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REPORT

Long-term memory for music: infants remember tempo and timbre

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Abstract

We show that infants' long-term memory representations for melodies are not just reduced to the structural features of relative pitches and durations, but contain surface or performance tempo- and timbre-specific information. Using a head turn preference procedure, we found that after a one week exposure to an old English folk song, infants preferred to listen to a novel folk song, indicating that they remembered the familiarized melody. However, if the tempo (25% faster or slower) or instrument timbre (harp vs. piano) of the familiarized melody was changed at test, infants showed no preference, indicating that they remembered the specific tempo and timbre of the melodies. The results are consistent with an exemplar-based model of memory in infancy rather than one in which structural features are extracted and performance features forgotten.

Introduction

Infants are able to remember melodies over long periods of time. Saffran, Loman and Robertson (2000) exposed 7-month-olds to a Mozart sonata every day for two weeks. After a two-week delay, infants preferred to listen to a novel piece over the familiarized piece. Fagen, Prigot, Carroll, Pioli, Stein and Franco (1997) played music while 3-month-old infants learned to kick a mobile. After a one-week delay, infants remembered how to kick the mobile only if the particular piece of music heard during familiarization was played. These findings parallel studies of infants' long-term retention of words (Jusczyk & Hohne, 1997) and nursery rhymes (Spence, 1996).

However, little is known about the nature of infants' long-term representations for melody. There are two types of information in music, *abstract structure* and *surface characteristics*. The *abstract structure* consists of the *relative* pitches and *relative* durations of the tones in the music, that is, the pitch distances between tones regardless of their absolute pitch level, and the ratios between durations, regardless of their absolute length. In order to abstract this structural information, a normalization process must be performed, whereby information about performance features such as absolute pitch, tempo and timbre, is discarded. The *surface* or *performance* characteristics include the exact pitch level, tempo, timbre and prosodic rendering. Both types of information are useful. A representation of the abstract structure enables the recognition of a melody across different performances, and the recognition of musical variations of a motif within a musical composition (Large, Palmer & Pollack, 1995). Thus, *Happy Birthday* is recognizable despite being sung at a variety of pitches and tempos, or even when played with embellishments and harmony on various musical instruments. On the other hand, the surface or performance features allow identification of the musician performing the work, and contribute to the emotional meaning expressed in the rendition. Although it has been suggested that only the abstract structural information is encoded by adults into long-term memory (Raffman, 1993), adults also appear to encode surface features into long-term memory as their recognition of melodies is superior when the same timbre is used during familiarization and test (Peretz, Gaudreau & Bonnel, 1998; Radvansky, Fleming & Simmons, 1995), and they can recognize popular tunes on the basis of the first 100 to 200 ms of the recording, which only contains information about timbre and the pitch of the first note (Schellenberg, Iverson & McKinnon, 1999).

A similar dichotomy exists in the speech domain. A normalization process to eliminate talker and context variability must occur in order to recognize speech

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phonemes. On the other hand, specific talker and context information must be retained in order to recognize voices and emotion in the speech. The extent to which these two types of information are encoded separately or in an overlapping representation in long-term memory in adults remains controversial (e.g. Houston & Jusczyk, 2000). However, studies showing better recognition for words produced by the same talker than by different talkers suggest that in adults the normalized phonetic information and the acoustic details may be tightly coupled (Palmeri, Goldinger & Pisoni, 1993).

Developmentally, Houston and Jusczyk (2000) have proposed that infants' memory for speech is initially exemplar based, such that each occurrence of an utterance is encoded with information about its acoustic features (particular talker, context, prosody, etc.) rather than as an abstracted phonetic or lexical item. Their conclusions are based on several studies. First, when read a story, infants remember voice characteristics of the talker for up to two weeks (Jusczyk, Hohne, Jusczyk & Redanz, 1993). Second, although infants can immediately recognize speech sounds across different talkers (Kuhl, 1979), 2-month-olds lose the ability to do so with a delay as short as 2 minutes (Jusczyk, Pisoni & Mullennix, 1992). Finally, the ability to recognize words across talkers improves with age. Seven-month-olds can generalize across two female or two male talkers, but not across a male and a female talker, whereas 10-month-olds can generalize in all cases (Houston & Jusczyk, 2000).

