Mem Cogn (2014) 42:1302–1314
DOI 10.3758/s13421-014-0434-x

Testing the absolute-tempo hypothesis: Context effects for familiar and unfamiliar songs

Matthew A. Rashotte · Douglas H. Wedell

Published online: 28 June 2014

Abstract In two experiments, we investigated context effects on tempo judgments for familiar and unfamiliar songs performed by popular artists. In Experiment 1, participants made comparative tempo judgments to a remembered standard for song clips drawn from either a slow or a fast context, created by manipulating the tempos of the same songs. Although both familiar and unfamiliar songs showed significant shifts in their points of subjective equality toward the tempo context values, more-familiar songs showed significantly reduced contextual bias. In Experiment 2, tempo pleasantness ratings showed significant context effects in which the ordering of tempos on the pleasantness scale differed across contexts, with the most pleasant tempo shifting toward the contextual values, an assimilation of ideal points. Once again, these effects were significant but reduced for the more-familiar songs. The moderating effects of song familiarity support a weak version of the absolute-tempo hypothesis, in which long-term memory for tempo reduces but does not eliminate contextual effects. Thus, although both relative and absolute tempo information appear to be encoded in memory, the absolute representation may be subject to rapid revision by recently experienced tempo-altered versions of the same song.

Keywords Music cognition · Context effects · Memory · Judgment

Music can reward listeners by creating the paradoxical experience of hearing something novel and familiar at the same time (Marcus, 2012). For instance, the famous four-note introduction to Beethoven's 5th Symphony is repeated throughout and becomes very familiar to the listener, but the experience also contains novelty when heard across different notes and tempi. In the popular-music domain, a sense of familiarity is generated by hearing the same melody over and over throughout the song, whereas novelty is generated by hearing different lyrics or instruments over the familiar melody. These experiences suggest that listeners have access to information in long-term memory that describes the absolute and relative features of music. Absolute features include absolute pitch, tempo, and timbre. Relative features include interval and contour information. Accessing interval and contour information plays an integral role in the experience of music. For instance, relative codes allow listeners to recognize songs such as *Happy Birthday* and *Here Comes the Bride* when they are played at novel tempi, pitches, or timbres. Evidence for the relative coding of music in long-term memory was established long ago by early researchers in music cognition (Attneave & Olson, 1971; Cuddy & Cohen, 1976; Dowling & Bartlett, 1981; Sloboda, 1985).

The degree to which long-term memory for music also includes fine-grained details such as absolute pitch and tempo values has also been a topic of scientific investigation. For instance, Levitin (1994) and Levitin and Cook (1996) found evidence that pitch and tempo are stored in great detail in listeners without extensive musical training. Levitin and Cook asked participants to sing from memory some of their favorite rock songs that they had not heard for at least several days. Most of the singing performances were fairly accurate, with 72 % of the participants being within 4 % of the original tempo. The researchers argued that these results supported an absolute-tempo hypothesis, according to which "long-term memory for tempo is very accurate and is near the discrimination threshold (as measured by [just noticeable differences] JND's) for variability in tempo" (p. 931). Levitin analyzed these same song reproductions for pitch accuracy and found that 67 % of the reproductions were within two semitones of the original version, suggesting that

M. A. Rashotte (✉)
Extended University at the University of South Carolina,
901 Sumter St., Byrnes 6th Floor, Columbia, SC 29208, USA
e-mail: Rashotte@sc.edu

D. H. Wedell
Department of Psychology, University of South Carolina, Columbia,
SC 29208, USA

pitches are also represented in long-term memory by absolute encoding. However, Moelants, Styns, and Leman (2006) challenged this interpretation, suggesting instead that participants chose songs that closely fit their vocal range, which improved their chances of reproducing the pitches heard on the recording. In support of this, they found lower levels of pitch accuracy when participants were given a list of nine popular songs to sing, including *Y.M.C.A.* and *Don't Worry Be Happy*. Furthermore, they found lower levels of tempo accuracy than had Levitin and Cook.

In addition to evidence for absolute tempo that is based on reproduction tasks that involve motor feedback, other researchers have found evidence that surface features of musical pitch are represented in long-term memory using music recognition tasks. For instance, Schellenberg and Trehub (2003) asked participants to discriminate between the original version of a popular all-instrumental TV theme song (e.g., *The Simpsons*) and pitch-altered versions that were shifted by one and two semitones. Their results showed that participants could identify the original version from the one-semitone-altered version at a slightly better than chance level, with discrimination performance improving for the two-semitone-altered version. Recently, Schellenberg, Stalinski, and Marks (2013) used a recognition task to show that listeners form memories for novel melodies that contain surface features such as pitch and tempo after only a couple of exposures.

Other researchers have tested memory for musical tempo by asking participants to make judgments of tempo-altered versions of a song. This approach utilizes music software to change the tempo of a song without its changing pitch. For instance, Straub et al. (2006) created tempo-altered versions of popular TV theme songs (e.g., *Knight Rider* and *X-Files*) that were 10 % and 30 % faster than the originals (i.e., 0 %). All participants were asked to recognize the original version relative to the 10 % faster version. However, half of the participants first listened to the 30 %-faster version and then made their judgments. Exposure to this extreme tempo-altered version significantly reduced participants' ability to discriminate the original-tempo version from the 10 %-faster version. The average correct rejection rate of the 10 %-faster version decreased from 68 % to 28 % after listening to the 30 %-faster version. Straub et al. interpreted these results as evidence that "Participants seem to rapidly integrate new auditory information into a flexible mental representation by means of quick context-driven updating" (p. 5).

This type of rapid updating in memory is consistent with models of recognition based on global assessment of familiarity to instances stored in memory (Hintzman, 1986; Nosofsky & Zaki, 2002), assuming that recent memory traces are more accessible at retrieval and, hence, shift the global representation toward recent values. Because the recently experienced 30 %-tempo-altered version has the same relative structure as the original, its values are retrieved along with the many other instances from long-term memory. Although it should be down-weighted due to its low frequency of occurrence, the results of Straub et al. (2006) suggest that recent instances are overweighted, and hence the remembered tempo value shifts toward the recently experienced tempo-altered values.

The results of Straub et al. (2006) imply that recently encountered contextual tempo clips can have a strong effect on memory for tempo of familiar songs, and thereby this finding puts in question the nature of the absolute-tempo hypothesis. A strong version of the hypothesis would imply that tempo is encoded in an absolute manner for highly familiar songs, and thus should not be subject to rapid contextual alteration. Alternatively, a weaker version of the absolute-tempo hypothesis implies that increased song familiarity will reduce but not altogether prevent rapid contextual shifts in the remembered tempo values. These versions can therefore be distinguished by considering the moderating role of song familiarity.

