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Memory for melody: infants use a relative pitch code

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Abstract

Pitch perception is fundamental to melody in music and prosody in speech. Unlike many animals, the vast majority of human adults store melodic information primarily in terms of relative not absolute pitch, and readily recognize a melody whether rendered in a high or a low pitch range. We show that at 6 months infants are also primarily relative pitch processors. Infants familiarized with a melody for 7 days preferred, on the eighth day, to listen to a novel melody in comparison to the familiarized one, regardless of whether the melodies at test were presented at the same pitch as during familiarization or transposed up or down by a perfect fifth (7/12th of an octave) or a tritone (1/2 octave). On the other hand, infants showed no preference for a transposed over original-pitch version of the familiarized melody, indicating that either they did not remember the absolute pitch, or it was not as salient to them as the relative pitch.

Keywords: Pitch; Development; Auditory perception; Infants

Pitch is one of the fundamental perceptual attributes of sound and is of paramount importance for decoding prosody in speech and melody in music. The pitch of a melody or speech utterance potentially can be encoded and remembered in two distinct ways, either in absolute or in relative terms. An absolute pitch code consists of the sequence of fundamental frequencies of each tone in a melody, or each vowel in a speech utterance. A relative pitch code, on the other hand, does not contain information about the actual

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fundamental frequencies. Rather, it consists of the sequence of pitch distances between successive melodic tones or vowels. The vast majority of adults encode musical pitch predominantly in relative terms. For example, they recognize a tune such as *Happy Birthday* whether it is sung with a high or a low starting note, as long as the relative pitch distances between tones are correct. For the most part, after a short time interval, adults do not remember precise absolute pitch information, although the experience of a particular musical composition or sound always at the same pitch may lead to some absolute pitch retention (Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003; Terhardt & Seewann, 1983). On the other hand, between 1 and 5 out of every 10,000 people encode pitch predominantly in absolute terms (Bachem, 1955; Brown et al., 2003). Such individuals can name isolated musical notes effortlessly without reference to other notes, but they tend to be poor at identifying pitch relations in tonal contexts (Miyazaki, 1993) and tend to use absolute pitch even in tasks requiring relative pitch (Miyazaki, 1995; Miyazaki & Rakowski, 2002).

There has been a recent surge of interest in absolute versus relative pitch processing in the developmental, neuroscience, and genetics communities, perhaps because absolute pitch is a rare cognitive ability that appears to depend on both genetic predisposition and specific experience during a critical period (e.g. Baharloo, Johnston, Service, Gitschier, & Freimer, 1998; Brown, Sachs, Cammuso, & Folstein, 2002; Chin, 2003; Ross, Olson, & Gore, 2003; Russo, Windell, & Cuddy, 2003; Saffran, 2003; Saffran & Griepentrog, 2001; Schellenberg & Trehub, 2003; Zatorre, 2003). Historically, absolute pitch processing was of interest because some considered it to be a coveted musical ability. In fact, focusing on absolute pitch information may be a musical hindrance, because it takes attention away from the musical pitch relations that form the basis of musical structure. Interestingly, monkeys and birds, which have not developed music and language, rely to a greater extent on absolute than on relative pitch encoding (e.g. Hulse, Takeuchi, & Braaten, 1992; Izumi, 2001). From this perspective, the ability to encode relative pitch and perceive melodic invariance across pitch transposition is a more sophisticated ability than remembering absolute pitch.

Most sounds with pitch are made up of a number of components or harmonics whose frequencies are integer multiples of the lowest or fundamental frequency, which corresponds to the pitch heard. Sound frequency is processed in absolute terms in the auditory periphery. The basilar membrane in the inner ear is tonotopically organized, that is, it responds maximally to different frequencies at different points along its length. This tonotopic (absolute) organization is maintained through subcortical structures and into primary auditory cortex. From this point, however, most people appear to use primarily a relative pitch code, as indicated by their event-related potential (ERP) responses to pitch changes. A relative pitch change, achieved by transposing the repeating standard pitch pattern from trial to trial and occasionally changing one note of the pattern, produces a preattentive cortical mismatch negativity (MMN) response as well as an attentive P3 response that reflects the operation of working memory (Fujioka, Trainor, Ross, Kakigi, & Pantev, 2004; Trainor, McDonald, & Alain, 2002). Absolute pitch processors, on the other hand, appear simply to categorize the isolated pitch of each sound, and show a greatly reduced P3 in response to pitch change (Hantz, Crummer, Wayman, Walton, & Frisina, 1992; Hirose et al., 2002; Klein, Coles, & Donchin, 1984). Furthermore, the size of areas in the right superior temporal cortex are smaller in absolute than in relative pitch processors (Keenan, Thangaraj, Halpern, & Schlaug, 2001), and absolute pitch processors show increased responses from posterior dorsolateral cortex, an area involved in conditional memory associations (Zatorre, Perry, Beckett, Westbury, & Evans, 1998).