Infants are also able to recognize melodies across some transformations when short retention intervals are used. For example, infants recognize melodies when they are transposed to higher or lower pitch levels (Trainor & Trehub, 1992; Trehub, Bull & Thorpe, 1984) and recognize rhythmic patterns when the tempo is altered (Trehub & Thorpe, 1989, but see Pickens & Bahrick, 1997). There is also evidence that infants remember musical performance features across very short retention intervals, in that they can distinguish between different renditions of a melody (Palmer, Jungers & Jusczyk, 2001). However, we know of no data on infants' recognition of transformed melodies after long retention intervals.

The focus of the present investigation is on whether infants remember two performance features of melodies over the long term. In particular, we tested whether infants remember the tempo (speed) and timbre (i.e. particular musical instrument) of melodies after a delay of one day. If infants' memory is exemplar-based, then infants familiarized with a melody at one tempo and in one timbre should develop a tempo- and timbre-specific long-term representation for that melody. Alternatively, if infants rely on an intrinsic abstraction process, whereby only the abstract structure (i.e. the relative pitches and relative durations) is encoded into long-term memory, then infants should forget the particular tempo and timbre of the melody over long delays, and treat instances of the melody at a new tempo or in a new timbre as equivalent to the original.

In asking questions related to the nature of infants' long-term memory representation for melody, it is important to note that infants can discriminate different tempos and timbres. As young as 2 months of age, infants discriminate tempo differences of 15% when the tempo is in the optimal processing zone of about 600 ms between beats (Baruch & Drake, 1997). As for timbre, there are to our knowledge no studies showing that infants discriminate musical instrument timbres. However, infants can recognize voices from a young age (Mehler, Bertoncini, Barriere & Jassik-Gerschenfeld, 1978; Mills & Melhuish, 1974), listen longer to loving over neutral voice timbres (Trainor, 1996) and are sensitive to spectral shape differences, one of the main physical correlates of timbre (Clarkson, Clifton & Perris, 1988; Trehub, Endman & Thorpe, 1990; Tsang & Trainor, 2002).

Although it appears obvious that infants must remember information over the long term if they are to recognize objects and acquire language and musical knowledge, it took considerable refinement of conditioning and preference measurement techniques to refute the view of a few decades ago that infant memory did not last longer than a few minutes (Bahrick, Hernandez-Reif & Pickens, 1997; Bahrick & Pickens, 1995; Courage & Howe, 1998, 2001; Rovee Collier & Gulya, 2000; Spence, 1996). Following studies by Jusczyk and Hohne (1997), Saffran *et al.* (2000) and Spence (1996), we employed a head turn preference procedure in which infants control how long they listen to each sound stimulus by their looking behaviour.

The head turn preference procedure has been used to show that infants have distinct listening preferences. For example, they prefer infant-directed over non-infant-directed speech (e.g. Fernald, 1992) and singing (Masataka, 1999; Trainor, 1996), native over foreign prosodic speech structures (Nazzi, Bertoncini & Mehler, 1998), higher- over lower-pitched singing (Trainor & Zacharias, 1998) and consonant over dissonant musical intervals (Trainor & Heinmiller, 1998; Trainor, Tsang & Cheung, 2002; Zentner & Kagan, 1998). Infants' preferences also change as a function of familiarity (Bahrick & Pickens, 1995; Bahrick *et al.*, 1997; Courage & Howe, 1998, 2001; Hunter & Ames, 1988) and this is what allows the assessment of musical memory. After exposure to a melody for a week, infants were expected to prefer to listen to a novel melody over the familiarized melody (Experiment 1). If infants' long-term memory is in terms of the

abstract structure and independent of the specific tempo and timbre heard during familiarization (i.e. the specific tempo and timbre are forgotten), then changing the tempo (Experiment 2) or timbre (Experiment 3) of the melodies at test compared to familiarization should not alter their novelty preference. If, on the other hand, these surface features are encoded in their long-term memory traces, then altering the tempo or timbre should make the melody sound less familiar, and result in a reduction in infants' novelty preference.

