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Memory for surface features of unfamiliar melodies: independent effects of changes in pitch and tempo

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Abstract A melody's identity is determined by relations between consecutive tones in terms of pitch and duration, whereas surface features (i.e., pitch level or key, tempo, and timbre) are irrelevant. Although surface features of highly familiar recordings are encoded into memory, little is known about listeners' mental representations of melodies heard once or twice. It is also unknown whether musical pitch is represented additively or interactively with temporal information. In two experiments, listeners heard unfamiliar melodies twice in an initial exposure phase. In a subsequent test phase, they heard the same (old) melodies interspersed with new melodies. Some of the old melodies were shifted in key, tempo, or key and tempo. Listeners' task was to rate how well they recognized each melody from the exposure phase while ignoring changes in key and tempo. Recognition ratings were higher for old melodies that stayed the same compared to those that were shifted in key or tempo, and detrimental effects of key and tempo changes were additive in between-subjects (Experiment 1) and within-subjects (Experiment 2) designs. The results confirm that surface features are remembered for melodies heard only twice. They also imply that key and tempo are processed and stored independently.

Memory for surface features of unfamiliar melodies: independent effects of changes in pitch and tempo

Imagine hearing *Happy Birthday* performed on a tuba very slowly. Now imagine hearing the same melody played on a piccolo very quickly. Your ability to imagine these previously unheard versions demonstrates that music is inherently an abstract domain, such that a melody's identity is based solely on *relations* between consecutive tones in terms of pitch and duration.[1] A useful way to think about melodies is to distinguish *abstract* from *surface* features (e.g., Halpern & Müllensiefen, 2008; Peretz, Gaudreau, & Bonnel, 1998; Trainor, Wu & Tsang, 2004). Whereas abstract features include the pitch and temporal relations between consecutive tones, surface features include pitch level (key), tempo (or speed), and timbre (i.e., the instrument on which a melody is performed). Alterations of the abstract structure change the identity of the melody, but changes to these surface features do not.

Listeners' memory for the abstract features of melodies is made clear by their ability to recognize a familiar melody when it is presented in a novel timbre, in a novel key (i.e., transposed), and/or at a novel tempo. In fact, one view holds that after a 1-min delay or longer, listeners' memories for melodies are comprised solely of abstract features particularly in the case of pitch (e.g., Krumhansl, 2000). In terms of fuzzy-trace theory (Brainerd & Reyna, 2002), listeners could be said to have good *gist* memory for melodies but poor or non-existent *verbatim* memory. A notable exception involves the relatively few people with absolute pitch (AP), who can produce or name musical tones without the use of a reference tone (Takeuchi & Hulse, 1993). In other words, people with AP have precise memory for a surface feature of music.

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[1] "Melody" is sometimes used to refer solely to successive pitch relations, as opposed to "rhythm", which refers to differences in tone durations. Here, we define melody as a coherent series of tones that differ in pitch and duration.

Although AP is typically considered to be an all-or-none phenomenon, there is now a body of evidence indicating that nonmusicians without AP encode and remember surface information about highly familiar music, including key as well as tempo and timbre. For example, participants sing a familiar pop song at a key that is close to that of the original recording (±2 semitones; Levitin, 1994). Moreover, singers' renditions of familiar folk songs (e.g., *Yankee Doodle*) are stable in key across days (Halpern, 1989), as are mothers' songs directed to their infants across sessions separated by a week or more (Bergeson & Trehub, 2002). These production tasks may reflect contributions of motor memory, however, rather than simply memory for key. Pitch stability could also arise from the limited vocal range of untrained singers.

Nevertheless, tasks that rely solely on perceptual judgments provide converging evidence of memory for key in nonmusicians. In one study (Schellenberg & Trehub, 2003), musically untrained adults heard two versions of a familiar TV theme song: one played at the standard key and one transposed by either one or two semitones. Their task was to identify the excerpt at the original key. Performance was above chance levels for both changes. Follow-up studies confirmed that children (Schellenberg & Trehub, 2008; Trehub, Schellenberg, & Nakata, 2008) and infants (Volkova, Trehub, & Schellenberg, 2006) are also able to recognize the correct key of familiar recordings, and that adults remember the pitch of the dial tone (Smith & Schmuckler, 2008). These findings point to accurate memory for the pitch height of familiar auditory stimuli that have been heard many times at *exactly* the same pitch, but they do not speak to the issue of memory for previously unfamiliar melodies. Much of the music we hear in everyday life is novel or much less familiar than, say, the theme song to *The Simpsons*.

Other findings indicate good memory for tempo and timbre, two other surface features of music. For example, untrained participants' sung renditions of pop songs are remarkably close to the original tempo (Levitin & Cook, 1996), and specific tunes that mothers sing to their infants are stable in tempo across time (Bergeson & Trehub, 2002). As with the production studies of pitch memory, however, these findings could reflect contributions of motor memory and may not extend to less familiar musical materials. Listeners also recognize familiar recordings from very brief (100 ms) excerpts (Schellenberg, Iverson, & McKinnon, 1999). Because they fail to do so when the same excerpts are played backwards (which has no effect on key), these results implicate remarkably detailed memory for the overall timbre (or sound quality) of recordings because excerpts this brief do not contain any information about tempo, rhythm, or pitch relations. In line with this view, changing the timbre of a musical piece from piano to orchestra (or vice versa) impairs listeners' ability to recognize it (Poulin-Charronnat et al., 2004).