Other recent research has shown strong effects on tempo judgments and pleasantness-of-tempo judgments to Beatles songs after exposure to tempo-altered versions (Rashotte & Wedell, 2012). In one experiment, participants listened to 12 tempo-altered clips of the Beatles song *Sgt. Pepper's Lonely Hearts Club Band* and either made tempo ratings (1 = *very slow tempo* to 9 = *very fast tempo*) or tempo pleasantness ratings (1 = *very unpleasant tempo* to 9 = *very pleasant tempo*). All participants listened to the same set of five "target" tempo clips (–12 %, –6 %, 0 %, 6 %, and 12 %). However, half of the participants were exposed to a fast context by including seven fast contextual clips (+9 %, +15 %, +18 %, +21 %, +24 %, +27 %, and +30 %). The other half was exposed to a slow context by including seven slow contextual clips (–9 %, –15 %, –18 %, –21 %, –24 %, –27 %, and –30 %). The effect of these contextual tempo clips on judgments was assessed through the common set of target clips. The results showed the average tempo judgments of the five target clips were faster in the slow context and slower in the fast-context group. This type of contrast effect has typically been found in ratings of nonmusical stimuli along a host of different dimensions (for a review, see Wedell, Hicklin, & Smarandescu, 2007). Some research has suggested that these shifts in tempo ratings could be due to response or linguistic factors, rather than to changes in perception (Erlebacher & Sekuler, 1971; Poulton, 1979). Inconsistent with this interpretation, the five target clips had different orderings of tempo pleasantness ratings in the fast and slow contexts. Specifically, the original-tempo version (0 %) was judged as being significantly more pleasant than the +6 %-tempo version in the slow context, but this relationship was reversed in the fast context. These disordinal effects of context are difficult to explain away in terms of response bias.

One result from the Rashotte and Wedell (2012) study that was perplexing was that participants' levels of familiarity with the Beatles song being judged did not reduce the context effects for either tempo or tempo pleasantness judgments in any of the three experiments. These results are difficult to explain in terms of the absolute-tempo hypothesis, since one would predict that participants most familiar with the songs would show reduced context effects, since the absolute values are more firmly established in memory. The two experiments that we report were designed to further investigate the role of song familiarity in moderating context effects and to more carefully test the different versions of the absolute-tempo hypothesis in two important ways. First, it may be that none of the participants in our earlier studies were sufficiently familiar with the Beatles songs, or at least had not listened to them extensively enough to form an absolute representation. To maximize the effects of familiarity, we conducted a survey and selected four major recording artists who had a song that nearly all of the respondents found highly familiar and had listened to frequently. We matched these familiar songs with songs by the same artist at nearly the same tempo, but that had been rated as being very unfamiliar by the respondents. Hence, we manipulated familiarity within subjects at an extreme level by varying song but keeping artist and tempo constant.

Second, we changed our tempo judgment task to a comparative judgment in which participants judged whether the presented tempo was faster or slower than the original. This procedure was likely to reduce or eliminate response and linguistic biases in judgments. With these new stimuli and judgment procedures, we were better able to test the strong and weaker versions of the absolute-tempo hypothesis. According to both versions, familiarity should lead to a reduction in contextual effects, since the representations in long-term memory for the tempos of familiar songs are well established. According to the strong version, context effects should only be found for the unfamiliar songs. In Experiment 1, we tested these hypotheses using comparative tempo judgments. The results from Rashotte and Wedell (2012) demonstrated dissociative context effects on tempo judgments and pleasantness judgments, indicating that different contextual mechanisms drive these two measures. Therefore, we conducted Experiment 2 as an additional test of these hypotheses, using pleasantness ratings rather than comparative tempo judgments, to examine whether the moderating effects of familiarity would differ for these two measures using the present musical stimuli.

Experiment 1

The purpose of Experiment 1 was to study the effects of context on songs varying in familiarity, and hence potentially in their long-term memory representations for tempo. Prior to the experiment, in a survey we asked a different set of participants to rate songs from many recording artists in terms of familiarity, frequency of listening, and ability to sing the song from memory, using 5-point scales. From this survey, we selected four artists, each with a very familiar and an unfamiliar song that were closely matched in tempo, although the tempos across artists varied widely. A short clip of approximately 8 s was taken from each song's chorus, and using software we manipulated the tempi without changing pitch. Our experimental procedure presented these tempo-altered song clips for the participant to judge in two stages. In Stage 1, they indicated whether the clip was faster or slower than the original. In Stage 2, they indicated how much faster or slower. Our manipulation of context was between subjects and consisted of presenting a preponderance of faster or slower versions of the song clips to participants. A strong version of the absolute-tempo hypothesis would predict no significant effects of context on participants' ability to judge whether the tempo-altered clip was faster or slower than the original for highly familiar songs, although the unfamiliar songs were predicted to show context effects and a Context × Familiarity interaction. A weaker version of the absolute-tempo hypothesis also predicted this two-way interaction, although it would allow context effects also to be significant for the highly familiar songs. Finding no moderating effects of song familiarity would be inconsistent with the absolute-tempo hypothesis.

Method

Participants and design The participants were 58 undergraduates from the University of South Carolina who received course credit for participating. The experiment had a 2 (Context) × 2 (Block) × 2 (Familiarity) × 5 (Target) factorial design. Half of the participants were randomly assigned to the fast context, and half to the slow context. The four artists chosen from the pretest survey were Eminem, Lady Gaga, Outkast, and the Black Eyed Peas. The artists' familiar and unfamiliar songs were matched closely in terms of beats per minute (BPM), as is shown in Table 1. From the original-tempo version, four clips with tempos –30 %, –27 %, –24 %,

Table 1 Songs used in Experiments 1 and 2, along with their tempo information.

Artist	Familiar Song (BPM)	Unfamiliar Song (BPM)
Eminem	My Name Is (86)	Rock Bottom (92)
Black Eyed Peas	Let's Get it Started (105)	The Boogie that Be (105)
Lady Gaga	Poker Face (119)	Electric Chapel (128)
Outkast	Hey Ya! (160)	PJ & Rooster (186)

BPM = Beats per minute

and –18 % slower than the original were created, and these made up the slow context. The fast context consisted of four clips with tempos 30 %, 27 %, 24 %, and 18 % faster than the original. Five clips with tempos of –12 %, –6 %, 0 %, 6 %, and 12 % were created and designated as the "target" clips. All participants heard the five target clips along with either four fast or four slow context clips. In two test blocks, the five target and four context clips were randomly presented to participants. Participants were not aware of the difference between target and contextual clips.

Materials and apparatus Desktop computers with 17-in. monitors and audio headphones that covered the ear and provided a high-quality listening experience were used to present all of the experimental materials. The clips from the eight songs were taken from compact discs and copied to a computer as WAV files and edited using Audacity audio software. The clip taken from the familiar Eminem song "My Name Is" was 8 s long and included the lyrics, "Hi! My name is . . . what? My name is . . . who? My name is . . . Slim Shady. Hi! My name is . . . huh? My name is . . . what?" The clip taken from the unfamiliar Eminem song "Rock Bottom" was 9 s long and included the lyrics, "That's rock bottom, when this life makes you mad enough to kill, that's rock bottom, when you want something bad enough to steal, that's rock bottom, when you feel that you have had it up to here, cause you mad enough to scream." The clip taken from the familiar Lady Gaga song "Poker Face" was 8 s long and included the lyrics, "Can't read my, can't read my, no he can't read my poker face, she's got to love nobody." The clip taken from the unfamiliar Lady Gaga song "Electric Chapel" was 7 s long and included the lyrics, "If you want me meet me at Electric Chapel, at Electric Chapel." The clip taken from the familiar Outkast song "Hey Ya!" was 8 s long and included the lyrics, "Heeeyyy . . . Yaaaaaaa., Heeyy Yaaaaaaaa." The clip taken from the unfamiliar Outkast song "PJ & Rooster" was 9 s long and included the lyrics, "Nobody wanted to dance, when I had a lot of time on my hands, now I got a lot of hands on my time, and everybody wanna be a friend of mine." The clip taken from the familiar Black Eyed Peas song "Let's Get It Started" was 9 s long and included the lyrics, "Let's get it started (ha), let's get it started in here, let's get it started (ha), let's get it started in here." The clip taken from the unfamiliar Black Eyed Peas song "The Boogie That Be" was 8 s long and included the lyrics, "Bounce boo to the boogie that be, you know I want you to come boogie with me." These original song clips were used to create tempo-altered clips that served as the contextual and target tempos, with the *Change tempo without changing pitch* function in Audacity. Altering the tempo of the original clip to a slower tempo increased the clip duration by several seconds, whereas changing to a faster tempo decreased the clip duration by several seconds. The results of altering the clips in terms of BPM are shown in Table 2. E-Prime software was used to administer the experiment and to collect tempo judgments.[1]