Experiment 1

Method

Participants

Sixteen 6-month-old infants participated (10 females, 6 males; age range = 23 to 30 weeks). Infants were born within two weeks of term, weighed at least 2500 g at birth, had no history of ear infections or family history of hearing impairment, and were healthy at the time of testing. One further infant was excluded for failing to complete the procedure.

Apparatus and stimuli

Two sets of digital recordings of two old English folk songs, Country Lass and Painful Plough (Figure 1), were made using Midi Orchestrator software, one in piano and one in harp timbre. The two songs were distinct in rhythm (duple vs. triple time) and mode (major vs. minor key). Otherwise, they had similar pitch ranges and numbers of notes (57 vs. 54), and were both presented at an average of 110 notes per s for a playing time of approximately 30 s. For the familiarization phase, four CD recordings were made, each containing six repetitions of one of the melodies in one of the timbres for a total playing time of three minutes.

For the test phase of the experiment, the digital sound files were played by a Power Macintosh 7300/180 computer connected to a Denon PMA-480R amplifier, connected in turn to two audiological GSI speakers located in a sound attenuating chamber (Industrial Acoustics Co.). The speakers were located on top of smoked Plexiglas-faced cabinets containing lights that made stationary toys in the cabinets visible, one on the left and one on the right side of the infant. The experimenter used a custom-built button box connected to the computer via a custom-built interface box and a Strawberry Tree I/O card to call for trials and record the infants' head turning behaviour.

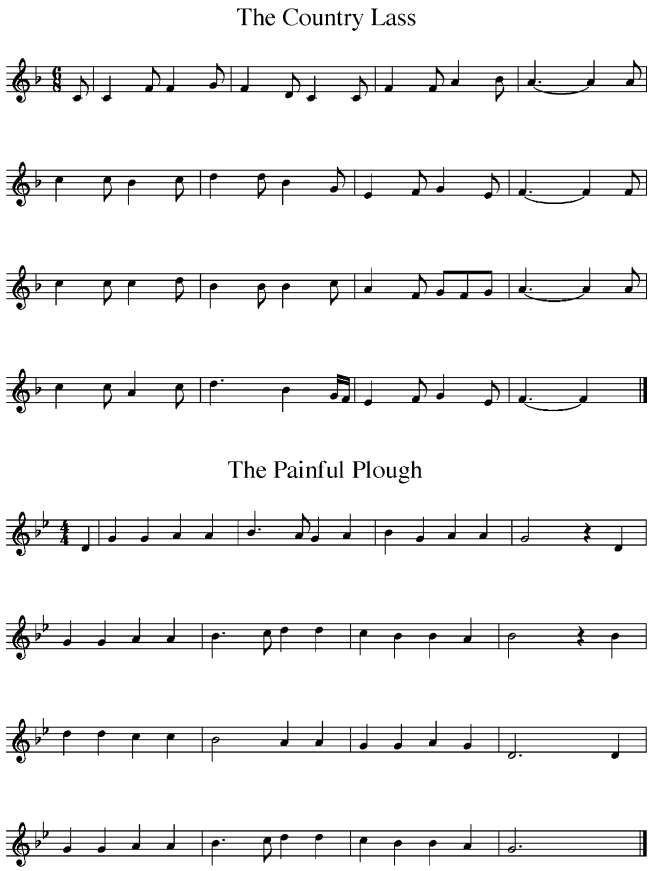

Figure 1 *The two old English folk song melodies used in the experiments.*

Procedure

Four infants were familiarized with Country Lass in piano timbre, four with Country Lass in harp timbre, four with Painful Plough in piano timbre and four with Painful Plough in harp timbre by listening to the piece for 3 minutes a day for seven days in their home. Parents kept track of their infants' listening schedule on a log sheet that was sent home with the CD.

