 16-item two-alternative forced-choice tests. The AP contrast test included the four three-tone sequences (two words and two part-words) employed as test items in Experiment 1; the RP contrast test included the four three-tone sequences (two words and two part-words) employed as test items in Experiment 2. Each test item consisted of a word paired with a part-word. On both tests, the counterbalancing meant that the items which were words for participants in Condition One were part-words for participants in Condition Two, and vice versa. The two three-tone sequences presented on each trial were separated by a 0.75 sec pause, with a 5-sec inter-trial interval.

Apparatus

The study was conducted in a small sound-attenuated room. The tone stream and the test were presented using a Sony Minidisk deck and speakers.

Procedure

Participants were tested individually, and instructed that they would hear a tape of continuous tones. Participants were randomly assigned to the AP or RP condition, and within each condition were assigned to either Condition One or Two. 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. Each test trial consisted of two 3-tone sequences. Participants were asked to indicate which of the two sequences sounded more like the materials on the tape heard during exposure. Subjects responded by marking either a 1 or 2 on an answer sheet, corresponding to whether the first or second tone sequence was more similar to the exposure stimuli.

Results and discussion

The first set of analyses asked whether learners successfully discriminated words from part-words (see Figure 2).

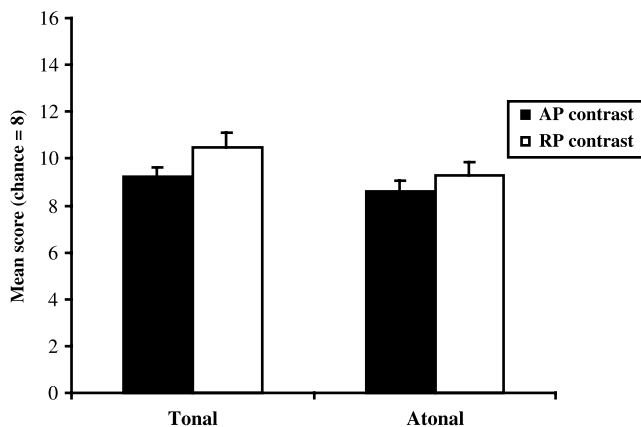


Figure 2 Adult forced-choice responses on the AP contrast and RP contrast. Tonal stimuli refer to the results from Experiment 3; atonal stimuli refer to the results from Saffran and Griepentrog (2001, Experiment 3).

Adults in the AP and RP conditions performed significantly better than would be expected by chance [AP: $t(19) = 2.94$, $p < 0.01$; RP: $t(19) = 3.84$, $p < 0.01$]. While performance was better in the RP condition [10.45 out of 16, SE = 0.64] than the AP condition [9.2 out of 16, SE = 0.40], the two groups were not significantly different: $t(38) = 1.65$, n.s.

To assess the effects of tonality on adult tone sequence learning, we compared these data to Saffran and Griepentrog's (2001, Exp. 3) results with atonal stimuli, in which only the participants in the RP condition exceeded chance performance. A two-way ANOVA including tonality (atonal versus tonal stimuli) and test contrast (AP versus RP) revealed a main effect of test contrast, with better performance on the RP contrast than the AP contrast [$F(1, 96) = 4.09$, $p < 0.05$]. The main effect of tonality was marginally significant, with better performance with tonal stimuli than atonal stimuli [$F(1, 96) = 3.35$, $p < 0.07$]. The test contrast \times tonality interaction was not significant [$F(1, 96) = 0.16$, n.s.]. These results suggest increased acquisition of both AP and RP patterns as the stimuli become more tonal. Performance which was at chance levels given an atonal AP task exceeded chance given a tonal AP task, indicating that adults can track AP cues, although RP acquisition was consistently superior.

General discussion

These results support the hypothesis that there is a developmental shift in pitch processing between infancy and adulthood. Regardless of the tonality of the input, infants preferentially detect absolute pitch patterns in

continuous, unsegmented, tone sequences, suggesting that infants represent very basic components of the musical environment. Adults, however, detect absolute pitch patterns in this paradigm only given tonal structure; relative pitch patterns are tracked regardless of tonality. This shift during development – from generally prioritizing absolute pitch patterns to generally prioritizing relative pitch patterns given continuous sequences of tones – is advantageous to the listener; while absolute pitches are certainly available in the auditory environment, they provide a poor basis for generalization from prior listening experiences for both music and speech (e.g. Saffran & Griepentrog, 2001).