While it has been established that the brain processes of adults with absolute pitch differ from those with relative pitch, the origins of these differences are still unclear. The development of absolute pitch is associated with early musical training and is very difficult to teach to adults (Bachem, 1940; Crozier, 1997). Its dependence on experience is also indicated by the superior performance of absolute pitch possessors at naming the more common white notes than the less common black notes of the piano (Miyazaki, 1988; Takeuchi & Hulse, 1991). On the other hand, experience is certainly not sufficient for the development of absolute pitch as the vast majority of children receiving early musical training develop only relative pitch. Familial aggregation of absolute pitch indicates a genetic contribution to the development of absolute pitch (Baharloo et al., 1998), as does the relatively high instance of absolute pitch in autism, a genetic disorder characterized by enhanced processing of local features of complex stimuli (Rimland & Fein, 1988). Furthermore, the presence of absolute pitch in autistic children is correlated with their performance on tests measuring the ability to process local visual information (Heaton, Hermelin, & Pring, 1998), and people with absolute pitch show some of the perceptual, personality, and language characteristics of those with autism (Brown et al., 2003), suggesting that absolute pitch processing is associated with a particular cognitive style.

In contrast to the idea that absolute pitch is associated with rare genetic traits, others have argued that early in life all infants rely mainly on absolute pitch, but that with increasing age and experience most shift to processing relative pitch (Sergeant & Roche, 1973; Takeuchi & Hulse, 1993). Empirically, however, there are little data to suggest a transition from absolute to relative pitch processing. Many studies in fact show that between 6 and 12 months, infants readily recognize melodies transposed to different pitch levels when the melodies are presented within seconds of one another and indeed treat transposed melodies as equivalent (e.g. Trainor & Trehub, 1992; Trehub, 2001; Trehub, Bull, & Thorpe, 1984). On the other hand, some studies using a statistical learning paradigm report that 8-month-old infants process absolute but not relative pitch (Saffran, 2003; Saffran & Griepentrog, 2001), suggesting that task requirements might influence whether infants focus on relative or absolute information. However, all of these studies used delays between familiarization and comparison on the order of seconds. Because by definition absolute pitch memory is the ability to identify the pitch of a tone without reference to a comparison tone, an optimal test of whether infants encode melodies into long-term memory in relative or absolute terms would involve using a long retention interval between familiarization and test.

Previous work has shown that after a week or two of exposure to a melody, infants remember it for days or even weeks (Fagen et al., 1997; Saffran, Loman, & Robertson, 2000; Trainor, Wu, & Tsang, 2004). Trainor et al. (2004) exposed 6-month-old infants to one of two old English folk songs at home for 7 days and showed that infants recognized the familiarized melody after a 1-day delay. Specifically, infants showed a novelty preference, preferring to listen to whichever melody they had not heard previously in comparison to that with which they were familiarized. Interestingly, if the tempo or timbre (piano versus harp) was changed between familiarization and test, infants no longer showed a preference, indicating that they remembered the absolute tempo and timbre of the familiarized melody. In the present study, we used the same methodology to test for relative and absolute pitch memory over a 1-day delay. In Experiment 1, infants were familiarized with one of the two old English folk songs as in Trainor et al. (2004). At test, melodies were transposed up or down in pitch compared to during familiarization. If infants continued to prefer the novel melody, it would show that they recognized it despite the relative pitch transformation, and that they encode relative pitch. In Experiment 2, at test the familiarized melody was presented in two versions, one at the pitch heard during familiarization and the other transposed either up or down. If infants recognized the absolute pitch of the melody, they would be expected to prefer the novel transposed version.

1. Experiment 1: relative pitch

1.1. Method

1.1.1. Participants

Thirty-two healthy infants between 5 1/2 and 6 1/2 months (13 female, 19 male; mean = 6.02 months, SD = .22) completed the required familiarization and testing. Another nine infants were excluded due to parents' failure to follow familiarization instructions (3) or failure to complete testing because of fussing (6). All infants were full term and healthy, with no familial history of hearing impairment.