Tests of listeners' memory for the surface characteristics of previously unfamiliar melodies have focused primarily on timbre. The basic finding is that when timbre changes from exposure to test, recognition declines whether the melodies are retrieved from short-term (Radvansky, Fleming, & Simmons, 1995; Radvansky & Potter, 2000) or long-term (Halpern & Müllensiefen, 2008; Peretz et al., 1998; cf. Warker & Halpern, 2005) memory. Timbre may be a unique surface feature because it provides information about the specific instrument (or voice) on which a melody is played or sung (Peretz et al., 1998; Radvansky & Potter, 2000). In other words, the *source* of an auditory event may be encoded into memory (Johnson, Hashtroudi, & Lindsay, 1993), and timbre may be a better source cue than key or tempo. Further evidence that timbre is especially salient and memorable comes from nonmusicians, who sometimes deem different melodies presented in the same timbre to be more similar than the same melody presented in different timbres (Wolpert, 1990).

In the present investigation, we examined whether listeners remember the key and tempo of previously unfamiliar but Western-sounding melodies. If so, recognition should be impaired when key and/or tempo are changed from exposure to test. In an earlier examination of the influence of tempo on long-term memory for melodies (Halpern & Müllensiefen, 2008), changing tempo from exposure to test decreased explicit memory (recognition ratings) as well as implicit memory (pleasantness ratings), whereas a timbre shift led to a decline in recognition but not in liking. In another study that tested working memory for melodies, transpositions had no effect on error rates (Radvansky & Potter, 2000).

Studies of infant listeners also inform the question of memory for surface features of melodies, and which features might be naturally salient. For example, when 6-month-olds have daily exposure to a mechanically generated (i.e., not performed) piano melody for a week, they prefer a novel melody on the eighth day (Trainor et al., 2004). This novelty preference disappears when the familiar melody is sped up or slowed down by 25 %, which implies that tempo-changing the melody makes it sound less familiar. By contrast, when infants are tested with a transposed version of the same familiarized melody on the eighth day, they still prefer a novel melody, which implies that they do not remember the key or that key is not particularly salient (Plantinga & Trainor, 2005). Even a direct comparison of the familiar melody at the old or a new key does not indicate a preference. When the stimuli are infant-compatible melodies (i.e., lullabies rather than folk songs), however, and presented in a vocal rather than an instrumental timbre, 6- and 7-month-olds recognize a familiar key (Volkova et al., 2006). Additional evidence that the voice makes melodies particularly memorable comes from adults, who exhibit better memory for melodies presented vocally (without words) compared to the same melodies played on an instrument (Weiss, Trehub, & Schellenberg, 2012).

When researchers examine adults' short-term memory for melodies, they often require listeners to make similarity judgments about standard and comparison melodies. Larger transpositions and decreasing the number of overlapping pitch classes (i.e., increasing *key distance*) make melodies sound more dissimilar (Bartlett & Dowling, 1980; Van Egmond, Povel, & Maris, 1996). When standard and comparison melodies are transposed equivalently across trials, manipulations that change tone order, mode, rhythm, or the actual melody (i.e., pitch relations) lead to lower similarity ratings (Halpern, 1984). When the standard and comparison are different melodies presented with the same tempo, timbre, key, and amplitude, listeners rely on the specific pitches, the total number of tones, overall pitch height, pitch intervals, tone durations, conformity to the underlying key, consonance, syncopation, and rhythmic regularity (Eerola, Järvinen, Louhivuori, & Toiviainen, 2001). In some instances, focusing on rhythm in order to determine melodic similarity is correlated negatively with focusing on pitch relations (Monahan & Carterette, 1985).

When listeners judge the similarity of different excerpts of music that comprise more than one note at a time (as in polyphony or homophony), their judgments are based primarily on surface features such as differences in amplitude (dynamics), articulation (staccato or legato notes), the number of tones played simultaneously (texture), and pitch direction (contour, Lamont & Dibben, 2001). When required to group brief sections from a contemporary piano piece on the basis of similarity, listeners rely primarily on surface features such as tempo, texture, overall pitch height, contour, and articulation (McAdams, Vieillard, Houix, & Reynolds, 2004). When the same stimuli are presented orchestrally (with multiple instruments), the different timbres play a role (McAdams et al., 2004). In studies of long-term memory for music, listeners remember the harmonic and metrical context in which a melody was originally presented (Creel, 2011), and the surface features (i.e., pitch height, tone duration, contour, dynamics, interval size) of contemporary piano music (Krumhansl, 1991). Nevertheless, to the best of our knowledge, no study has compared long-term memory for melodies that remain unchanged from exposure to test with those that have been shifted in key and/or tempo.

In real-life listening situations, a new rendition of a piece of music often varies on multiple dimensions from a previously heard version. For example, in a new version of a previously recorded song (e.g., The Beatles' *All You Need is Love*), key, tempo, and timbre may all differ from that of the original recording. In any vocal rendition of *Happy Birthday*, key, tempo, and timbre (i.e., the particular singing voices) almost always differ from previously performed versions. It is important therefore to study the effects of changes in multiple cues simultaneously. Accordingly, a secondary goal of the present study was to examine whether key and tempo are processed additively or interactively, by testing listeners' memory for previously unfamiliar melodies that varied from exposure to test in key, tempo, or key and tempo.

Some evidence points to separate encoding of pitch and time in music, such that simultaneous changes in both dimensions have additive rather than interactive effects. For example, when listeners are asked to judge how complete a musical fragment sounds, their evaluations can be explained by an additive combination of measures of the tonal (pitch) stability and metrical (time) stability of the final musical event (Palmer & Krumhansl, 1987a, b). Similar findings emerge when listeners judge how well a test tone fits with a preceding musical context (Prince, Thompson, & Schmuckler, 2009).