Procedure Participants were tested in groups of up to four in a large laboratory room with computers spaced about 2 m apart. Figure 1 shows how participants completed each step of the experiment. The instructions informed participants that they would hear tempo-altered clips from eight songs by four artists, with some clips being familiar and others unfamiliar. After each clip, participants judged whether the clip was faster or slower than the original (binary comparative judgments) and then indicated how much faster or slower (graded comparative judgments), as is shown in Fig. 1. The experimental trials began with a song chosen randomly from the set of eight songs. Participants then clicked the mouse to listen to the original-tempo version clip (i.e., 0 % tempo change, or "distortion") in order to familiarize or refamiliarize them with the song. Then, the four context and five target clips were presented randomly in the first test block, followed by a second test block with a different random ordering. Therefore, the full set of trials for a given song was 18, with the first test block of nine trials averaging less contextual exposure, sincee the four context and five target clips were randomly interspersed. By the second block, the full set of four contextual clips would have been sampled. Afterward another song was randomly selected, and the process was repeated until all eight songs had been tested. Following the experimental trials, participants were presented with the name and artist of each song clip that they had heard and were asked to indicate their level of familiarity with each song before the experiment began on three rating scales: familiarity, frequency, and singability. The familiarity scale was anchored by 0 = *not at all familiar* to 4 = *very very familiar*. The frequency scale was a six-category scale, with 0 = *never heard the song*, 1 = *heard the song less than 10 times*, 2 = *heard the song between 10 and 50 times*, 3 = *heard the song between 50 and 100 times*, 4 = *heard the song between 100 and 200*, and 5 = *heard the song more than 200 times*. The singability scale was a five-point scale spanning 0 = *can't sing any of the song*, 1 = *can sing only a couple of words*, 2 = *can sing the main part but not other parts*, 3 = *can sing the main parts and other parts*, and 4 = *can sing almost the entire song*.

[1] Note that digitally speeding or slowing the tempo can create artifacts such as subtle changes in pitch and rhythm. Such artifacts may enable the participant to better detect the original clip, presumably reducing contextual effects. However, differences due to any such perceptual artifacts should be the same for familiar and unfamiliar songs, and thus did not confound our interpretation of the main independent variables.

Table 2 Percentages of tempo distortion change (in beats per minute) for the contextual and target song clips used in Experiments 1 and 2

Song Type	% Change	Eminem		Black Eyed Peas		Lady Gaga		Outkast	
		F MYN	U RB	F LGS	U BTB	F PF	U EC	F HY	U PJ&R
SC	–30	60	64	74	74	83	90	112	130
SC	–27	63	67	77	77	87	93	117	136
SC	–24	65	70	80	80	90	97	122	141
SC	–18	71	75	86	86	98	105	131	153
T	–12	76	81	92	92	105	113	141	164
T	–6	81	87	99	99	112	120	150	175
T	0	86	92	105	105	119	128	160	186
T	6	91	98	111	111	126	136	170	197
T	12	96	103	118	118	133	143	180	208
FC	18	102	109	124	124	140	151	189	220
FC	24	107	114	130	130	148	159	198	231
FC	27	109	117	133	133	151	163	203	236
FC	30	112	120	137	137	155	166	208	242

SC = slow context, T = target, FC = fast context; % Change = percentage that the original tempo was speeded up or slowed down; F = familiar song; U = unfamiliar song. MYN = My Name Is; RB = Rock Bottom; LGS = Let's Get It Started; BTB = Boogie That Be; PF = Poker Face; EC = Electric Chapel; HY = Hey Ya!; PJ&R = PJ & Rooster.

Results

The three familiarity rating scales showed strong differences between the songs, as we had expected from the pretesting survey. The familiarity, frequency, and singability ratings were close to the bottom of the scales for the four songs predicted to be unfamiliar, and near the top of the scales for the four songs predicted to be familiar, as is shown in Fig. 2. The Eminem song "My Name Is" was slightly less familiar to undergraduates than were the other three familiar songs.

The binary comparative judgments for each tempo clip of the four familiar songs were averaged together and compared to the corresponding averages of the four unfamiliar songs, as is shown in Fig. 3. The top two panels describe the proportions of times that each tempo clip distortion level was judged to be faster than the original tempo for familiar songs across test blocks. The bottom two panels show these relationships for the unfamiliar songs. The psychometric functions for the fast context are shifted to the right of those for the slow context, reflecting an assimilative shift of the point of subjective equality (PSE), which is the tempo value corresponding to a .5 proportion on the psychometric function. In each panel, the PSE for the slow context is below zero (i.e., a song was remembered as having a tempo slower than the original), and the PSE for the fast context is above zero. Consistent with both versions of the absolute-tempo hypothesis, these effects appear larger for the unfamiliar songs than for the familiar songs. With increased exposure across test blocks to the contextual songs, the effects of context increased for both familiar and unfamiliar songs. Inconsistent with a strong version of the absolute-tempo hypothesis, the effects of context appear strong and reliable for highly familiar songs.

These effects were statistically tested by a repeated measures analysis of variance (ANOVA) conducted on the PSE computed for each participant. The PSE was computed by fitting a logistic function to each participant's data in each of the four conditions (first-block familiar songs, second-block familiar songs, first-block unfamiliar songs, and second-block unfamiliar songs), using only the target stimuli.[2] The 2 × 2 × 2 (Context × Familiarity × Block) ANOVA resulted in three significant effects. The main effect of context was significant, $F(1, 56) = 328.2$, $p < .001$, $\eta_p^2 = .854$, with the PSE being slower than the original tempo in the slow context ($M = –6.13$) and faster in the fast context ($M = 4.35$). We also found a significant Context × Familiarity interaction, $F(1, 56) = 10.12$, $p < .01$, $\eta_p^2 = .153$, with the PSE difference across contexts being significantly greater for unfamiliar songs ($M_{Fast} = 4.64$ and $M_{Slow} = –7.29$) than for familiar songs ($M_{Fast} = 4.06$ and $M_{Slow} = –4.96$). Finally, the Context × Block interaction was

[2] We used only the five targets to estimate PSEs so that the estimates would not be biased by inclusion of contextual values that differed across conditions. If the estimated PSE was outside the range of the target values (–12 % to 12 %), it was replaced by the closest extreme target value (–12 % or 12 %), since extrapolated values are unreliable. Note that only three participants had PSE values beyond the target range. As an index of fit, the majority of R^2 values for these estimates across participants were greater than .90.