1.1.2. Stimuli and materials

The two old English folk songs used in Trainor et al. (2004), "Country Lass" and "Painful Plough," were used in order to allow direct comparisons between studies. The two melodies were chosen as they are unlikely to be familiar to the infants. They are in a similar folk song style, with similar pitch ranges and numbers of notes and a playing time of 30 s. They contrasted in meter (6/8 and 4/4, respectively) and mode (major and minor, respectively). Both melodies were produced using the acoustical grand piano instrumentation in the Cakewalk program on a personal computer with a Sound Blaster AWE64 Gold sound card. For the familiarization phase, six repetitions of either Country Lass or Painful Plough were burned onto separate CDs for distribution to subjects. For testing, the melodies were transposed both up and down by both a perfect fifth (7/12th of an octave) and by a tritone (1/2 octave), resulting in four transpositions for each melody. The sounds were presented with a Power Macintosh 7300/180 computer, a Denon PMA-480R amplifier, and two audiological GSI speakers at approximately 52 dB (A) over a background of 25 dB (A). The loudspeakers were located inside a large Industrial Acoustics Co. sound-attenuating booth.

1.1.3. Procedure

Each parent was given a CD containing six repetitions of one of the two songs to play to their infant for 3 min per day. Parents kept a daily log sheet. On day 8, the infant came to the lab for testing. After the parent had filled out a questionnaire about the family's musical history and had signed the consent form, infants were tested using the head-turn preference procedure (e.g. see Trainor et al., 2004). Each infant was presented with the song they heard at home and the unfamiliar song, both in the same transposition type, creating four test conditions, transposition up by a perfect fifth, transposition down by a perfect fifth, transposition up by a tritone, and transposition down by a tritone. Eight infants were tested in each condition.

For testing, parent and infant were seated in the sound booth between the two speakers, facing the experimenter. The speakers were situated on top of boxes with smoked Plexiglass fronts. Each box contained a toy that could be illuminated and made visible to the infant. On each trial, the experimenter attracted the infant's attention forward and began a trial by pressing a button on a box connected to the computer indicating that the infant was ready for stimulus presentation. The computer then activated a flashing light in the cabinet under the speaker on one side of the infant, illuminating a toy. When the infant turned toward the toy, the experimenter pressed a second button to initiate the playing of the melody for that side. The experimenter held the button down until the infant looked away. The light stayed on and the music continued to play until the button was released for longer than 2 s. The next trial took place on the other side. Again, the infant's attention was centered, the light on that side flashed, and when the infant looked, music played and the toy in the box on that side was illuminated. This time, the second melody was presented and, as before, remained on for as long as the infant looked in that direction. Trials of the familiar and novel melodies alternated in this manner for 20 trials. The computer kept track of listening times on each trial. The side of first presentation (left or right) and melody heard on the first trial (novel or familiar) were counterbalanced across infants. For each infant, the novel melody always played from one side, and the familiar from the other. Both the experimenter and the parent listened to music over headphones at a volume that masked the sound stimuli in order to prevent either adult from influencing the infant's responses. The experimenter and parent were unaware of which music was played from which speaker.

1.2. Results and discussion

The dependent measures were the average listening time across the 10 familiar-melody trials and the average listening time across the 10 novel-melody trials. Which melody was novel and which familiar varied across infants. An ANOVA with trial type (novel, familiar) as a within subjects factor, and transposition direction (up, down) and transposition type (fifth, tritone) as between subjects factors revealed only a significant effect of trial type, $F(1, 28) = 5.54$, $P = .03$. Infants looked significantly longer in order to hear the novel melody in comparison to hear the familiar melody (Fig. 1), indicating that they recognized the melody across the relative pitch transposition. The results of this experiment were compared directly with those from Experiment 1 of Trainor et al. (2004), in which infants completed exactly the same procedure, but without any transposition. A t-test with the difference between listening times to novel and familiar trials as the dependent variable revealed no difference between the novelty preference when there was a transposition between familiarization and test (current experiment) and when there was not (from Experiment 1, Trainor et al., 2004), $t(46) = .36$, $P = .72$. Thus, transposing

