Infants' Memory for Isolated Tones and the Effects of Interference

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in most adults, pitch memory for single tones is of short duration, and the presence of interference reduces performance in pitch matching tasks. We show that 6-month-old infants can remember the pitch of a tone for at least 2.5 s but that, like adults, their memory is disrupted by tones interpolated between repetitions of the tone-to-be-remembered. For both infants and adults, we found a significant negative correlation between the number of interference tones and proportion correct in detecting a change in pitch. Performance reached chance levels with 5 interference tones for infants, and 15 interference tones for adults. This indicates that although there may be a developmental increase with age in the length of time a memory can be held, for both 6-month-old infants and adults, memory for the absolute pitch of isolated tones fades rapidly.

Received April 26, 2007, accepted June 2, 2008.

Key words: development, infant, memory, absolute pitch, relative pitch

Introduction

Pitch is a fundamental characteristic of melody and harmony in music and prosodic information in speech. In both music and speech, meaning is conveyed primarily by the relations between successive pitches rather than by the pitches of individual tones or phonemes. For example, it is not the sequence of specific pitches that allows recognition of a familiar melody, but the sequence of relations between successive pitches, or relative pitch. Similarly, emotion in music is conveyed largely by relative pitch (Schellenberg, Krysciak, & Campbell, 2000). For example, a rising pitch pattern is interpreted as conveying happiness, while a falling pitch pattern is interpreted as conveying sadness (Collier & Hubbard, 2001) regardless of the absolute pitch. Pitch patterns in speech are also associated with expression of emotion. Utterances expressing love-comfort, for example, tend to have descending pitch contours, while those expressing fear have fairly flat pitch contours, and those expressing surprise have bell-shaped contours (Trainor, Austin, & Desjardins, 2000). Given the importance of relative compared to absolute pitch information, it is not surprising that most adults do not explicitly remember absolute pitch information for long periods of time.

In most adults, memory for the pitch of an isolated tone is of short duration and subject to the effects of interference. When presented with a sine tone, adults can accurately reproduce that tone following a silent interval of up to 16 s (Ross, Olson, Marks, & Gore, 2004). However increasing the length of the silent interval (Bachem, 1954) or interpolating tones in the silent period (Deutsch, 1970; Ross et al., 2004; Siegel, 1974), disrupts pitch memory. In contrast to the majority of people, including musicians, there are individuals whose memory is not disrupted by tonal interference (Bachem, 1954; Ross et al., 2004; Siegel, 1974). They are said to have absolute pitch, which is traditionally defined as the ability to name a pitch or to produce a tone of a given pitch without a reference tone (Baggaley, 1974). Historically, it has been considered a rare ability possessed by about 1 in 10,000 individuals (Profita & Bidder, 1988). However everyone has at least a crude form of absolute pitch (Bergeson & Trehub, 2002; Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003) in that they can sing songs at comparable pitch levels on different repetitions, and are above chance levels (although not extremely good) at identifying the correct pitch level of popular songs heard repeatedly at the same pitch level, such as television themes. However, there are marked differences between people with absolute pitch as traditionally defined and the rest of the population. For example, although individuals without absolute pitch can learn to recognize one or more specific tones (Cuddy, 1968; Levitin, 1999; Meyer, 1899), this ability always remains effortful, and without practice it is quickly lost (Meyer, 1899). Even in tests of pitch memory that do not require knowledge of note names, there are significant differences in performance

Music Perception volume 26, issue 2, pp. 121–128, issn 0730-7829, electronic issn 1533-8312 DOI:10.1525/mp.2008.26.2.121

between individuals with absolute pitch and those without (Ross et al., 2004; Siegel, 1974).

Research on infant auditory memory has focused primarily on relatively complex stimuli, such as words, stories, and melodies, even when memory for a particular feature of the stimuli such as pitch is being investigated. For example, we know that six-month-old infants can detect a change in pitch to a single-component of a brief tonal melody (Chang & Trehub, 1977; Trehub, Bull, & Thorpe, 1984; Trehub, Thorpe, & Morrongiello, 1985) and can recognize familiar three tone sequences in a statistical learning task (Saffran, 2003; Saffran & Griepentrog, 2001). However, no direct test of infant memory for the pitch of a single tone has yet been reported. Most evidence from studies using complex stimuli suggests that infants primarily encode pitch relations rather than absolute pitch (Chang & Trehub, 1977; Plantinga & Trainor, 2005; Trainor & Trehub, 1992; Trehub et al., 1984; Trehub et al., 1985). For example, Trehub et al. (1984) exposed infants to repetitions of a 6-tone melody and tested whether they could detect a transposition (shift of the entire melody up 3 semitones (or 1/4 octave) of the melody. When there was no interference, infants detected the transpositions, but when three 262-Hz tones were interpolated between repetitions of the melody, infants treated the original and transposed melodies as equivalent. Trainor and Trehub (1992) presented a repeating melody, where repetitions were transposed with respect to each other. Infants were able to detect an occasional wrong note in the melody, implying that they treated the transpositions as equivalent. Using a different approach, Plantinga and Trainor (2005) familiarized infants with a melody over seven days. After a one-day retention interval, infants recognized the familiar melody presented at a new pitch, and gave no evidence that they remembered the absolute pitch.