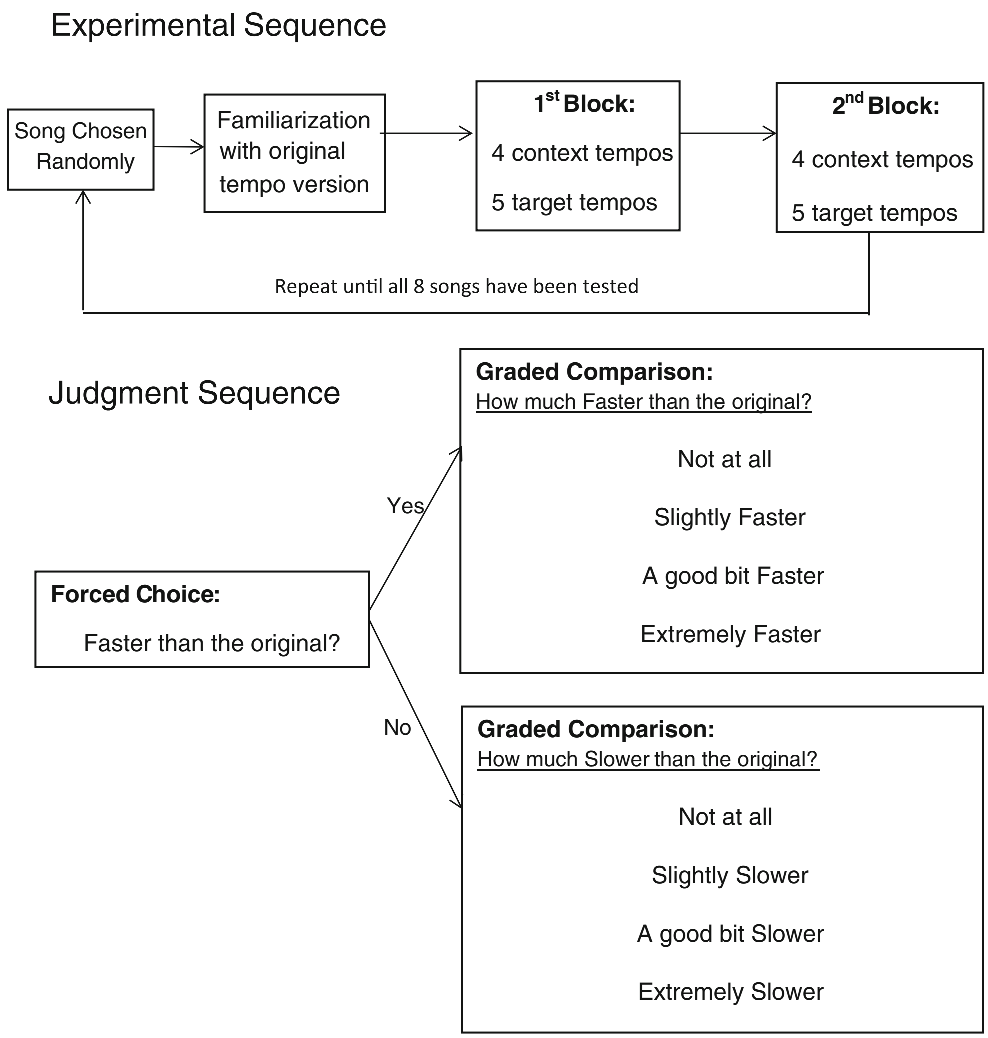

Fig. 1 Experimental and judgment sequences

significant, $F(1, 56) = 13.39$, $p < .001$, $\eta_p^2 = .193$, indicating that the effect of context increased from the first block ($M_{Fast} = 3.50$ and $M_{Slow} = -5.47$) to the second block ($M_{Fast} = 5.19$ and $M_{Slow} = -6.78$).

A repeated measures ANOVA was conducted on the discriminability index for each participant from the logistic fit to their data described above. The only significant effect was a main effect of familiarity, $F(1, 56) = 6.11$, $p < .05$, $\eta_p^2 = .098$, with discriminability being greater for the familiar songs. To quantify this effect, we used the group data shown in Fig. 3 to calculate the relative JNDs for familiar and unfamiliar songs. For familiar songs the relative JND was 3.95, and for unfamiliar songs it was 4.57. This difference corresponds to the generally steeper slopes of the functions for the familiar songs.

As a test of the strong version of the absolute-tempo hypothesis, independent-samples t tests of the context manipulation on the PSE for each block were conducted. In each case, the effect of context was significant at $p < .001$. Thus, even familiar songs showed significant effects of context on PSE.

The PSE analyses were based on binary judgments that did not allow for evaluating the tempo clip as being equal to the original, and so may have some resultant bias. Therefore, a second set of analyses were based on the graded-comparison judgments, in which participants indicated how much faster or slower the tempo of the clip was, relative to the original tempo (see Fig. 1). These judgments were quantified as –3, –2, –1, 0, 1, 2, and 3. The averages of these judgments for each tempo clip distortion level across the four familiar and four unfamiliar songs are shown in Fig. 4. The five target clips were analyzed with a 2 × 2 × 2 × 5 (Context × Familiarity × Block × Target) repeated measures ANOVA. This analysis produced the same three significant effects we had found for the PSE results: a main effect of context, $F(1, 56) = 318.1$, $p < .001$, $\eta_p^2 = .850$; a