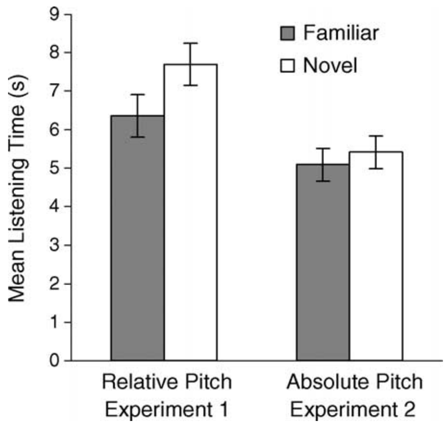

Fig. 1. Infants' preferences as measured by the amount of time they choose to listen to novel compared to familiar versions. Left panel: for relative pitch transpositions (Experiment 1) infants prefer the novel compared to the familiar melody, regardless of the transposition type, indicating that they remember melodies in terms of relative pitch. Right panel: infants show no preference for the familiar melody transposed to a novel pitch compared to the same melody at the familiar pitch (Experiment 2), indicating that either they do not remember the absolute pitch or it is not salient to them. Error bars represent within subject variability (Loftus & Masson, 1994).

the melodies appears to have no effect on recognition, suggesting strongly that infants use a relative pitch representation in long-term memory.[1]

The lack of a difference between transposition types also argues for a relative pitch code. Transpositions of a perfect fifth up or down (seven semitones, or 7/12th of an octave difference) are said to be closely related to the original key because the two keys share all but one scale note. The key resulting from a tritone transposition, however, has only one note in common with the original key. For example, the notes in the key of G are G, A, B, C, D, E, F#, the notes of a perfect fifth transposition up are D, E, F#, G, A,B, C#, and the notes of the tritone transposition are C#, D#, E#, F#, G#, A#, B#. In short-term memory, where absolute pitch information is available, melodies are more easily recognized when transposed to related compared to unrelated keys (Trainor & Trehub, 1993). The fact that transposition type had no effect on melody recognition in the present study suggests that precise absolute pitch information was not retained in long-term memory by the infants. This is particularly interesting in light of previous studies showing that infants do remember changes in the absolute tempo and timbre of melodies when tested with these same melodies (Trainor et al., 2004).

Experiment 1 shows that at 6 months infants process relative pitch, and provides no evidence that they retain absolute pitch information. However, recent research suggests that even adults with relative pitch have some access to absolute pitch representations in long-term memory although for most it remains a somewhat imprecise ability (Halpern, 1989), both in terms of above-chance but relatively low levels of performance at identifying

[1] The results are the same in both Experiments 1 and 2 whether the first 10 trials or the second 10 trials or all 20 trials are analyzed.

the pitch of familiar tunes (Schellenberg & Trehub, 2003), and the size of pitch errors in performance, which are larger than for those with true absolute pitch (Levitin, 1994). In Experiment 2, we test more directly whether infants remember the absolute pitch of a melody over the long-term by testing their preference for the familiarized melody at the familiar pitch compared to the familiar melody at a new pitch (the novel stimulus). Memory for absolute pitch should result in a novelty preference for the familiar melody at the new pitch. No difference in looking times between the two versions of the melody would indicate that the absolute pitch of a melody is not a salient characteristic of melodies for infants.

2. Experiment 2: absolute pitch

2.1. Method

2.1.1. Participants

Thirty-two healthy infants between 5 1/2 and 6 1/2 months of age (15 female, 17 male; mean = 6.1 months, SD = .28) completed the testing. Another 12 infants were excluded due to parents' failure to follow familiarization instructions (2) or failure to complete testing because of fussing (10). The data from one of the 32 infants completing the testing was excluded from the analysis because the difference between listening time to novel and familiar was more than three standard deviations from the mean of the group.

2.1.2. Stimuli

The stimuli were the same two folk songs and the same four transposition types used in the previous experiment.

2.1.3. Procedure

The procedure was identical to that of Experiment 1 except that at test each infant was presented with two versions of the melody heard at home, one at the same pitch as heard at home (familiar) and the other at a new pitch (novel). The novel pitch was either a perfect fifth or a tritone up or down from the original melody.

2.2. Results and discussion

An ANOVA with pitch (novel, familiar) as a within subjects factor, and transposition direction (up, down) and transposition type (fifth, tritone) as between subjects factors yielded no significant main effect of pitch, $F(1,27) = .009$, $P = .924$ and no interactions. Infants showed no preference for either the familiar pitch or the novel pitch (Fig. 1), suggesting that either they did not encode the absolute pitch or that it is not salient to them. (Even when the infant whose difference between novel and familiar exceeded 3 SD was included in the analysis, the effect was far from significant $F(1,28) = .011$, $P = .574$). Furthermore, the difference between listening times to novel and familiar melodies was significantly greater in Experiment 1 than in Experiment 2, $t(61) = 2.00$, $P = .025$, supporting the conclusion that 6-month-old infants remember a familiar melody predominantly in terms of relative pitch.