On the eighth day, infants' preferences were tested in the lab for the familiarized (either Country Lass or Painful Plough) versus the novel piece (either Painful Plough or Country Lass), both played in the timbre heard at home (either piano or harp). Each infant was seated on his or her parent's lap across from the experimenter. Both the parent and the experimenter listened to masking music, and were deaf to what the infant was hearing. Each trial was initiated by the experimenter pressing one button on the button box when the infant was looking forward. Each trial began with a light flashing in the cabinet on either the right or left side of the infant. When the infant looked at the flashing light, the experimenter

signaled the infant's head turning behaviour to the computer via another button on the box. This caused the computer to begin playing either the familiarized or the novel melody and the light to remain on. The trial ended when the infant looked away for at least 2 s, at which time the light and music were extinguished. The next trial occurred on the other side and consisted of the other melody. Within each familiarization condition, two of the infants had their first test trial on the left and two on the right. Crossed with this factor, two of the infants heard the familiar melody first and two heard the novel melody first. Successive trials began where the previous trial of that melody had ended, and when the end of the melody was reached, it began again from the beginning. Trials of the familiarized and novel melodies alternated until the infant had completed 20 trials, and the measure of preference was the relative amount of time infants spent listening to the familiar versus novel melody.

Results and discussion

Because significant habituation can occur across 20 trials, the average looking time per trial was calculated separately for the first and second halves of the test session. An ANOVA with melody type (familiar, novel) and test half (first 10 trials, second 10 trials) as within-subject factors, and timbre (harp, piano) and familiar melody (Country Lass, Painful Plough) as between-subjects factors revealed only a main effect of melody type, $F(1, 12) = 7.20$, $p < .02$. Specifically, infants looked longer in order to hear the novel melody than the melody to which they were familiarized at home, indicating that they remembered the familiarized melody (Figure 2).

These results corroborate those of Saffran *et al.* (2000), and show that infants' memory for melodies can be measured in a preference paradigm. In Experiment 2, we tested whether infants' long-term representations for melodies are specific to the tempo heard during familiarization.

Experiment 2: tempo

Method

Participants

Sixteen 6-month-old infants participated (8 females, 8 males; age range = 25 to 27 weeks), meeting the same health criteria as those in Experiment 1. All infants tested were included in the final sample.

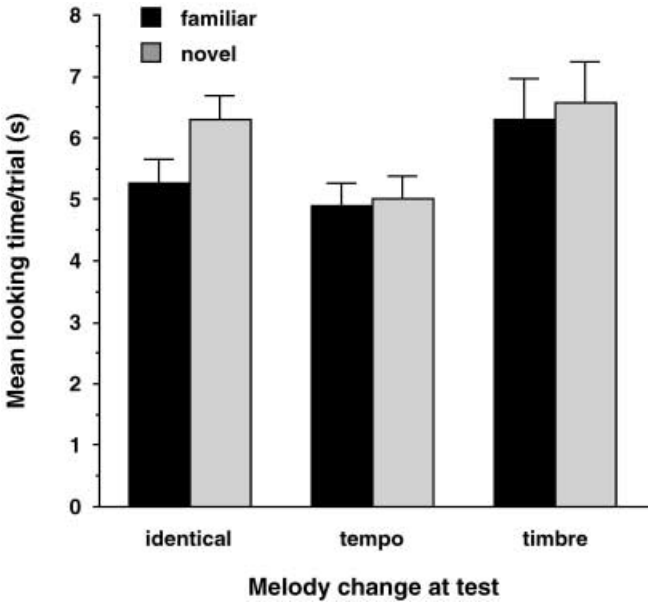

Figure 2 *Mean looking times per trial for the familiar and novel melodies when presented at the same timbre and tempo as during familiarization (left panel, Experiment 1), when the tempo was altered at test (middle panel, Experiment 2), and when the timbre was altered at test (right panel, Experiment 3). Error bars represent 95% confidence intervals based on the within-subject variability and are calculated according to the formula derived by Loftus and Masson (1994).*

Apparatus and stimuli

The apparatus and stimuli were identical to those of Experiment 1 with the following exceptions. Only the harp CDs of the Country Lass and Painful Plough were used for familiarization. New digital recordings of these were made for testing at tempos that were 25% faster and 25% slower than the originals to yield four new recordings: Country Lass fast, Country Lass slow, Painful Plough fast and Painful Plough slow.