Thus, there is ample evidence from studies using complex stimuli that infants process pitch relations, but less evidence to suggest that they remember absolute pitch. It has been suggested that infants may outperform adults at remembering absolute pitch information (Saffran, 2003; Saffran & Greipentrog, 2001; Takeuchi & Hulse,1993; Trainor, 2005). Sergeant and Roche (1973) found that young children more accurately produced the first note of a learned melody, while older children more accurately reproduced the relative pitch, suggesting that relative pitch ability developed with age and /or experience. Saffran and her colleagues (2001, 2003) tested infants' and adults' ability to use both absolute and relative pitch in a statistical learning task and found that infants were able to use absolute but not relative pitch cues while adults were much better at using relative pitch cues. In this paper we address the question of absolute pitch processing in infants in a different way; specifically we ask whether infants can remember the pitch of a single tone rather than the absolute pitch of patterns and whether that memory is disrupted by the presence of interference tones. If infants are absolute pitch possessors, they should be able to remember the pitch of an isolated tone, and their memory should not be affected by the presence of tonal interference; that is, we would expect their performance to be similar to that of adults with absolute pitch (Bachem, 1954; Ross et al., 2004; Siegel, 1974). However, if infant memory for the pitch of an isolated tone is disrupted by the presence of interference, this would provide converging evidence that infants rely mainly on relative pitch.

We first conducted a pilot study in which 70 adults were asked to make same/different judgments about the pitch of 36 pairs of piano tones separated by 16 s. Trials were grouped into 3 blocks of 12 trials each according to the number of interference tones (0, 9, or 15) that occurred in the 16 s interstimulus interval (ISI). Participants were asked to indicate whether the last tone of a trial was the same or different from the first tone. The test tones on change trials varied from the initial tone by a semitone either up or down. Interference tones were the same duration and loudness as the tones to be compared. Proportion correct was significantly above chance levels of .50 with 0 ($M =$ .90, $SE = .02$) and 9 ($M = .67$, $SE = .02$) interference tones, but not with 15 ($M = .52$, $SE = .02$) interference tones. Taking the proportion correct for each number of interference tones for each subject, there was also a significant negative correlation between the number of interference tones and proportion correct, $r(208) = -.74$, $p < .001$. The results of this pilot study replicate those of earlier studies showing that for most adults, memory for the pitch of a single tone is reduced by the presence of interference tones (Bachem, 1954; Deutsch, 1970; Ross et al., 2004; Siegel, 1974).

To test infants, we translated our adult pilot study into a conditioned head-turn procedure in which infants were rewarded with an animated toy for responding when there was a change in the pitch of a repeating background tone with an interstimulus interval (ISI) of 2.5 s. In Experiment 1 we tested memory with no interference in the ISI. In Experiment 2 we tested the effects of the interpolation of different numbers of tones in the ISI. If infants do not possess absolute pitch, we would expect to see a negative correlation between the number of interference tones and proportion of correct responses, similar to what we found in our pilot study with adults.

Experiment 1: Infant Memory for Pitch

Method

PARTICIPANTS

Ten healthy 6-month-old infants (7 males, 3 females) participated in the study. All infants were born within 2 weeks of full term, were healthy at the time of testing, and had no history of chronic ear infections or suspicion of hearing loss. An additional seven infants did not pass training and one infant failed to complete the study due to fussiness.

STIMULI

Infants were presented with a repeating background stimulus, a single 200 ms tone, D4 (294 Hz), with an interstimulus interval (ISI) of 2.5 s, presented at 70 dB over a background noise level of 26 dB. The change stimulus in both training and test was either C4 (262 Hz) or E4 (330 Hz); that is, either 2 semitones (1/6 octave) up or down from the background stimulus. The timing was identical whether or not there was a change. The tones were created in the Cakewalk program using acoustical grand piano instrumentation on a personal computer with a Sound Blaster AWE64 Gold sound card, and recorded using CoolEdit. For testing, the sound files of the notes were transferred to a Macintosh G4 computer. The sounds were presented through an NAD C352 stereo integrated amplifier connected to an audiological GSI speaker to the left of the infant.

