Does this sound familiar? Effects of timbre change on episodic retrieval of novel melodies

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Abstract

Three experiments investigated episodic retrieval of novel melodies and tested how a change in timbre between study and test affects the two processes underlying recognition memory, conscious recollection and familiarity. In Experiments 1 and 2, conscious recollection and familiarity were operationalized using the *remember/know* paradigm. We additionally assessed the influence of the number of presentations during learning in Experiment 1, and the effect of massed versus distributed learning in Experiment 2. Experiment 3 confirmed that participants could also indicate a change in timbre explicitly (same versus different timbre classifications). In all experiments, melodies were better recognized when the timbre at study and test was identical. Effects of timbre change were more pronounced for recollection than familiarity. Distributed learning specifically enhanced the same-timbre advantage on recollection. Together, these results suggest that timbre serves both as a context cue and as an integrated feature of a melody.

keywords: melody, timbre, memory, recognition, recollection, familiarity

1. Does this Sound Familiar? Effects of Timbre Change on Episodic Retrieval of Novel Melodies

Think of the various instantiations of "Happy Birthday" you have heard throughout your life: You heard the song sounded by different voices, at different pitch levels, and at different tempi, but you were always able to recognize the song. In other words, the same melody may be presented at different tempi, at different pitch levels, or with various timbres and still be easily identified as the same unique melody. In musicological terms, melody refers to a sequence of pitch intervals and duration ratios – regardless of the melody's absolute pitch level, the absolute tempo or the timbre of the actual presentation. However, numerous findings suggest that information about pitch level, timbre, or tempo is often spontaneously retrieved along with a familiar melody. For example, adults are able to discriminate between the original and a pitch-shifted version of television theme songs (Schellenberg & Trehub, 2003). Similarly, infants respond differently when a piece of music is played by a novel instrument or at a different pitch level than before (Trainor, Wu, & Tsang, 2004). Moreover, participants are better at recognizing unfamiliar melodies played by the same instrument during the test phase compared to the encoding phase (Halpern & Müllensiefen, 2008; Peretz, Gaudreau, & Bonnel, 1998, see also Warker & Halpern, 2005; for related data see Poulin-Charronnat, et al., 2004). Similar effects obtained for visual objects (Cooper, Ballesteros, Schacter, & Moore, 1992; Schacter & Cooper, 1993) and for spoken words (Church & Schacter, 1994) have been explained by the fact that sensory features of test items re-activate the corresponding features of the studied item's memory trace (Cooper, et al., 1992; Schacter & Cooper, 1993; Snodgrass, Hirshman, & Fan, 1996).

The sensory matching effects observed in melody recognition suggest that features not crucial to the identification of a melody are nevertheless encoded and stored in memory. Whether timbre, in particular, constitutes an integrated part of the melody's memory trace or may be stored as a separable but linked context feature remains an open question. In favor of the notion that timbre and pitch are processed in an *integrated* fashion, it has been shown that it is easier to *perceptually compare* the pitches of two tones when both tones are presented in the same timbre same versus in a different timbre (e.g. Melara & Marks, 1990; Pitt & Crowder, 1992). By contrast, previous findings that a timbre change between study and test affected explicit but not implicit measures of melody *recognition* (Peretz, et al., 1998; Halpern & Müllensiefen, 2008; see also Warker & Halpern, 2005) have been taken as evidence that timbre information is not integrated in the memory trace of the melody, but may rather be stored as a separate context feature (Peretz, et al., 1998). Hence, results based on more perceptual tasks suggest an integrated processing of pitch and timbre (but see Semal & Demany, 1991), whereas the available memory studies are more consistent with the notion that timbre information is stored separately from the melody proper.