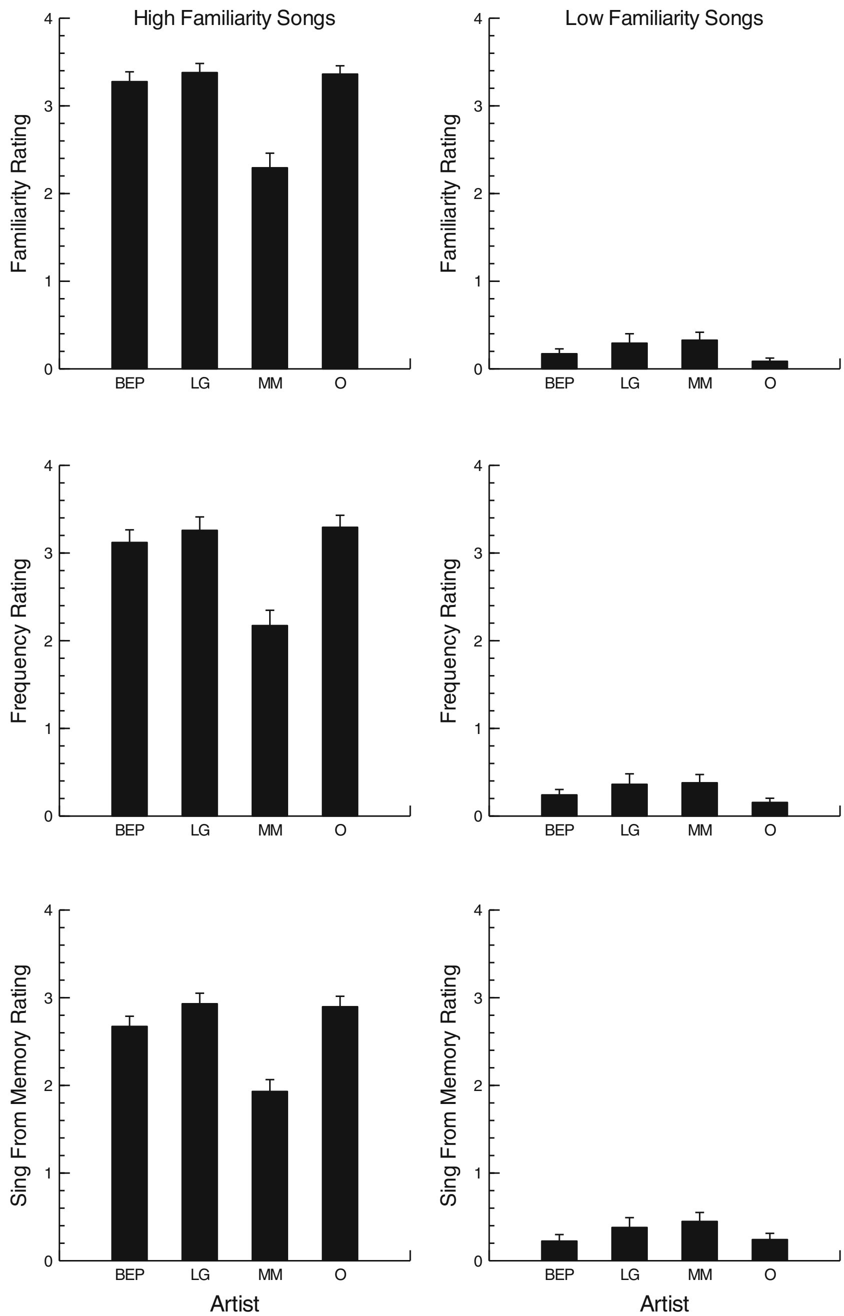

Fig. 2 Experiment 1: Ratings of familiarity, frequency, and singability for the high- and low-familiarity songs. BEP = Black Eyed Peas, LG = Lady Gaga, MM = Eminem, O = Outkast

Context × Familiarity interaction, $F(1, 56) = 21.2$, $p < .001$, $\eta_p^2 = .275$; and a Context × Block interaction, $F(1, 56) = 73.5$, $p < .001$, $\eta_p^2 = .568$. The relevant means are shown in Table 3. Additionally, we observed a main effect of familiarity, $F(1, 56) = 9.1$, $p < .01$, $\eta_p^2 = .140$ (in which unfamiliar songs were rated higher than familiar songs) and a main effect of target, $F(4, 224) = 836.8$, $p < .001$, $\eta_p^2 = .800$, reflecting the higher judgments given the faster targets. This effect was primarily in the linear component, $F(1, 56) = 1{,}250.3$, $p < .001$, $\eta_p^2 = .957$, although we also found a significant cubic component, $F(1, 56) = 12.2$, $p < .001$, $\eta_p^2 = .179$. A significant Familiarity × Target interaction also emerged, $F(4, 224) = 5.1$, $p < .001$, $\eta_p^2 = .083$, reflecting steeper functions (i.e., greater discriminability) for the familiar songs. Finally, a Familiarity × Target × Context interaction was apparent, $F(4, 224) = 3.6$, $p < .01$, $\eta_p^2 = .060$, reflecting that the change in steepness occurred primarily in the slow context.

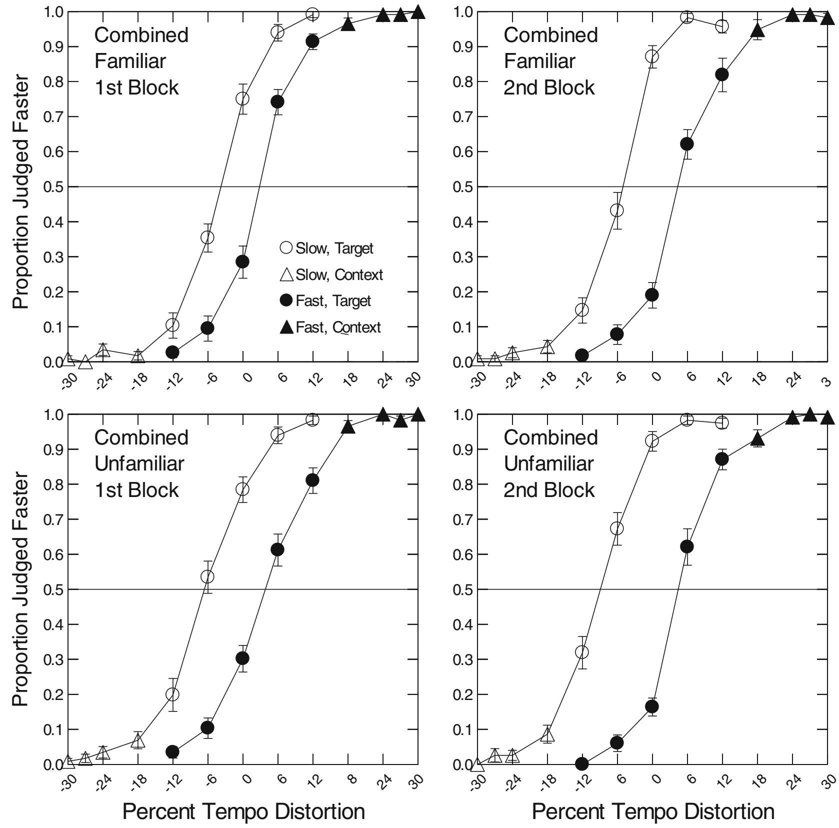

Fig. 3 Experiment 1: Binary comparative judgments of target tempo to the original tempo held in memory, as a function of context, familiarity, and test block. The point of subjective equality (PSE) for each function is the tempo value corresponding to where the function crosses the .5 value. Context effects are pervasive. Targets are shown as circles and contextual stimuli as triangles, and bars represent standard errors

Discussion

The goal of this experiment was to test strong and weak versions of the absolute-tempo hypothesis. A strong version predicted that highly familiar songs would show no contextual bias in tempo judgments, whereas a weak version predicted significant contextual bias for familiar songs. Both versions predicted reduced bias for familiar songs relative to unfamiliar songs, due to an enduring representation for familiar songs. Participants already had been exposed to the highly familiar songs many times before the experiment began, whereas the participants had very low levels of exposure, if any at all, to the unfamiliar songs. On the basis of the frequency rating scale, participants estimated that they had heard the familiar songs between 50 and 100 times, whereas only several exposures were reported for the unfamiliar songs. The singability scale estimates indicated that participants could sing the main parts and other parts of the familiar songs from memory, whereas participants estimated that they could only sing a single word of the unfamiliar songs.

The procedure for testing absolute tempo memory was based on having participants indicate whether each tempo clip version of the song was faster or slower than the original tempo, which had been presented just prior to the first test block. This technique for evaluating memory for tempo was different from those of previous investigators (Bailes & Barwick, 2011; Bergeson & Trehub, 2002; Levitin & Cook, 1996; Moelants et al., 2006) because it did not rely on reproducing the tempo by singing. This may constitute a stronger test of the hypothesis for three reasons. First, we manipulated context so that systematic errors in memory could be demonstrated, but prior research had not. Second, testing perceptual judgments of tempo may be more sensitive than procedures involving singing, which participants may be reluctant to do. Finally, production tasks may be self-correcting and based on motor memory instead of perceptual memory, and hence may obscure systematic distortions of memory.