PROCEDURE

The infant was seated on his/her mother's lap facing the experimenter inside a large Industrial Acoustics Co. sound-attenuating booth with a speaker on the left. The speaker was situated on a box that contained four compartments. Each compartment contained a mechanical toy and lights. It was not possible to see into the compartment unless the compartment light was on. Infants were tested using the go/no-go conditioned head-turn response procedure in which head turns toward the speaker are reinforced with an illuminated, activated toy only when occurring within 2 s of a change in the background note. Both the parent and the experimenter heard masking music through headphones so as to be unaware of what the infant was hearing. The background stimulus was presented continuously throughout the experiment. When the infant was facing the experimenter, and was attentive, the experimenter initiated a trial by pressing a button on a box that was connected to the computer via a custom-built interface to a NI PCI-DIO96 I/O card. When the infant turned toward the speaker, the experimenter recorded the turn by pressing another button. During training, all trials were change trials, and the infant learned the contingency between the response (turning when there is a change in the background stimulus) and reinforcement (the illuminated, activated toy). The infant was required to turn on four consecutive change trials within 20 trials in order to continue with the experiment.

During the experiment, twenty-four trials, 12 control and 12 change trials, were presented in a quasi random order for each subject, with the restriction that no more than two control trials were presented consecutively. On control trials, there was no change from the background stimulus. On half of the change trials, C4 was presented in place of D4; on the other half, E4 was presented. If the infant made a turn toward the speaker of at least 45° within 2 s of the onset of a change trial, a toy in one of the compartments under the speaker lit up and "danced." Once the light was extinguished and the infant's attention was again centered on the experimenter, the next trial began. Head turns at other times were not reinforced. The computer kept track of any head turns within 2s of the onset of a change trial as well as within 2s of the onset of a control trial so as to provide an index of the rate of false alarms.

Results

The mean proportion correct, based on hits and correct rejections, was .62, which is above chance levels of .50, $t(9) = 5.75$, $p < .001$, indicating that infants are able to remember the pitch of a tone for at least 2.5 s. It is likely that infant memory is longer than 2.5 s, but we were primarily interested in establishing a base from which to measure the effect of interference tones on infant memory, which we test in Experiment 2. If infant memory works similarly to that of adults, we would expect performance to decline with increasing number of interference tones.

Experiment 2: Is Memory for Pitch Disrupted by Interference?

Method

SUBJECTS

Thirty healthy, full-term 6-month-old infants (15 males, 15 females) participated in the study. There were 3 conditions with 10 infants in each condition as in Experiment 1. All infants were born within 2 weeks of full term, were healthy at the time of testing, and had no history of chronic ear infections or suspicion of hearing loss. An additional nine infants did not pass training, two more did not finish the study, and data from two infants was not used due to technical problems.

STIMULI

In training, the repeating background stimulus was the same as in the previous study, a 200 ms single tone, D4, with a 2.5 s ISI. The training changes were also the same as in Experiment 1, either up or down 2 semitones. During testing, interference tones were interpolated in the ISI. We attempted to make the task as simple as possible for the infants. Based on studies showing that interference is reduced if the standard and interference tones are perceptually different from each other, and can be grouped into separate streams (Alain & Woods, 1993; Jones, Macken, & Harries, 1997), we made the interference tones both shorter and softer than the standard tones (78 dB, 200 ms for standard tones; 70 dB, 100 ms for interference tones), and separated them temporally from the standard and comparison tones.

There were three conditions: 3 interference tones, 5 interference tones, and 15 interference tones. In the background stimulus for the test procedure in Condition 1, the 2.5 s between repeating D4 tones was filled by 1100 ms of silence, three 100 ms interference tones, and another 1100 ms of silence. In Condition 2, it was filled by 1000 ms of silence, five 100 ms interference tones, and another 1000 ms of silence. In condition 3, it was filled by 500 ms of silence, fifteen 100 ms interference tones, and 500 ms of silence. Thus, the length of time that a pitch was to be remembered and compared with the following pitch in each condition was 2.5 seconds just as it was in Experiment 1 (see Figure 1). Interference tones were chosen randomly on each trial from the following 12 notes: A3 (220 Hz), A4 (440 Hz), A#3 (233 Hz), B3 (247 Hz), C#4 (277 Hz), D#4 (311 Hz), F4 (349 Hz), F#4 (370 Hz), G3 (196 Hz), G#3 (208 Hz), G4 (392 Hz) and G#4 (415 Hz). For the test change, the D4 was replaced by either C4 or E4, 2 semitones down or up as in Experiment 1.