Jones (1987, 1993; Jones & Boltz, 1989) stresses that the salience of any tone in a sequence is a combination of temporal and pitch accents. In some instances, the two dimensions interact, meaning that temporal accents influence pitch perception, and, conversely, that pitch accents influence temporal perception. For example, listeners' ability to discern whether a comparison tone has the same pitch as a standard tone is better when the comparison tone occurs at an expected (on the beat) rather than an unexpected (off the beat) position in the perceived meter (Jones, Johnston, & Puente, 2006; Jones, Moynihan, MacKenzie, & Puente, 2002). Listeners are also better at detecting a pitch change to a single tone in a melody if the tone occurs at a point with greater rhythmic emphasis, as determined by longer tone durations or inter-tone intervals (Jones, Boltz, & Kidd, 1982). When listeners are instructed to ignore differences in tone duration while determining if a sequence of pitches is the same as one heard earlier, accuracy suffers when the durational patterning changes from learning to test (Jones & Ralston, 1991). Judgments of the temporal order of tones presented sequentially are also less accurate when the sequence has a more complicated pitch structure (i.e., with more contour changes; Boltz, Marshburn, Jones, & Johnson, 1985). Moreover, the tempo of a tone sequence is judged to be slower when the sequence is presented at a lower pitch (Boltz, 2011) or when it has more contour changes or larger pitch intervals (Boltz, 1998). In a study that examined the perception of emotion conveyed by melodies, pitch structure interacted with rhythmic structure although the effects varied across the different stimulus melodies and the particular emotion that was conveyed (Schellenberg, Krysciak, & Campbell, 2000).

Whether musical pitch and time are psychologically additive or interactive depends on the context. In one study, both temporal and pitch accents influenced the perceived meter, but the two-way interaction depended on the particular scoring method (Ellis & Jones, 2009). In another study (Prince, Schmuckler, & Thompson, 2009), metrical irregularities influenced memory for the pitch of a tone only when the intervening tone sequence was atonal (i.e., not conforming to a musical key). When the intervening sequence was tonal (i.e., in a clear key), pitch memory was not influenced by manipulating the comparison tone to be on or off the beat. Because the participants were musically trained, however, they may have had particularly good memory for the pitch properties of tonal music, which allowed them to ignore metrical irregularities. Other findings indicate that interactions between pitch and time are asymmetrical, such that a temporal phase-shift of one or two tones influences perceived key, but a pitch phase-shift of identical magnitude does not affect the perception of meter (Abe & Okada, 2004). Conversely, judgments of whether a test tone that follows a preceding context is "on the beat" are affected by the tone's pitch stability, yet "in-key" or "out-of-key" judgments are unaffected by the tone's metrical position (Prince, Thompson, et al., 2009). In any event, none of these findings bears directly on the question of additive or interactive effects of key and tempo in long-term memory for real melodies.

In two experiments, we examined whether changes in key and tempo affect recognition for melodies heard twice previously, and, if so, whether the two manipulations have additive or interactive effects. To the best of our knowledge, our study is the first to examine memory for entire melodies that varied in key, tempo, or key and tempo. During an exposure phase, listeners heard a set of unfamiliar melodies. In a subsequent test phase, they heard the same melodies plus an equal number of novel melodies. Some of the old melodies were shifted in key, tempo, or key and tempo. Listeners' task was to rate whether they heard the melody—irrespective of key and/or tempo changes—during the exposure phase. Key and tempo were manipulated between subjects in Experiment 1 and within subjects in Experiment 2. Based on findings of memory for the key and tempo of highly familiar recordings (e.g., Schellenberg & Trehub, 2003; Levitin & Cook, 1996), and of memory for the tempo of previously unfamiliar melodies (Halpern & Müllensiefen, 2008), we hypothesized that changes in key and/or tempo would decrease recognition. The available literature precluded predictions about whether key and tempo manipulations would be additive or interactive.

Pilot study

Before examining effects of key and tempo changes on recognition memory for melodies, it was necessary to determine manipulations that were approximately equal in psychological magnitude (or perceptual salience). Otherwise, spurious interactions could emerge simply because one manipulation was stronger than the other. Our method was modeled after the one used recently to equate manipulations of tempo and amplitude (Thompson, Schellenberg, & Letnic, 2012).

Preliminary testing revealed that when our stimulus melodies were presented at 110 beats per minute (bpm), a transposition of 6 semitones reduced subsequent recognition memory without floor or ceiling effects, which motivated us to determine an increase in tempo that was approximately equal in psychological magnitude. We contrasted 110 bpm with six faster tempi: 130, 150, 170, 190, 210, and 230 bpm. Because the task was expected to be challenging, we recruited 12 highly motivated listeners. Each was a graduate student or research assistant working in a laboratory studying auditory communication.

The stimuli were nine different versions of *Twinkle Twinkle Little Star* (first and second lines) presented in a piano timbre. Two had a tempo of 110 bpm but differed in key by 6 semitones. The low version had a starting pitch of D#4 (i.e., in the octave above middle C), such that its median pitch (adjusted for duration) was midway between G4 and G#4. The high version was transposed upward by 6 semitones (starting pitch A4). The other seven versions were presented at an intermediate pitch (starting tone F#4) and varied in tempo from 110 to 230 bpm in 20-bpm increments.

We explained the goal of the pilot study to listeners, who were tested individually. On each trial, they heard *Twinkle* four times. The initial two versions, separated by 1 s of silence, varied in key (by 6 semitones) but not in tempo. The final two versions, also separated by 1 s of silence, varied in tempo (by different magnitudes) but not in key. There was a 2-s silent interval between the initial two versions and the final two versions. The task was to compare the tempo change to the key change by providing a rating on a 5-point scale that asked whether the key change or tempo change was greater in psychological magnitude (1 = *tempo change smaller than pitch change*, 3 = *tempo and pitch tempo changes equal*, 5 = *tempo change larger than pitch change*). Because there were six different tempo changes and the order of the initial two melodies (low-high or high-low) and the final two melodies (slow-fast or fast-slow) was counterbalanced, there were 24 trials presented in a different random order for each listener.