3. General discussion

The results of this study suggest that by 6 months of age infants, like adults, store melodic information primarily according to a relative and not an absolute pitch code in long-term memory. After a delay of 1 day, infants at 6 months recognized a familiar melody although it was presented at a new pitch, and recognition was as good for transpositions to related as to unrelated keys. The possibility that infants also remember the absolute pitch of a familiar melody cannot be ruled out, but the present results argue against robust absolute pitch memory. In Experiment 2, infants showed no preference for listening to a transposed compared to a non-transposed version of a familiar melody. Furthermore, melody recognition in Experiment 1 was as good for transposed as non-transposed melodies, and for transpositions to related and unrelated keys, which is not the case for short-term memory in either infants or adults (Trainor & Trehub, 1993).

Our results correspond with those of Trehub and her colleagues who concluded from studies of short-term memory that infants focus mainly on relational and not absolute pitch aspects of a melody (e.g. Chang & Trehub, 1977; Cohen, Thorpe, & Trehub, 1987; Trainor & Trehub, 1992; Trehub, 2001; Trehub, Thorpe, & Morrengiello, 1985; Trehub & Trainor, 1990, 1993; Trehub, Trainor, & Unyk, 1993). Our results also parallel those from studies of infants' encoding of speech stimuli, which show that young infants are able to recognize particular phonetic units across changes in pitch (Cheour et al., 2002; Jusczyk, Pisoni, & Mullennix, 1992; Kuhl, 1979). It is possible that infants may show more evidence of absolute pitch memory in certain tasks where relative pitch cues are impoverished and/or normal musical phrase structure is absent (Saffran, 2003; Saffran & Griepentrog, 2001). However, in our study where relative and absolute pitch memory for normal well-structured melodies are compared, infants clearly encoded primarily relative pitch.

That relative pitch processing already predominates 6-month-old infants' encoding of melodic information rules out the idea of a general shift during the preschool period from absolute pitch processing to relative pitch processing (Saffran, 2003; Saffran & Griepentrog, 2001; Sergeant & Roche, 1973; Takeuchi & Hulse, 1993). This in turn rules out the idea that absolute pitch in older children arises in certain individuals from the maintenance of general early primitive absolute pitch abilities present in the preschool period in the presence of musical experience that stops the shift from absolute to relative processing. The results leave open the question, however, of why absolute pitch develops in a small number of people. The two most plausible possibilities are (1) that good absolute pitch memory arises from a rare general genetic predisposition to focus on local as opposed to global features, and is therefore present in a few individuals from a very young age, and (2) that absolute pitch replaces relative pitch processing during the preschool period in a few individuals in the presence of specific experience. It is also possible that both factors are necessary: a genetic predisposition and specific experience during a critical period.

The finding that infants do not appear to remember absolute pitch over the long-term is interesting in the context of research showing that they do remember the voice quality or timbre of particular talkers (Houston & Jusczyk, 2000; Jusczyk et al., 1992) and the timbre of familiar melodies (Trainor et al., 2004). In adults, also, speech sound recognition is degraded across a change in talker (Palmeri, Goldinger, & Pisoni, 1994), as is recognition of a melody across a change in instrument timbre (Peretz, Gaudreau, & Bonnel, 1998; Radvansky, Fleming, & Simmons, 1995). An answer to the question of why timbre is better remembered than absolute pitch likely lies in a consideration of the importance of each stimulus attribute in the human environment. Timbre is a critical perceptual feature for voice and object identification, so retention of specific timbres is very helpful for recognizing people and things in the world. However, because people produce the same speech sounds and melodies at a variety of pitch levels, relative pitch is much more useful than absolute pitch for recognizing specific speech sounds and melodies.

It is still possible that there is a developmental shift from predominantly absolute pitch processing to predominantly relative pitch processing that takes place before 6 months of age. At birth, the neurons in auditory cortex are largely formed but the connections between them are few and immature (Moore & Guan, 2001). Possibly, relative pitch processing requires more mature cortical functioning, and very young infants who rely on subcortical processing encode only absolute pitch. By 6 months, there are some fast, mature synaptic connections in deeper cortical layers (Moore & Guan, 2001) that lead to qualitative changes in the function of auditory cortex (Trainor, 2004; Trainor et al., 2003). Thus, in the first month or two after birth, infants may process predominantly absolute pitch using subcortical structures. In such a case, there would be a developmental shift from absolute to relative pitch processing, but it would take place during the first month after birth in conjunction with a switch from predominantly subcortical to predominantly cortical processing of pitch. Further research is needed to test this possibility. What is clear from the present study is that by 6 months of age infants are primarily relative pitch processors.

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