1.1. Familiarity and Recollection

Retrieval of the learning context is a defining feature of episodic memory. According to dual-process models, recognition memory retrieval is supported by two independent processes: *Familiarity* and *recollection* (see Yonelinas, 2002 for a review). For example, when watching a movie, we may be certain to have seen a particular actress previously – but we may not remember in which other film. The underlying memory process is often referred to as familiarity (also called memory for content, e.g. Spencer & Raz, 1995). However, when watching that same movie, it may also have occurred to us that we just saw the respective actress in film x, which would be an example of recollection. These processes have been dissociated by various experimental manipulations, and they also rely on distinct brain regions (Yonelinas, 2002). Recollection supports memory for context, i.e. the controlled retrieval of the spatio-temporal context in which each item was studied. This association is achieved via a binding mechanism thought to depend specifically on hippocampal activation (e.g. Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000). By contrast, familiarity supports a fast and global feature matching based on overall similarity between an item and its putative memory trace, regardless of specific details, supported by cortical structures surrounding the hippocampus (e.g. Ranganath, et al., 2004). Notably, more recent evidence suggests that encoding processes play a key role for the distinction between item and context: When participants are asked to explicitly generate a relation between several originally separate items, a unitized memory trace is formed. For instance, participants are presented with words on a red or green background screen, and are either asked to associate the corresponding object with a red or green object or to visualize the corresponding object in the background color. In the former case, recollection is needed to retrieve the object pairing, whereas familiarity is sufficient to retrieve details about the unitized representation of all components of the memory trace in the latter case (Diana, Yonelinas, & Ranganath, 2008; Diana, Van den Boom, Yonelinas, & Ranganath, 2011; Opitz & Cornell, 2006).

A large number of studies has provided empirical support for the distinction between familiarity and recollection (Yonelinas, 2002), but the majority of these findings is based on verbal or visual material. For instance, changing the items' perceptual characteristics between study and test was found to affect familiarity but not recollection of verbal material (e.g. Gregg & Gardiner, 1994) and both familiarity and recollection for visual material (e.g. Yonelinas & Jacoby, 1995) with larger effects for recollection (e.g. Rajaram, 1996). This pattern suggests that the distinction may depend in part on the material used. So far, only few studies investigated the distinction between recollection and familiarity using melodies (Gardiner, Kaminska, Dixon, & Java, 1996; Gardiner & Radomski, 1999; Java, Kaminska, & Gardiner, 1995; see also McAuley, Stevens, & Humphreys, 2004 for related data). However, none of them assessed whether a change in timbre affects both processes to the same extent. Moreover, it is generally accepted that memory for associations between items and their context depends primarily on recollection (e.g. Yonelinas, 1997). Therefore, if timbre is stored in memory as a separate context feature, a change of timbre between study and test should primarily affect conscious recollection, i.e. the retrieval of item and context (see also Peretz, et al., 1998). By contrast, if timbre is part of an integrated memory representation of a melody, a change of timbre should affect familiarity ratings, i.e. the retrieval of a unified representation including both item and timbre information.

1.2. The Current Study

So far, only few studies have investigated the role of timbre change for the episodic retrieval of novel melodies (Halpern & Müllensiefen, 2008; Peretz, et al., 1998; see also Warker & Halpern, 2005).

Hence, one motivation for the current study was to add to that literature. More specifically, we examined how timbre change affects episodic retrieval based on conscious recollection and familiarity. To dissociate these retrieval processes, the *remember/know* paradigm (Tulving, 1985) was used in the present study. In this paradigm, after an *old* response, participants are asked to further specify whether they are able to consciously recollect episodic information about the item (*remember*) or if they consider the item as familiar but cannot consciously recollect it (*know*, see also Appendix A). The probability of a remember response can be taken as an index of recollection. By contrast, the probability of a know response is not a direct indicator of familiarity (Yonelinas & Jacoby, 1995; see also Yonelinas, 2002): Because the participants are instructed to respond know only if they *cannot* consciously recollect it, the proportion of *know* responses underestimates the overall familiarity of the items. Therefore, the proportion of *remember* responses also needs to be taken into account (Yonelinas, 2002, see Methods Section for details).

When using well-known melodies[1] encountered in real life as material for investigating memory, one faces a serious problem: For well-known melodies, it is highly likely that a verbal label will be used for storage and later access. Thus, when well-known pieces of music are used, one cannot differentiate whether participants truly encode and retrieve the melody itself or an associated verbal label (Halpern & Bartlett, 2010). We therefore used newly composed melodies, which did not resemble well-known melodies (as ensured by a pilot study). Notably, pilot work with this material showed that memory for novel melodies is surprisingly poor. By contrast, well-known melodies can still be recognized after several decades (Halpern & Bartlett, 2010), suggesting that many repeated learning episodes might gradually strengthen memory for new melodies over time. To improve memory performance and to assess the relation between the number of presentations and memory performance for this material, we therefore also manipulated the number of presentations in the study phase. Thus, Experiment 1 investigated how a timbre change between study and test affects recollection and familiarity. Depending on whether timbre acts as a context feature, as an integrated

[1] To avoid an ambiguous use of the term *familiar*, we will refer to melodies with pre-experimental exposure as *well-known* and restrict the use of the term familiarity to the dual-process terminology explained above.

part of the melody, or both, a change in timbre should impair recollection, familiarity, or both processes. In addition, it was assessed whether increasing the number of presentations during encoding improved episodic retrieval for musical material.