We calculated an average rating (from four original ratings) for each of the six tempo changes separately for each listener, and then regressed these ratings on the tempo change. Even though the N was small (i.e., six different tempo changes), the correlation was significant for 8 of 12 listeners, $r \geq 0.74$, $N = 6$, $p \leq 0.05$ (one-tailed), which indicated that their equivalence ratings varied systematically and linearly with the magnitude of the tempo change. We subsequently averaged ratings over these eight "systematic" listeners, and then regressed the grand means on the tempo change. A rating of three (i.e., equivalent manipulations) was inserted into the regression equation such that we could solve for a tempo value, which was 174 bpm. Thus, an increase in tempo from 110 to 174 bpm was determined to be approximately equivalent in psychological magnitude to a pitch change of 6 semitones. In the two experiments that follow, low melodies had a median pitch of G4, high melodies had a median pitch of C#5 (6 semitones higher), slow melodies had a tempo of 110 bpm, and fast melodies had a tempo of 174 bpm.

Experiment 1

Method

Participants

Listeners were 96 undergraduate students recruited from an introductory course in psychology without regard to music training. There were 23 males and 73 females between the ages of 17 and 30 years ($M = 19.1$, SD = 1.8). On average, they had 3.5 cumulative years of music training (SD = 4.3), which included private, group, and school lessons (range 0–18). As in previous samples from the same population (e.g., Ladinig & Schellenberg, 2012; Schellenberg, Peretz, & Vieillard, 2008), the distribution was skewed positively (mode = 0, median = 2). Listeners received partial course credit for their participation.

Apparatus

The stimuli were created using Finale Notepad and Garageband software installed on Macintosh computers. Testing was conducted in a double-walled sound-attenuating booth (Industrial Acoustics Co.). A Macintosh computer running custom-made software created with PsyScript (Slavin, 2010) was used to present stimuli and record responses. Melodies were presented at a comfortable volume through computer speakers. Listeners used the keyboard and mouse to input their responses and to advance the trials.

Stimuli

The stimuli comprised 24 melodies of similar duration (i.e., approximately 30 s, 12–16 measures), 19 of which were used previously by Weiss et al. (2012) in their study of memory for timbre. All melodies came from collections of British and Irish folk songs. These genres were selected so that the melodies would be unfamiliar to listeners while adhering to Western tonal structure, as in Schellenberg (1996, Experiment 1). Each melody contained tones that varied in duration and pitch. On average, the melodies had tones with 5.0 unique durations (SD = 1.3, range 3–8) and 9.1 unique pitches (SD = 1.8, range 6–13). Figure 1 illustrates two representative melodies in musical notation.

The melodies were initially recorded note by note (i.e., not performed) using Musical Instrument Digital Interface (MIDI) software (Finale) that automatically added subtle differences in amplitude to highlight the metrical structure (i.e., alternating strong and weak beats). The MIDI files were subsequently opened in Garageband, assigned to a piano timbre, and manipulated in key and tempo. Each melody had four different versions. Low and slow versions were transposed from the written notation so that the median pitch (adjusted for duration) for each was G4 (i.e., in the octave above middle C) and the tempo was 110 bpm. Equating for median pitch meant that successful melody recognition could not rely on cues from overall pitch height. It also meant that musical key varied across melodies. The beat unit corresponded to quarter-notes in the notated melodies. Because the melodies differed in terms of the number of short (8th or 16th) and long (half or whole) notes, they also varied in perceived speed (i.e., average number of notes per minute) in both tempo conditions. High and slow versions of each melody were transposed upward in pitch by 6 semitones (median pitch = C#5). Low and fast versions were sped up to 174 bpm, and high and fast versions were transposed and sped up. Each melody was saved as an MP3 digital sound file.

Procedure

The entire procedure took approximately 45 min. Before the test session began, participants heard multiple versions of *Happy Birthday* to demonstrate that changes in key and tempo had no bearing on the identity of a melody. A standard version of the tune was presented first followed by a higher version, a lower version, a faster version, a slower version, a higher and faster version, and finally a lower and slower version. After the demonstration, all listeners confirmed that they understood that changes in key and tempo do not affect the identity of a tune.
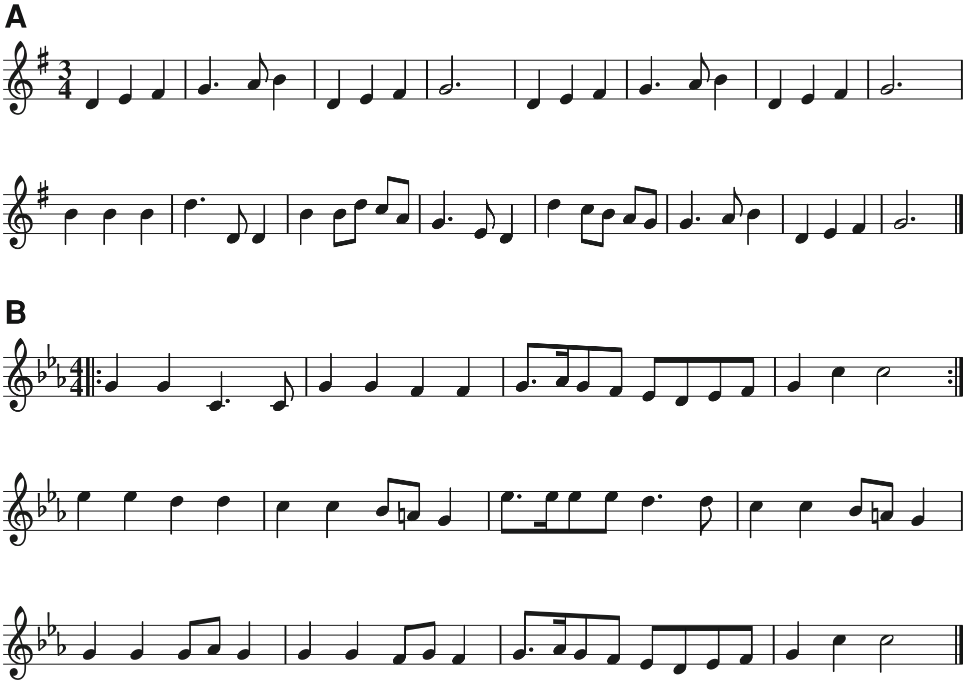
Fig. 1 Two representative melodies from the stimulus set. Both are illustrated in their low versions, with a median pitch (adjusted for duration) of G4. Melody A is in G major with a 3/4 time signature. Melody B is in C minor with a 4/4 time signature. High versions of the same melodies were transposed upward by 6 semitones. The tempo was 110 beats per minute for the slow versions (beat = quarter-note) and 174 beats per minute for the fast versions