Procedure

Infants were familiarized as in Experiment 1, but only with either the Country Lass harp (8 infants) or the Painful Plough harp (8 infants) CD. The preference test was conducted as in Experiment 1, with infants receiving alternating trials of these two melodies. For half of the infants, the melodies were played 25% slower, and for half 25% faster, than during familiarization.

Results and discussion

An ANOVA was conducted with melody type (familiar, novel) and test half (first 10 trials, second 10 trials) as

within-subject factors, and tempo at test (faster, slower) and familiar melody (Country Lass, Painful Plough) as between-subjects factors. There were no significant main effects or interactions. In particular, the main effect of melody type was highly non-significant, $F(1, 12) = .13$, $p = .72$, indicating that changing the tempo from familiarization to test eliminates the novelty preference for the new melody seen in Experiment 1 (Figure 2). Performances in Experiment 1 (no change) and Experiment 2 (tempo change) were compared directly with a *t*-test, with the dependent variable being the difference between novel and familiar looking times. Performance was significantly better in Experiment 1 than in Experiment 2, $t(30) = 1.70$, $p < .05$, confirming that changing the tempo reduces the novelty preference. To make sure that the effect was not due to a few outliers, the *t*-test was repeated with the two highest and two lowest performing infants eliminated from both experiments. This had the effect of reducing the variance, and the effect actually became stronger, $t(22) = 2.19$, $p < .02$. The lack of preference in Experiment 2 implies that changing the tempo made the melody heard at home sound less familiar, indicating that infants remembered the tempo of the original melody. It is possible that infants still recognized the familiarized melody, but we can at least conclude that their long-term memory representations are not simply in terms of abstract structure, but contain instance-based information about the surface feature of tempo as well. In Experiment 3, we asked whether infants' long-term memory representations are also specific to the timbre of the familiar melody.

Experiment 3: timbre

Method

Participants

Sixteen 6-month-old infants participated (8 females, 8 males; age range = 24 to 28 weeks), meeting the same health criteria as those in Experiment 1. One further infant was excluded for failing to complete the procedure.

Apparatus and stimuli

These were identical to those of Experiment 1.

Procedure

Each infant was familiarized as in Experiment 1, that is, on one of the four CDs. The preference test was also conducted as in Experiment 1, with infants receiving alternating trials of the two melodies. However, this time the novel and familiar melodies at test were presented in the opposite timbre to that heard during familiarization. For example, an infant hearing Country Lass on piano during familiarization would be tested on his or her preference for Country Lass on harp (familiar melody) versus Painful Plough on harp (novel melody).

Results and discussion

An ANOVA was conducted with melody type (familiar, novel) and test half (first 10 trials, second 10 trials) as within-subject factors, and timbre heard at home (harp, piano) and familiar melody (Country Lass, Painful Plough) as between-subjects factors. The main effect of interest, melody type, was highly non-significant, $F(1, 12) = .16$, $p = .70$, indicating that changing the timbre from familiarization to test eliminates the novelty preference for the new melody seen in Experiment 1 (Figure 2). Because the variance was larger in Experiment 3 than in Experiment 1, proportion looking to hear the novel melody (i.e. novel looking time/(novel + familiar looking times)) was used to compare performance across Experiments 1 (no change) and 3 (timbre change). There was a trend for better performance in Experiment 1, $t(30) = 1.20$, $p = .12$. When the two best and two worst performing infants were eliminated from both Experiments 1 and 3, further reducing the variance difference between experiments, the difference between experiments became significant, $t(22) = 1.90$, $p < .04$.

The ANOVA also revealed a significant interaction between timbre heard at home and melody heard at home, $F(1, 12) = 6.63$, $p < .03$, a significant main effect of timbre heard at home, $F(1, 12) = 9.70$, $p < .009$, and a trend for melody heard at home, $F(1, 12) = 4.54$, $p < .06$. In particular, infants looked longer if they heard Country Lass at home, looked longer if they heard piano at test, and looked particularly long if they heard Country Lass at home and were presented with piano timbre at test.