Pitch perception was assessed in these experiments using a statistical learning task: given multiple different types of possible primitives over which to compute statistics, including both absolute and relative pitches, which primitives entered into learners' computations? The answer appears to be dependent on the developmental and/or experiential state of the listener. In addition, the use of pitch cues is driven by the nature of the task. Other types of input appear to lead infants to focus on relative pitch cues. For example, infants discriminate based on relative pitch given materials in which simple melodies are repeated in transposition (removing AP as a cue for discrimination), and the task is to notice a change in the melody (e.g. Lynch & Eilers, 1992; Trainor & Trehub, 1992, 1993a). We suggest that rather than conflicting with the literature showing that infants attend to relative pitch and pitch contour, the current results add to the literature by suggesting that infants also have access to absolute pitch cues tracked over time. In particular, absolute pitch cues might be preferentially detected given unsegmented materials like those used here, where learners are forced to track the patterns in the input to find substructures like 'tone words', a context in which pitch contours would not be very informative. It is also possible that despite the increment in musicality provided by the tonal context, the current materials are insufficiently musical to lead infants to preferentially listen for melodic structure in the form of relative pitches; additional musical cues and/or the use of more natural-sounding materials, such as piano tones rather than sine waves, might be required to elicit relative pitch processing given unsegmented input. Alternatively, removing absolute pitches as a useful segmentation cue, as in prior studies using materials in transposition, may elicit relative pitch processing; we are currently exploring this hypothesis (Saffran, in progress).

However musically impoverished the stimuli, the results suggest that infants are not impervious to tonality. The flip in listening preferences from a novelty preference given atonal structure to a familiarity preference

given tonal structure suggests that infants may be processing these materials differently. While the exact basis of this processing difference remains unknown, these results are consistent with suggestions that infants possess the necessary foundational abilities to induce the beginnings of tonal structure, although it is clear from the prior literature that a great deal of additional experience is required for adult-like tonal representations to emerge. Infant-directed music is perhaps the ideal vehicle for the acquisition of Western tonal structure, given its simple and regular structure. The lullabies and children's play songs present cross-culturally may function like infant-directed speech in highlighting the building blocks of the adult system (e.g. Trehub, Unyk & Trainor, 1993).

An interesting implication of these results concerns the nature of the learning process tapped by the statistical learning task. A number of studies, using linguistic, visual non-linguistic, and auditory non-linguistic materials, have demonstrated that learners are adept at tracking the sequential statistics which can serve as segmentation cues in continuous input (e.g. Fiser & Aslin, 2001; Hunt & Aslin, 2001; Saffran, 2001; Saffran & Griepentrog, 2001; Saffran *et al.*, 1996, 1999). These findings suggest that the statistical learning mechanism underlying performance across these tasks is itself quite general, and not tailored specifically for music or linguistic processing. However, the output of the mechanism appears to be influenced by the specific domain into which the output is integrated. In the current experiments, the presence of tonal structure led infants to show a different pattern of listening responses, suggesting that infants' prior knowledge of Western tonal structure was engaged by this learning process. Similarly, infants exposed to statistically defined 'words' appear to attempt to integrate these novel sound sequences into their developing knowledge of English (Saffran, 2001). Despite the apparent generality of the learning mechanism, its output is apparently represented differently as a function of the infant's prior domain-specific knowledge.

These results reveal a striking pattern of similarities and differences in music processing by infants and adults. Despite limited experience with their culture's musical structure, 8-month-old infants possess the capacity to induce the beginnings of tonal structure; the requisite capacities for the implicit learning of tonality may already be in place (see also Cohen, 2000). At the same time, infant and adult perceptual learning render quite different outcomes due to the processing of different primitives; given the same input, infants are representing the absolute levels of pitches rather than their relationships. This shift in basic perceptual representations is interestingly similar to the beginnings of speech

perception, where the immature state is in many ways more impressive than the adult state: young infants can discriminate phonetic contrasts from non-native languages, while older infants and adults cannot (e.g. Werker & Tees, 1984). By combining the study of infants' basic perceptual capacities with the study of learning, and examining the relationship between perception and other aspects of the developing system, such as the interaction between speech perception and the beginnings of word learning (e.g. Stager & Werker, 1997), and the interaction between tonality and pitch perception, we may begin to observe the ontogenesis of these extraordinary human capacities.

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