The actual test session began with an exposure phase. The melodies were divided into two sets of 12 (A and B), with both sets comprising four major-key melodies in 3/4 meter, four major melodies in 4/4, one minor melody in 3/4, and three minor melodies in 4/4. Listeners heard all 12 melodies from a single set in random order, followed by a second presentation of the same 12 melodies in a different random order. Half of the listeners heard Set A melodies; the other half heard Set B. After each presentation, listeners rated how happy or sad the melody sounded on a 7-point scale ranging from −3 to 3 (−3 = *Sad*, 0 = *Neutral*, 3 = *Happy*). Emotionality ratings ensured that participants listened to each melody, but were of no theoretical interest. Trials were self-paced, and listeners initiated subsequent trials by pressing the spacebar.

After the exposure phase, there was a delay of 10–15 min during which participants filled out two questionnaires. The first was the Big Five Inventory (John, Donahue, & Kentle, 1991), a self-report measure used widely in studies of personality. This questionnaire had 44 items and was included simply as a distractor task and of no theoretical interest. The second questionnaire asked for information about demographics and history of music training.

After participants completed both questionnaires, they returned to the testing booth to complete the recognition phase, which included all 24 melodies (Sets A and B) presented in random order. The experimenter told listeners that they would hear a second set of melodies: some old (i.e., presented in the exposure phase) and some new, and confirmed again that they understood that a change in key and/or tempo does not alter the identity of a melody. The listener's task was to identify whether each melody was heard before, irrespective of changes in key and/or tempo. After hearing each melody, listeners used a 7-point scale to make their recognition ratings (1 = C*ompletely sure I didn't hear that tune before*, 4 = *Not sure whether or not I heard that tune before*, 7 = *Completely sure I heard that tune before*).

Equal numbers of participants ($n = 32$) were tested in each of three conditions. In the key-change condition, all melodies were presented at the slow tempo throughout the procedure. In the exposure phase, six melodies were presented in the low key and six were presented in the high key. During the recognition phase, half of the melodies were the 12 from the exposure phase and the remaining 12 were new. Six of the old melodies were played at the same key as the exposure phase, and six were played at a different key, with transposition (high-to-low or low-to-high) counterbalanced. Half of the new melodies were also presented in the low key, with the other half in the high key, so that pitch height was not a cue to oldness or newness. Across participants, a counterbalanced design ensured that each melody appeared equally often as a high or low old melody, or a high or low new melody, which ruled out possible effects of some melodies being inherently more memorable than others.

The tempo-change condition was identical except that all melodies were presented at the low pitch throughout the procedure, and the two pitch levels were substituted with two tempi: 110 and 174 bpm. In the exposure phase, half of the melodies were slow and half were fast. In the

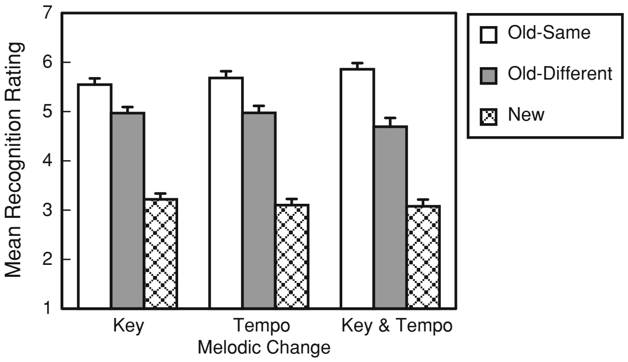

Fig. 2 Mean recognition scores for old-same, old-different, and new melodies in Experiment 1 as a function of whether the melodic change involved a shift in key, tempo, or key and tempo. *Error bars* are standard errors

recognition phase, the new melodies were either slow or fast, and half of the old melodies were changed in tempo. The key-and-tempo-change condition was also identical except that the melodies were presented in low/slow or high/fast versions. Half the melodies were low/slow in the exposure phase and half were high/fast. In the recognition phase, the new melodies were either low/slow or high/fast, and half of the old melodies were changed in key and tempo. Thus, across conditions, low/slow melodies were contrasted with high/slow melodies (key change), low/fast melodies (tempo change), and high/fast melodies (key and tempo change).

Results and discussion

For each listener, we calculated three scores: an average recognition rating for the six old melodies that were unchanged from exposure to test (old-same), an average for the six old melodies that changed in key and/or tempo from exposure to test (old-different), and an average for the 12 new melodies (new). Descriptive statistics are illustrated in Fig. 2 separately for the three conditions. We initially compared mean ratings to the midpoint of the scale (i.e., 4) using one-sample t tests. In the key, tempo, and key-and-tempo change conditions, respectively, ratings for old-same melodies, Cohen's $d = 2.16$, 2.17, and 2.62, and old-different melodies, $d = 1.39$, 1.21, and 0.69, were higher than the midpoint, whereas ratings for new melodies, $d = 1.17$, 1.28, and 1.19, were lower than the midpoint, $ps < 0.001$. In other words, listeners had explicit memory for the melodies presented in the exposure phase, regardless of whether they were shifted in key and/or tempo.