In this experiment, infants had not previously heard the particular versions of the melodies presented at test, as the timbre was changed from familiarization. Under these less familiar conditions, intrinsic preferences might be expected to play more of a role in the measured looking time preferences. Intrinsic preference for Country Lass might be expected because it is in a major ('happier') key and has a simpler time signature (2/4 vs. 6/8). The intrinsic preference for piano may depend on general familiarization as pianos are much more common than harps. The important point, however, from the perspective of the present study, is that neither the timbre heard at home nor the familiar melody interacted with melody type (familiar, novel), so that these factors did

not affect our ability to evaluate whether infants show a novelty preference when the familiarized melody is presented in a different timbre. The main finding is that changing the timbre from familiarization to test eliminates the novelty preference seen in Experiment 1, implies that changing the timbre makes the melody heard at home sound less familiar, and indicates that infants remember the timbre of the melody. As in Experiment 2, we conclude that infants' long-term memory representations for melody contain surface structure information.

General discussion

The results show definitively that infants remember the tempo and timbre of the familiarized melodies over long periods of time, because changing the tempo or timbre at test eliminates their preference for the novel melody. Thus, their long-term memory representations are not simply of the abstract musical structure, but contain surface or performance features as well. The question of whether or not the infants recognized the familiarized melody across the tempo and timbre changes is more difficult to answer. If infants recognized the melody, but also noted the tempo or timbre change, a trend toward a novelty preference would be expected. However, there was no hint of a preference when either the tempo or the timbre was changed (p values > .70).

The possibility that infants did not recognize the melodies across the tempo and timbre transformations parallels findings in the speech domain where infants do not readily recognize words produced by different talkers across time delays, and is consistent with exemplar-based encoding (Houston & Jusczyk, 2000). It also parallels findings that adults more easily recognize familiarized melodies when the timbre remains constant (Peretz *et al.*, 1998; Radvansky *et al.*, 1995). Finally, it should be noted that adults often have more than one representation for the same melody. For example, most adults are unaware that Twinkle Twinkle Little Star and Baa Baa Black Sheep are actually the same melody. Because of the different lyrics, adults have two separate representations for this melody.

The specific features of tempo and timbre may be very salient to infants. Pickens and Bahrick (1997) found that 7-month-olds categorized different tempos across variations in rhythmic patterns, but were unable to categorize rhythmic patterns across changes in tempo. Timbre may also be very salient to infants, as they recognize their mother's voice from an early age (DeCasper & Fifer, 1980; Mehler *et al.*, 1978; Mills & Melhuish, 1974). Thus, infants appear to attend to these surface features that are often conceptualized as problematic variability in extracting the essential meaning of a piece of music (Hanslick, 1957, originally published in 1854).

Another interesting dimension in this regard is that of absolute pitch. Most adults do not have absolute pitch in that, although they remember the relative pitch distances between notes of a melody, they cannot remember exact pitches over long time delays (Levitin, 1994; Takeuchi & Hulse, 1993). However, there is some evidence that infants may focus more on the absolute than the relative pitch level (Saffran & Griepentrog, 2001), although this remains controversial (Trehub, 2002). We are currently investigating infants' memory for relative and absolute pitch as we have done in the present paper for timbre and tempo.

A final question concerns whether the learning situation affects the type of representations that infants make. In the familiarization infants received in the present study, the melody was always presented at the same tempo and timbre. Interestingly, this may not be very different from the input they receive in the natural world. Bergeson and Trehub (2002) found that mothers varied the tempo of songs sung to their infants by less than 3% on average across a one-week period. Whether this stability is due to vocal production constraints on the part of the mother or to the fact that mothers tend to express the same emotion in a song every time, the fact remains that infants are apparently exposed to songs rendered at the same tempo across repetitions, not only on recordings but when sung to by their mothers. The question of interest for future research is whether infants exposed to a melody at a variety of tempos or timbres would show generalization to a new tempo or timbre. In any case, the present research clearly shows that infants' long-term memory representations for melodies contain tempo- and timbre-specific information, consistent with an exemplar model of memory encoding in which surface or performance features of melodies are encoded as part of the memory trace.

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