PROCEDURE

The procedure was identical to that of the previous experiment.

Results

Mean proportion correct (hits and correct rejections) was significantly above chance levels of 50% for 3 interference tones, $t(9) = 2.46$, $p < .05$ two-tailed but not for 5 interference tones or 15 interference tones (see Figure 2).

A one-way ANOVA with number of interference tones as the independent variable and proportion correct as the dependent variable across Experiments 1 and 2 revealed a significant difference between conditions, $F(3, 36) = 7.41$, $p = .001$ ($MSE = 0.006$). Multiple comparisons with Bonferroni correction indicated that there was a significant difference between the 0 interference and 15 interference conditions, $p < .001$, and between the 3 interference and 15 interference conditions, $p = .01$. No other differences were significant.

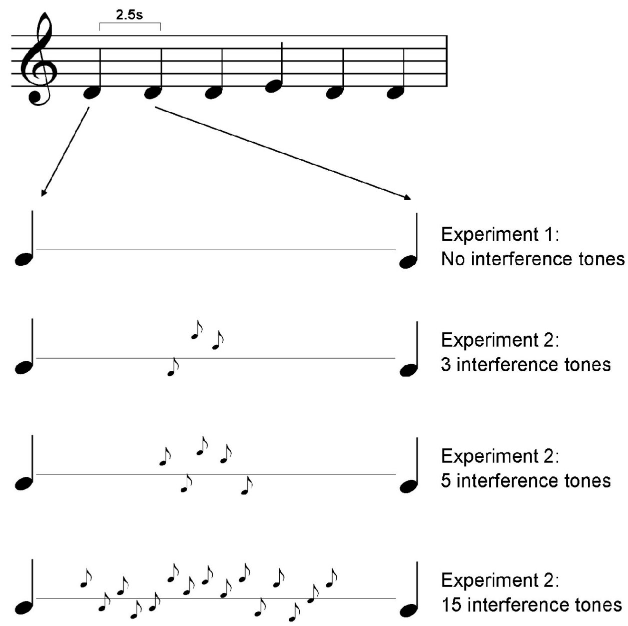

FIGURE 1. Visual illustration of the experimental design. In Experiment 1 there were no interference tones. In Experiment 2, the interference tones (3, 5, or 15) were centered in the 2.5 s interstimulus interval, which remained constant across all conditions.

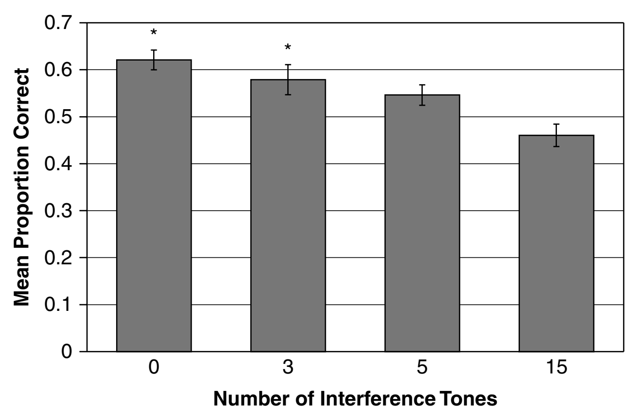

FIGURE 2. Infants' mean proportion correct in the 0, 3, 5, and 15 interference tone conditions. Asterisks indicate performance above the chance level of .5 ($p < .05$). Number of interference tones was negatively correlated with proportion correct, $r(38) = -.62$, $p < .001$. Error bars represent the standard error of the mean.

A one-way ANOVA with false alarms as the dependent variable showed that the number of false alarms did not differ significantly across Experiment 1 and the three conditions of Experiment 2, $F(3, 36) = 0.17$ (MSE = 4.96). This suggests that the infants did not differ in their tendency to respond across conditions, but differed in their ability to detect the change in pitch of the repeated tone. Familiarization did not differ across conditions as there was no significant difference in the number of training trials required across conditions, $F(3, 36) = .79$, $p = .51$ ($MSE = 16.28$). Finally, there was a significant negative correlation between proportion correct and number of interference tones, $r(38) = -.62$, $p < .0001$ (see Figure 2), indicating a decline in memory with increasing interference.