For each of the three conditions, we conducted a repeated-measures analysis of variance (ANOVA) with type of change as the independent variable (old-same, old-different, new). For listeners in the key-change condition, the main effect of change was significant, $F(2, 62) = 121.23$, $p < 0.001$, partial $\eta^2 = 0.80$. Old-same melodies received higher recognition ratings than old-different melodies, $t(31) = 3.38$, $d = 0.82$, $p = 0.002$, which received higher ratings than new melodies, $t(31) = 12.71$, $d = 2.56$, $p < 0.001$.[2] For listeners in the tempo-change condition, the results were similar. The main effect of change was significant, $F(2, 62) = 97.97$, $p < 0.001$, partial $\eta^2 = 0.76$. Old-same melodies were recognized better than old-different melodies, $t(31) = 4.63$, $d = 0.90$, $p < 0.001$, and old-different melodies received higher recognition ratings than new melodies, $t(31) = 9.07$, $d = 2.49$, $p < 0.001$. Finally, for listeners who heard a change in key and tempo, the main effect of change was also significant, $F(2, 62) = 92.84$, $p < 0.001$, partial $\eta^2 = 0.75$. As in the other two conditions, old-same melodies received higher recognition ratings than old-different melodies, $t(31) = 7.09$, $d = 1.36$, $p < 0.001$, which received higher ratings than new melodies, $t(31) = 6.77$, $d = 1.81$, $p < 0.001$.

Although a mixed-design ANOVA might seem like the obvious way to test for an interaction between the key and tempo changes, such an analysis would reveal an interaction if the key and tempo manipulations had *additive* effects (i.e., a larger difference between old-same and old-different melodies in the condition with a change in key and tempo compared to conditions with a change in key or tempo). As an alternative, we used multi-level modeling on old melodies with one within-subjects factor (old-same vs. old-different) and one between-subjects factor (the three conditions). Tests of fixed effects included key (same or different), tempo (same or different), and the interaction between key and tempo. Although main effects of the key change, $F(1, 93) = 13.48$, $p < 0.001$, and the tempo change, $F(1, 93) = 21.09$, $p < 0.001$, were significant, there was no interaction between key and tempo, $F < 1$.

Additional analyses examined whether music training was associated with the difference in recognition ratings between old-same and old-different melodies. Because of the skewed distribution, we divided the samples into two groups: those with 2 or more years of lessons and those with <2 years of lessons. The two groups did not differ in any of the three conditions, $ps > 0.4$.

In short, the analyses confirmed that musically trained and untrained listeners remembered surface features of melodies—specifically key and tempo—after two exposures, such that changes in these features caused decrements in recognition memory. The results also provided evidence that key and tempo were processed and stored independently.

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[2] For all pairwise comparisons, Cohen's d was calculated using the average SD.

Experiment 2

Experiment 2 was similar to Experiment 1 except that key and tempo manipulations were repeated measures rather than between-subjects variables.

Participants

Listeners were 32 undergraduates recruited and compensated as in Experiment 1. There were 15 males and 17 females between the ages of 18 and 39 years ($M = 19.4$, SD = 3.7). The participants had an average of 4.8 years of music training (SD = 9.3), which included private, group, and school lessons (range 0–51 cumulative years, positively skewed distribution, median = 2, mode = 0). None had participated in Experiment 1.

Apparatus and stimuli

Same as in Experiment 1.

Procedure

The procedure was identical to Experiment 1 with the following exceptions. For half of the listeners, the 12 melodies in the exposure phase (i.e., from Set A or Set B) were divided equally among the four key/tempo combinations with three melodies per combination. In the recognition phase, all 24 melodies were presented in the low/slow version. For the other half of the listeners, all 12 melodies were low and slow during the exposure phase. In the recognition phase, the old melodies were divided equally among the four key/tempo combinations, as were the new melodies. Thus, for each listener, low/slow melodies contrasted with high/slow (key change), low/fast (tempo change), and high/fast (key and tempo change) melodies, such that one-quarter of the old melodies were exactly the same from exposure to test, one-quarter were shifted in key, one-quarter were shifted in tempo, and one-quarter were shifted in key and tempo. The order of the melodies in both phases was randomized separately for each listener. The stimuli were assigned to the various versions in a balanced Latin-square design, such that each melody was old (or new) for half of the participants, each melody underwent one of the three changes an equal number of times, and the three possible changes were counterbalanced with whether the melody was old or new.

Results and discussion

We calculated five scores for each listener: one for new melodies (averaged over 12 ratings), as well as separate scores (each averaged over 3 ratings) for old-same melodies, old key-shifted melodies, old tempo-shifted melodies, and old key- and tempo-shifted melodies. Descriptive statistics are illustrated in Fig. 3. A preliminary analysis confirmed that mean recognition ratings were lower than the midpoint of the scale (i.e., 4) for new melodies, $d = 0.97$, $p < 0.001$, but higher than the midpoint of the scale for old melodies, whether they were they were unchanged from exposure to test, $d = 1.86$, $p < 0.001$, or changed in key, $d = 1.38$, $p < 0.001$, tempo, $d = 0.89$, $p < 0.001$, or key and tempo, $d = 0.51$, $p = 0.007$. Once again, then, listeners had explicit memory for melodies heard during the exposure phase whether or not they were shifted in key and/or tempo.