The results clearly favored a weak version of the absolute-tempo hypothesis over the strong version. We found highly significant effects of context on the PSE and graded comparison judgments for very familiar pop songs, indicating a deviation from absolute tempo memory. Consistent with the weak version of the hypothesis, we found a significant Context × Familiarity interaction, indicating that context effects were moderated by familiarity, such that highly familiar songs were less susceptible to contextual bias, and hence must

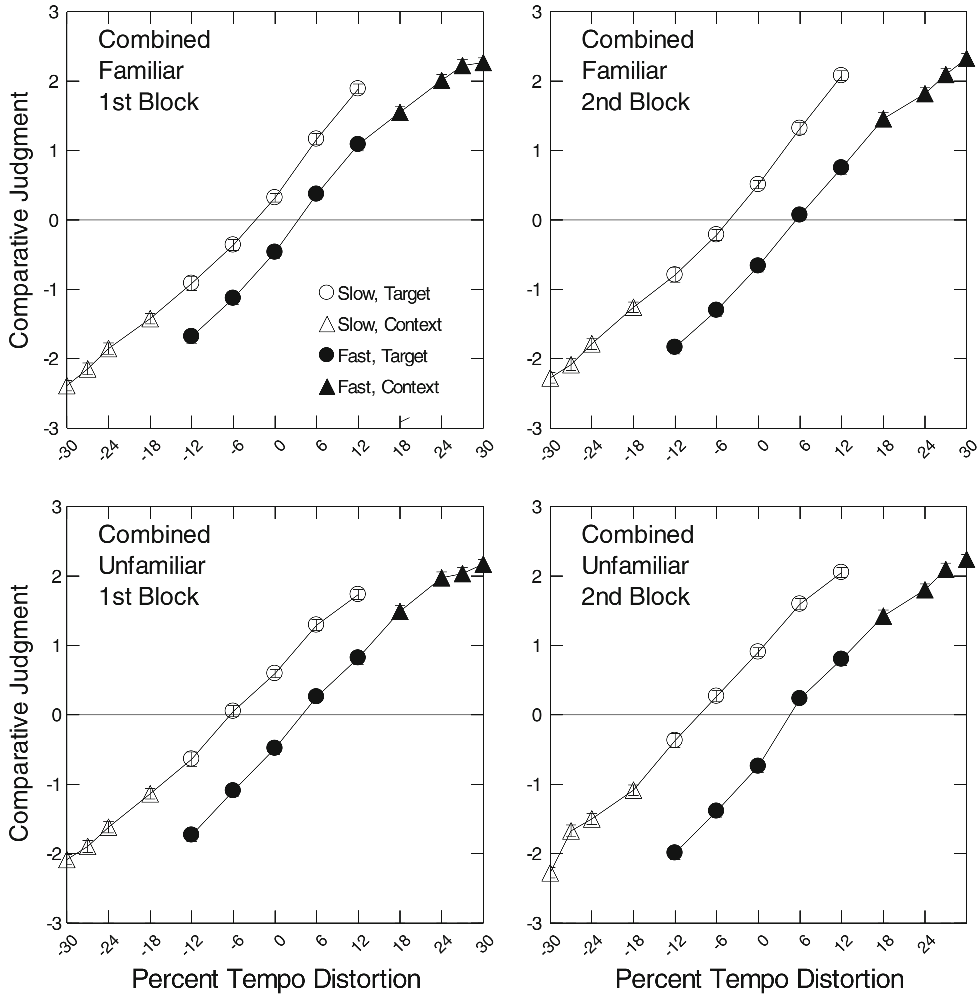

Fig. 4 Experiment 1: Graded comparative judgments as a function of familiarity, context, test block, and tempo distortion. Contextual shifts are significant in each panel, but they increase with test block and song unfamiliarity. Targets are shown as circles and contextual stimuli as triangles, and bars represent standard errors

have more-stable memory representations. The significant Block × Context effect indicated that as participants were exposed to more contextual versions, their memory for the original tempo was less accessible, and hence bias increased.[3]

One may argue that our results should be tempered by the fact that most of the bias effects were within two JNDs of the original. Levitin and Cook (1996) used a criterion for absolute memory performance as performance lying between one and two JNDs of the original tempo. Other researchers have suggested stricter criteria, according to which memory should be within one JND (Bailes & Barwick, 2011). Using the JNDs reported in the results, the PSE shift in the slow context was –1.26 JND and in the fast context was 1.03 JND for familiar songs. Although these effects are not much greater than a JND

[3] Note that the shift in PSE can be interpreted in at least two ways. One interpretation is that the remembered tempo of the original song was shifted toward the values of contextual songs, an assimilation effect on the remembered value. An alternative interpretation is that the perceived values of the presented stimuli were shifted away from the contextual values, a contrast effect on the perception of the current stimulus. In either case, evaluating the original tempo as being systematically either faster or slower than the original in memory represents a systematic memory distortion.

Table 3 Means of the graded target ratings for Experiment 1 as a function of context, familiarity, and test block

Context	Familiar		Unfamiliar	
	Block 1	Block 2	Block 1	Block 2
Fast	–0.364	–0.597	–0.447	–0.617
Slow	0.419	0.579	0.607	0.889
Difference	–0.783	–1.176	–1.054	–1.506

Negative differences indicate contrast effects on ratings.

shift in each context, the shift across contexts is more than two JNDs, and these effects are highly significant. Although one may dispute the magnitude of these effects, they are clearly reliable and inconsistent with the strong version of the absolute-tempo hypothesis. Hence, our results provide further evidence for the dual coding of musical stimuli in terms of absolute and relative codes, but suggest that the absolute codes may be difficult to fully recover in the presence of recently experienced contextual song tempi. This is consistent with Straub et al. (2006), who asserted that instability of absolute tempo memory may be due to adaptation effects.

Given the pervasive effects of context on judgment (Wedell et al., 2007), it is perhaps not surprising that contextual shifts in PSE occurred even with highly familiar songs that have been heard many times. Prior research in other domains has shown some reduction in contextual bias with experience, but typically even experts with a high degree of experience with the stimulus materials tend to show context effects (O'Reilly, Leitch, & Wedell, 2004). Wedell (1996) demonstrated null effects of context in simultaneous comparative judgments; however, in those experiments the introduction of a brief, 3-s retention interval resulted in significant context effects. The present results reinforce the idea that recent contextual experiences are quickly incorporated into the tempo representation of a song, and thereby make it difficult to retrieve unbiased absolute tempo representations. Nevertheless, these results provide clear confirmation that absolute tempo information is stored in memory, as was revealed by comparison of familiar and unfamiliar songs.

Experiment 2

Experiment 2 was conducted to answer two questions: First, could tempo pleasantness for the familiar and unfamiliar songs used in Experiment 1 be likewise affected by the tempo context, and second, does song familiarity moderate context effects on tempo pleasantness for these songs? Previous research had demonstrated a dissociation of context effects for tempo ratings and pleasantness ratings, with tempo ratings resulting in more-general context effects (Rashotte & Wedell, 2012). Because of these differences, it may be that the familiarity effects demonstrated in Experiment 1 would not generalize to shifts of pleasantness ratings. Rashotte and Wedell did not find that familiarity level moderated context effects on either tempo or pleasantness judgments of Beatles songs. However, in that research familiarity was a measured rather than a manipulated variable, with participants reporting greater or lesser familiarity with the songs. In the present investigation, familiarity level was manipulated between songs (see Fig. 2). On the basis of previous research (Rashotte & Wedell, 2012), we expected to find that shifting tempo context would produce a significant effect on the target tempo rated most pleasant, reflecting an assimilative shift in the peak of the tempo pleasantness function (ideal point) with context. Shifts toward the contextual stimuli might reflect a preference for stimuli high in prototypically (Repp, 1997), with the prototype being altered by the recent context. Experiment 2 allowed for another test of the strong and weak versions of the absolute-tempo hypothesis. According to a strong version, tempo pleasantness judgments should be stable and unaltered by context for highly familiar songs. However, contextual shifts of the target tempo rated as being most pleasant should occur for unfamiliar songs, a Context × Familiarity interaction. A weak version of the hypothesis would predict this same interaction, but it would allow for significant context effects on tempo pleasantness for the highly familiar songs. Because in Experiment 2 we used the same songs and contextual manipulations as in Experiment 1, differing only in the type of judgment made, the results from the two experiments were directly comparable.