These results indicate that infants can remember the pitch of a repeated tone when tonal interference is absent or minimal, but with increasing numbers of interference tones, performance is reduced to chance levels. These results parallel the finding of a negative correlation between number of interference tones and proportion correct responses found in the pilot study with adults. The results also suggest that infant memory for the pitch of a tone might be more easily disrupted than adult memory. Infants performed at chance levels with 5 interference tones while adult performance was above chance for 9 interferences tones, declining to chance with 15 interference tones. However, this inter pretation must be treated with caution as difference across age groups may be due to the verbal instructions given adults, or to adults' superior attention and ability to concentrate.

Discussion

Pitch memory for a single tone in 6-month-old infants appears to be similar to that of adults without absolute pitch in that infants can remember the pitch for at least 2.5 s, but interpolating interference between the standard and comparison tones interferes with that memory. This study also adds to the evidence of a developmental change in auditory memory (Gomes et. al, 1999; Keller & Cowan, 1994). Keller and Cowan (1994) found that memory for the pitch of a tone persisted longer in adults than in children and that memory was longer in 10- to 12-year-olds than in 6- to 7-year-olds. This finding was replicated with electrophysiological methods (Gomes et al., 1999). Participants all exhibited an MMN to a change in the pitch of a standard tone when the interstimulus interval was 1s, but only older children and adults exhibited a response to the change when the interstimulus interval was 8 s. The present study is consistent with this converging evidence for developmental change in auditory memory in that even with short retention intervals, infant memory for the pitch of an isolated tone appears to be more easily disrupted than adult memory.

The results of the present study suggest that infants, like most adults, do not store precise absolute pitch information for isolated tones. Rather, long-term pitch memory appears to be based largely on relative pitch information, that is, the relation between successive pitches, regardless of the absolute starting pitch (Chang & Trehub, 1977; Plantinga & Trainor, 2005; Trainor & Trehub, 1992; Trehub et al., 1984; Trehub et al., 1985).

Relative pitch is an important source of information in both speech and music. It allows generalization across variations in particular instances, which vary in timbre, duration, and pitch. In adults, the auditory system appears to extract sound features critical for a particular task from the signal and map them onto categorical information stored in memory, while ignoring irrelevant features. Most languages use intonation (that is, relative pitch) to convey meaning or emphasis. For example, if the utterance, "You did that," goes up in pitch at the end, it is perceived as a question, while if it goes down in pitch, it is perceived as a statement. The exact pitch of the utterance is not important; it is the relations between successive pitches that provides the information. Vowel representation also appears to be relational in that it is dependent on an invariant frequency ratio between the first and second formants, while the fundamental frequency or pitch is largely irrelevant for speech category classification (Jacobsen, Schroger, & Alter, 2004). Even in tonal languages, where the same syllable can have different meanings depending on the pitch contour, it is the relational contour differences that determine meaning and not the exact pitch of the utterance, as this will vary across speakers.

Similarly for music perception, meaning is based primarily on the relations between pitches, and melody recognition relies much more on pitch relations than on absolute pitch. The ability to extract and encode pitch relations between successive notes allows for recognition of melodies across performers and performances. For example, adults recognize a familiar melody whether it is sung by a male or female, or played on different instruments at different pitch levels.

For infants, extracting pitch relations while ignoring absolute pitch would be the most efficient way to learn language and music. By two months, infants display the ability to discriminate between stop consonants (Jusczyk, Pisoni, & Mullennix, 1992) and vowels (Marean, Werner, & Kuhl, 1992) across voices that vary in pitch and timbre, indicating infants' ability to abstract the relevant information for classification from the speech signal while ignoring the variation in absolute pitch. By at least as young as five months, infants also respond to a melody that has been shifted in pitch as if it were the same as the original (Chang & Trehub, 1977; Plantinga & Trainor, 2005; Trehub et al., 1984).

The finding of the present study that interference tones disrupt memory for the pitch of isolated tones across an interval as short as 2.5 s gives strong support to the idea that infants do not readily transfer absolute pitch information to long-term memory. In conjunction with the previous literature, this suggests that infants rely primarily on relative pitch information in the development of music and language abilities.

Author Note

Judy Plantinga is now at University of Toronto Mississauga. This research was supported by a grant to LJT from the Natural Sciences and Engineering Research Council of Canada. We thank Janice Wright for help in testing the infants and Lisa Hotson for comments on an earlier draft.

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