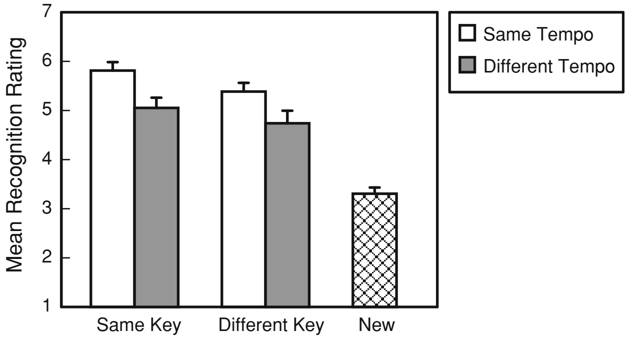

Fig. 3 Mean recognition scores for melodies in Experiment 2 as a function of whether the melodies were new or shifted in key and/or tempo. *Error bars* are standard errors

The principal analysis focused solely on old melodies. A two-way repeated-measures ANOVA with key (same or different) and tempo (same or different) as independent variables revealed a significant main effect of key, $F(1,\ 31) = 6.22$, $p = 0.018$, $d = 0.41$, and a significant main effect of tempo, $F(1,\ 31) = 17.31$, $p < 0.001$, $d = 0.75$. As shown in Fig. 3, melodies that were shifted in key or tempo received lower recognition scores than melodies that remained unchanged, and melodies that were shifted in key and tempo received the lowest recognition scores of all. As in Experiment 1, there was no hint of an interaction between pitch and tempo, $F < 1$, indicating that the two dimensions were processed and remembered additively. When music training was included in the ANOVA as a between-subjects variable (i.e., ≥2 years of lessons vs. <2 years), there was no main effect of music training, $F < 1$, and no interactions involving music training, ps > 0.2.

The findings replicated those of Experiment 1. Musically trained and untrained listeners had long-term memory for the key and tempo of melodies they heard twice in the exposure phase, and the key and tempo changes had detrimental effects on recognition memory that were additive rather than interactive.

General discussion

Response patterns provided unequivocal evidence that (1) listeners remembered the key and tempo of previously unfamiliar melodies after only two exposures and (2) changes in key and tempo made additive contributions to decrements in recognition. Because these effects were independent of music training, they inform us about the structure of mental representations for melodies in the typical listener. In the discussion that follows, we focus initially on memory for key and tempo, and secondly on evidence that these two surface features are processed and stored independently.

In general, melodies that were shifted in key or tempo from the exposure to the test phase were recognized poorly compared to unchanged melodies. In other words, although the relations in pitch and tone duration that define a melody are invariant over changes in key and tempo, both of these surface features operated as important reference frames that facilitated recognition during re-presentation. Accordingly, when these features were changed, recognition suffered. Moreover, the duration of the retention interval between the exposure and test phases ensured that key and tempo information was stored in long-term memory.

Our results are in line with the encoding specificity principle, in which retrieval from memory is facilitated when the context at the time of recall matches the context at the time of encoding (Tulving & Thompson, 1973). More generally, despite the view that long-term memory for music may be unique in the sense that it contains only relational information (e.g., Krumhansl, 2000), melodies are actually remembered like other stimuli, in which gist information (i.e., the identity or meaning of the stimulus) is stored along with verbatim information (i.e., contextual and surface features; Brainerd & Reyna, 2002). For example, in speech, listeners remember both the linguistic and nonlinguistic details, such that memory for spoken words deteriorates when the speaker changes from exposure to test (Nygaard, 2005). Similarly, readers remember both linguistic and nonlinguistic details of text, such that memory for written words deteriorates when the font is changed from exposure to test (Reder, Donavos, & Erickson, 2002).

Our findings confirm that listeners remember surface features of melodies other than timbre (Halpern & Müllensiefen, 2008; Peretz et al., 1998; Radvansky et al., 1995; Radvansky & Potter, 2000). Previous research documented that listeners remember the key and tempo of familiar recordings heard multiple times, including favored pop songs (Levitin, 1994; Levitin & Cook, 1996), themes from television shows and movies (Schellenberg & Trehub, 2003; Schellenberg et al., 2008; Trehub et al., 2008), and in the case of infants, expressively sung lullabies (Volkova et al., 2006). The present findings go much further by providing evidence of memory for the key and tempo of melodies heard twice. The recordings in the earlier studies comprised multiple instruments and/or singing with words. By contrast, the present stimuli were monophonic sequences of piano tones taken from collections of folk melodies. Although our stimulus melodies may seem impoverished in this respect, they were nonetheless ecologically valid in the sense that they were real melodies played on a familiar instrument with a regular beat (or meter). Moreover, melodies without words or harmony (e.g., someone whistling or humming a tune) are common in everyday life. In the future, one could test whether memory for melodies played on a single instrument is exaggerated because recognition relies on whatever cues are available.

Although other researchers have examined memory for melodies presented in transposition, their goal was to examine memory for abstract features (i.e., pitch relations; e.g., Bartlett & Dowling, 1980; Dowling & Bartlett, 1981; Dowling & Fujitani, 1971; Halpern, 1984; Halpern, Bartlett, & Dowling, 1995; Van Egmond et al., 1996) or whether some pitch relations are remembered better than others (Schellenberg, 2001; Schellenberg & Trehub, 1996, 1999). Because any change in relative pitch involves a change in absolute pitch, studies of relative pitch are compelled to present melodies in transposition to exclude the possibility that listeners are simply detecting a note that has been shifted in pitch rather than a change in pitch relations.

Future research could examine whether memory for the surface features of melodies is evident across a longer delay (e.g., a day, week, or month). Another unanswered question involves the extent to which melodies need to be shifted in key or tempo to cause a decrement in recognition, which would, in turn, provide a measure of the accuracy of listeners' memory for these surface features. In our view, very small changes, say on the order of half a semitone or 5 bpm, are almost certain not to influence recognition. In other words, listeners' memory for key or tempo is unlikely to be very exact. In the study by Schellenberg and Trehub (2003), listeners were 58 and 70 % correct (chance = 50 %) at determining which of two versions of the same excerpt from a TV theme song was at the correct pitch when the foil was transposed by 1 or 2 semitones, respectively. Although performance was better than chance in both conditions, it was closer to chance than to perfect, particularly in the case of 1-semitone transpositions. We presume that memory for the key of MIDI-generated piano melodies would be less exact than for recordings with multiple instruments because the melodies have much less spectral information. One possible starting point would be to compare recognition of melodies transposed by 0, 2, 4, 6 or 8 semitones. In previous research with transpositions that varied in size (Bartlett & Dowling, 1980; Van Egmond et al., 1996), there was no condition with melodies that were not transposed, and the focus was on short-term memory as revealed by same/different judgments. It would be particularly interesting to determine whether the accuracy of long-term melodic memory is a negative linear function of transposition size, or, alternatively, whether transpositions have a deleterious effect only when they exceed a certain threshold.