Method

The participants were 47 undergraduates from the University of South Carolina, who received course credit for participating. The experiment had a 2 (Context) × 2 (Block) × 2 (Familiarity) × 5 (Target) factorial design. A total of 23 participants were randomly assigned to the fast context, and 24 were assigned to the slow context. The same materials and procedure used in Experiment 1 were used again, except that the tempo pleasantness rating scales were used in place of binary and graded comparative tempo judgment scales. After participants had listened to a song clip, they were asked to rate the tempo pleasantness on a scale anchored by 1 = *not at all pleasant tempo* and 9 = *very very pleasant tempo*. For each song, this was repeated for 18 trials before proceeding to the next song. After participants had listened to all of the song clips, they were again asked to indicate their level of familiarity, as in Experiment 1.

Results

Participants again rated their familiarity on the three scales as being very close to ceiling for the four familiar songs, and close to floor for the unfamiliar songs (very similar to the results of Exp. 1 shown in Fig. 2). Thus, we again validated the strong familiarity manipulation.

For the analysis of context, we calculated the most pleasant target tempo in each test block, which is simply the mean of the target tempos receiving the highest tempo pleasantness rating in that block. The most pleasant target tempo was calculated from only the five target tempo clips, which restricted the estimation of the ideal tempo value to between –

12 % and 12 %. This means that the ideal tempo value might not be as extreme as the true ideal point value if that value lay outside that target range.

Tempo pleasantness ratings were averaged together across blocks and across the four familiar and four unfamiliar songs for each context, and are shown in Fig. 5. All four tempo pleasantness functions show the characteristic single-peaked form, with the peak corresponding to the most pleasant tempo value. For both the familiar songs (left panel) and the unfamiliar songs (right panel), the effect of context was to shift the tempo pleasantness rating function toward the contextual values. This effect of context appears much larger for the unfamiliar songs than for the familiar songs.

A 2 × 2 (Context × Familiarity) ANOVA was computed on the most pleasant target tempo. A significant main effect of context was found, such that the most pleasant target tempo was faster in the fast than in the slow context, $F(1, 45) = 20.91$, $p < .001$, $\eta_p^2 = .317$ ($M_{\text{Slow}} = 1.75$ % and $M_{\text{Fast}} = 7.50$ %). A significant Context × Familiarity interaction was found, $F(1, 45) = 5.97, p < .05, \eta_p^2 = .117$. This interaction reflected a larger effect of the fast and slow contexts on tempo pleasantness ratings for the unfamiliar songs ($M_{\text{Slow}} = 1.25$ % and $M_{\text{Fast}} = 9.00$ %) than for the familiar songs ($M_{\text{Slow}} = 2.25$ % and $M_{\text{Fast}} = 6.00$ %). The strong version of the absolute-tempo hypothesis predicted no significant differences with context for the familiar songs. However, these ideals differed significantly, $t(45) = -2.60$, $p < .05$. Ideals also differed significantly with context for the unfamiliar songs, $t(45) = -4.99$, $p < .001$.

Discussion

In Experiment 2, we used a strong manipulation of familiarity to test whether context effects on tempo pleasantness would be reduced for highly familiar songs. Previous research did not find a moderating effect of familiarity (Rashotte & Wedell, 2012); however, in those studies familiarity was a measured rather than manipulated variable. By presenting songs by popular artists that were either highly familiar to most participants or rarely heard, the experimental manipulation presented a more powerful test of the moderating effects of familiarity. A strong version of the absolute-tempo hypothesis predicts no effect of context on tempo pleasantness for highly familiar songs, because these are so engrained in long-term memory, but a significant effect on unfamiliar songs for which a stable long-term memory representation has yet to be established. A weaker version also predicts that familiarity will moderate shifts in tempo pleasantness, but it allows for significant shifts in tempo pleasantness for familiar songs, since strict absolute encoding of tempo might not be possible. The results were consistent with the results on judgments of tempo found in Experiment 1. The significant Context × Familiarity interaction supported the absolute-tempo hypothesis, which predicts that familiarity will moderate context effects. However, the significant shift in the pleasantness functions observed for the familiar songs was consistent only with the weak version.

Because previous research has demonstrated dissociations between the context effects for tempo judgments (which take the form of contrast effects) and tempo pleasantness ratings (which take the form of assimilative shifts in the ideal points), the results of Experiment 2 provided further evidence for the dual encoding of musical tempi in relativistic and absolute forms. It was more difficult to shift the most pleasant target tempo with regard to contextual tempi for familiar than for unfamiliar songs, supporting absolute tempo memory coding. However, significant shifts in tempo pleasantness were still

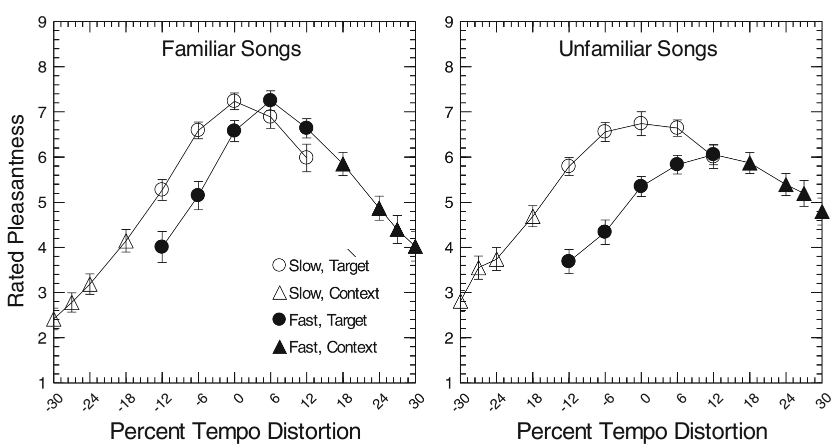

Fig. 5 Experiment 2: Tempo pleasantness ratings as a function of familiarity, context, and tempo (combined across songs). The ideal tempo values shift significantly for both familiar and unfamiliar songs, but much more so for the latter. Targets are shown as circles and contextual stimuli as triangles, and bars represent standard errors

observed for the highly familiar songs, supportive of the influence of relative coding.

General discussion

The term *absolute tempo* has been used in the literature to reflect the stable and accurate memory representation of tempo for highly familiar songs that have an established recorded tempo standard (Levitin & Cook, 1996). Support for the absolute-tempo hypothesis has been primarily based on reproduction tasks in which participants without extensive musical training sang recorded pop songs from memory. Our experimental research was concerned with testing the degree to which memory for tempo is indeed absolute for highly familiar pop songs. In particular, would perceptual judgment tasks support the conclusions from production tasks? Would absolute standards be upheld in the face of contextual manipulations designed to shift perceptions? Finally, would these effects be observed across different types of judgment tasks: comparative judgments of tempo, and judgments of the pleasantness of different-tempo versions of the same song?