As for tempo, our findings indicate that the threshold for tempo memory is smaller than a change of 64 bpm. In an earlier study (Halpern & Müllensiefen, 2008), decrements in melody recognition were evident with even smaller changes in tempo (18–24 bpm). Our use of a relatively large tempo change in the present study was motivated by our goal of making it approximately equivalent to the key change in psychological magnitude. Future research could also consider timbre changes in conjunction with key and/or tempo changes to provide a more complete account of memory for the surface features of music. One might also ask these sorts of questions in reverse and test the extent to which surface features can be changed and leave a melody's identity recognizable. Although both key and tempo manipulations in the present experiments were relatively large, melodies shifted in key and/or tempo received higher recognition ratings than new melodies (see Figs. 2, 3). We speculate that listeners would continue to recognize the abstract features that define a melody under more extreme changes. In a study of recognition for familiar melodies presented in a piano timbre (Andrews, Dowling, Bartlett, & Halpern, 1998), listeners were successful with tempi as slow as approximately 20 bpm (almost 3 s per note) or as fast as 300 bpm (less than 200 ms per note), with better performance observed among musically trained listeners. For successful recognition of familiar melodies presented with pure tones, however, tempo manipulations cannot be so extreme (Warren, Gardner, Brubaker, & Bashford, 1991).

Our results also serve to de-mystify AP and its ontogeny. At the very least, we can be certain that adult listeners recruited without regard to music training have memory for approximate key, which they use as a cue to melody recognition. Combined with findings of memory for the key of richer musical stimuli among listeners of all ages (Levitin, 1994; Schellenberg & Trehub, 2003; Schellenberg et al., 2008; Trehub et al., 2008, Volkova et al., 2006), it is clear that the mystery of AP involves not pitch memory per se, but rather the ability to link arbitrary note names to musical pitches. The proposed trajectory from absolute to relative pitch processing over development (Takeuchi & Hulse, 1993) also needs to be reconsidered in light of memory for key (cited above) and for pitch relations (e.g., Plantinga & Trainor, 2005; Schellenberg & Trehub, 1996, 1999) among listeners of all ages. Nevertheless, although both forms of pitch processing may be evident across the lifespan, the perceptual salience of pitch relations as opposed to key may indeed increase with increasing age and exposure to music. For example, 6-year-olds consider the same melody presented in transposition to be as dissimilar as two different melodies, whereas adults consider two different melodies to be equally dissimilar whether or not they comprise the same pitches (Stalinski & Schellenberg, 2010).

Our other main result was that key and tempo functioned additively in their influence on melody recognition. An overview of the literature makes it clear that pitch and temporal dimensions of music are additive in some contexts but interactive in others, such that a strict either/or debate may be counter-productive (Prince, Thompson, et al., 2009). Our experiments are arguably more ecologically valid, however, than many others that explored this question. For example, although it is doubtful that long-term representations of music contain much if any information about individual notes or chords, previous studies focused on memory for a single tone (e.g., Jones et al., 1982, 2002, 2006; Prince, Schmuckler, et al., 2009), evaluations of single tones following a musical context (Prince, Thompson, et al., 2009), or evaluations of music that varied in its final tone (Palmer & Krumhansl, 1987a) or chord (Palmer & Krumhansl, 1987b). Other researchers examined memory for impoverished tone sequences (Boltz, 1998, 2011). In the present context of testing memory for entire melodies, key and tempo cues to recognition were clearly additive rather than interactive.

Studies of *congenital amusia* provide additional evidence of independent processing of pitch and time in music (Peretz, 2008). Amusics typically get little enjoyment from music and perform poorly on tests of music aptitude despite normal IQ and hearing, typical exposure to music in childhood, and no brain damage after birth. When presented with an isochronous sequence of five repeated tones, they demonstrate poorer performance than controls at identifying whether the fourth tone is displaced in pitch by one semitone or less (Hyde & Peretz, 2004), even though they exhibit sensitivity to harmonic relations (Tillmann, Gosselin, Bigand, & Peretz, 2012) and neural responses to even smaller (quarter-tone) pitch changes (Peretz, Brattico, Järvenpää, & Tervaniemi, 2009). In fact, amusia appears to be the specific consequence of a fine-grained and selective deficit in pitch perception because affected individuals perform as well as controls when the task is changed to ask whether the fourth tone in a five-tone isochronous sequence is displaced slightly in time (Hyde & Peretz, 2004). Amusics' deficit in pitch perception impairs music perception and enjoyment more generally because changes of one semitone are important in Western music (i.e., in the major scale, *mi* and *fa* are separated by one semitone, as are *ti* and *do*). Amusia has also been linked with abnormal brain structure and function (Hyde, Zatorre, & Peretz, 2011; Loui, Alsop, & Schlaug, 2009). Other studies of patients with brain damage report cases of poor pitch processing with intact rhythm perception, and of poor rhythm perception with intact pitch processing (for a review see Peretz & Zatorre, 2005).

To conclude, melody recognition is an intricate interplay between abstract features that define a melody and surface features that are specific to individual renditions. Changes in surface features—specifically key and tempo—impair the ability of participants to recognize a previously heard melody. Such changes appear to have additive effects, which suggest that key and tempo are processed and stored independently in long-term memory.

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