Our experiments were designed to test between what we refer to as *strong* and *weak* versions of the absolute-tempo hypothesis (Levitin & Cook, 1996). The strong version implies that not only will increasing familiarity with a song lead to greater tempo memory accuracy, but also that well-established tempo memory should be stable and accessible under conditions of contextual manipulations designed to distort short-term memory. This is a tall order, given the pervasive effects of context (Wedell et al., 2007). The weak version includes the moderating effects of familiarity but does not assume that the absolute tempo memory representation will be stable and accessible under conditions of contextual manipulations. We used a comparative judgment procedure to help reduce response and linguistic biases on judgments that might restrict the interpretation of our previous results (Rashotte & Wedell, 2012). Furthermore, song familiarity was a manipulated variable instead of a selected or measured variable. Additionally, we calculated the value of the song's tempo in memory with PSE estimates from a perceptual task rather than a production task. In both experiments, the results supported a weak version of the absolute-tempo hypothesis. Significant context effects on highly familiar songs were found for both tempo judgments and tempo pleasantness ratings, and these increased for unfamiliar songs.

These results are consistent with long-term memory for tempo being dually encoded in terms of both relative and absolute features. Our results do not contradict Levitin and Cook (1996), who found fairly accurate memory for tempo in a reproduction task using highly familiar songs. Indeed, it may be that song reproduction tasks are self-correcting, because they include action as well as perception (Witt, 2011; Witt, Proffitt, & Epstein, 2010). On the other hand, the earlier experiments did not provide a strong test of the absolute-tempo hypothesis, as they did not include manipulations designed to bias memory. Our contextual manipulation provided such a test. Even though the songs that we included in the study were highly familiar to our undergraduate participants, the participants still showed biased memory for tempo and a shift in the tempo rated most pleasant. Future research should consider including contextual manipulations in a song reproduction task to determine whether perceptual and production tasks differ with regard to how resistant the absolute tempo representation is to manipulations of tempo context. Absolute tempo memory may still be accessible through a production route if production and perception mechanisms use different access codes for absolute tempo. Support for the strong version could be found using singing- or tapping-based tempo reproduction tasks if the context effects induced through listening-based tasks do not generalize to reproduction tasks.

In conclusion, we have explored the nature of the representation of absolute tempo in memory. The observed interaction of familiarity and context provides compelling evidence for absolute encoding of tempo information in memory, along with relative encoding that provides coherence across variations of the same pattern. However, the results also indicate that retrieval of this absolute representation is still biased by recent exposures to tempo-altered versions of these songs. Thus, the absolute tempo representation appears to be subject to rapid contextual updating. Although the undergraduate participants in our study showed contextual effects when retrieving tempo representations of highly familiar songs, these results leave open the possibility that other populations, such as highly trained musicians, might develop the more stable and veridical tempo memory described by the strong version of the absolute-tempo hypothesis.

References

Attneave, F., & Olson, R. K. (1971). Pitch as a medium: A new approach to psychological scaling. *American Journal of Psychology, 84,* 147–166.

Bailes, F., & Barwick, L. (2011). Absolute tempo in multiple performances of aboriginal songs: Analyzing recordings of *Djanba 12* and *Djanba 14. Music Perception, 28,* 473–490. doi:10.1525/mp.2011.28.5.473

Bergeson, T. R., & Trehub, S. E. (2002). Absolute pitch and tempo in mother's songs to infants. *Psychological Science, 13,* 72–75.

Cuddy, L. L., & Cohen, A. J. (1976). Recognition of transposed melodic sequences. *Quarterly Journal of Experimental Psychology, 28,* 255–270.

Dowling, W. J., & Bartlett, J. C. (1981). The importance of interval information in long-term memory for melodies. *Psychomusicology, 1,* 30–49.

Erlebacher, A., & Sekuler, R. (1971). Response frequency equalization: A bias model for psychophysics. *Perception & Psychophysics, 9,* 315–320. doi:10.3758/BF03212657

Hintzman, D. L. (1986). "Schema abstraction" in a multiple-trace memory model. *Psychological Review, 93,* 411–428. doi:10.1037/0033-295X.93.4.411

Levitin, D. J. (1994). Absolute memory for musical pitch: Evidence from the production of learned melodies. *Perception & Psychophysics, 56,* 414–423.

Levitin, D. J., & Cook, P. R. (1996). Memory for musical tempo: Additional evidence that auditory memory is absolute. *Perception & Psychophysics, 58,* 927–935.

Marcus, G. F. (2012). *Guitar zero: The new musician and the science of learning*. New York, NY: Penguin Press.

Moelants, D., Styns, F., & Leman, M. (2006, August). *Pitch and tempo precision in the reproduction of familiar songs*. Paper presented at the 9th International Conference on Music Perception and Cognition, Bologna, Italy.

Nosofsky, R. M., & Zaki, S. R. (2002). Exemplar and prototype models revisited: Response strategies, selective attention, and stimulus generalization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 924–940. doi:10.1037/0278-7393.28.5.924

O'Reilly, D. M., Leitch, R. A., & Wedell, D. H. (2004). The effects of immediate context on auditors' judgments of loan quality. *Auditing, 23,* 89–105.

Poulton, E. C. (1979). Models for biases in judging sensory magnitude. *Psychological Bulletin, 86,* 777–803. doi:10.1037/0033-2909.86.4.777

Rashotte, M. A., & Wedell, D. H. (2012). Context effects on tempo and pleasantness judgments for Beatles songs. *Attention, Perception, & Psychophysics, 74,* 575–599. doi:10.3758/s13414-011-0255-y

Repp, B. H. (1997). The aesthetic quality of a quantitatively average music performance: Two preliminary experiments. *Music Perception, 14,* 419–444. doi:10.2307/40285732

Schellenberg, E. G., Stalinski, M. S., & Marks, B. M. (2013). Memory for surface features of unfamiliar melodies: Independent effects of change in pitch and tempo. *Psychological Research, 78,* 84–95.

Schellenberg, E. G., & Trehub, S. E. (2003). Good pitch memory is widespread. *Psychological Science, 14,* 262–266.

Sloboda, J. A. (1985). *The musical mind: The cognitive psychology of music*. Oxford, UK: Oxford University Press, Clarendon Press.

Straub, S., Vitouch, O., Ladinig, O., Augustin, D., Carbon, C.-C., & Leder, H. (2006, August). *Memory representations of musical tempo: Stable or adaptive?* Paper presented at the 9th International Conference on Music Perception and Cognition, Bologna, Italy.

Wedell, D. H. (1996). A constructive–associative model of contextual dependence of unidimensional similarity. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 634–661. doi:10.1037/0096-1523.22.3.634

Wedell, D. H., Hicklin, S. K., & Smarandescu, L. O. (2007). Contrasting models of assimilation and contrast. In D. A. Stapel & J. Suls (Eds.), *Assimilation and contrast in social psychology* (pp. 45–74). New York, NY: Psychology Press.

Witt, J. K. (2011). Action's effect on perception. *Current Directions in Psychological Science, 20,* 201–206. doi:10.1177/0963721411408770

Witt, J. K., Proffitt, D. K., & Epstein, W. (2010). When and how are spatial perceptions scaled? *Journal of Experimental Psychology: Human Perception and Performance, 36,* 1153–1160. doi:10.1037/a0019947