2. Experiment 1

2.1. Methods

2.1.1. Sample.

Seventy-eight participants with normal hearing (self-report) took part in Experiment 1. One participant was excluded because of a *negative* Pr value (i.e. more old responses to new than to old items, suggesting predominantly guessing). The data of one additional participant could not be analyzed because of technical problems. The final sample consisted of 76 participants (18 - 47 years, mean age 23 years, SD = 5; 6 male, 75 students of the Heinrich-Heine-University Düsseldorf). Fourty-nine participants played or had played a musical instrument, but not at a professional level (between 1-24 years of experience, summed over instruments; M = 8, SD = 6). Participants were randomly assigned to the one-trial or four-trial learning condition: In the one-trial learning condition, participants heard each melody in one learning trial (N = 39, 28 of which played or had played a musical instrument between 1-21 years, M = 8, SD = 4). In the four-trial learning condition, participants heard each melody in four learning trials (N = 37, 21 of which played or had played a musical instrument between 1-24 years, M = 8, SD = 7). Notably, a correlation was observed between musical experience and overall memory performance (Pr scores, for details see 2.1.4), r = .25, p = .029. However, experimental groups differed neither with respect to the number of participants with a formal musical education (χ^2 = 1.87, p > .17) nor with respect to the mean amount of musical experience for those with a formal musical education (t_{47} = -0.41, p > .68). All participants gave written informed consent. They were paid 6 € or received course credit for participation.

2.1.2. Material.

Forty-eight single-line melodies were composed for the experiment (representative examples can be found in Appendix B and in the supplementary material). All melodies adhered to Western tonality and metre (i.e. regular accents). The durations of the melodies were between 4 and 10 s (mean 6 s), and the pitch range of the melodies lay between C4 and A5 flat. A pilot study (7 participants, all students of the Heinrich-Heine-University) was conducted to assess whether any of the melodies resembled a melody heard previously outside the laboratory. Each melody was categorized as previously known by no more than one participant. Melodies were first generated as MIDI Files and mixed as stereo wave files using Cubase Studio 4, Version 4.5.2 (Steinberg). To equate the sound pressure levels between melodies, all melodies were normalized using Audacity (http://audacity.sourceforge.net). All 48 melodies were created in two different timbres: trumpet and piano. The trumpet timbre was created using the virtual instrument Vienna Instruments Special Edition, Version 2.0 (Vienna Instruments), sound 14S TrC legato/staccato. The piano timbre was created using Ivory Grand, Version 1.64.00 (Synthogy), Expressive Concert D10. Eight additional melodies (created as described above) were used only in the practice block. All melodies were presented via headphones (K77, AKG, AKG Acoustics GmbH, Wien).

2.1.3. Task and procedure.

To assess whether the number of presentations improves memory performance and possibly also differentially affects *remember/know* judgments, participants were randomly assigned to a one-trial or a four-trial learning condition: In the former condition, participants heard each melody twice within the same learning trial (1 x 2, one-trial condition, N = 39). In the latter condition, participants heard each melody eight times in four learning trials, (4 x 2, four-trial condition, N = 37).

Participants were first provided standardized instructions on the entire memory task. They were then familiarized with both the study phase and the test phase in a practice block (learning list: four items, test list: eight items). During the practice block, participants also adjusted the sound volume of the melodies so that they could hear the melodies at a comfortable listening level. In the experiment proper, participants learned 24 randomly selected melodies (old melodies), twelve in piano timbre and twelve in trumpet timbre (random assignment). In the test phase, the 24 old melodies were presented along with 24 new melodies (twelve in piano timbre, twelve in trumpet timbre). Twelve old melodies were presented in the same timbre as in the learning phase (same timbre condition, six piano, six trumpet), the remaining melodies were presented in the other timbre (different timbre condition, six piano, six trumpet).

During the study phase, each melody was presented twice in succession in a learning trial (inter-stimulus interval: 500 ms). Both presentations were monaural, either both on the left side, both on the right side or one left and one right. Participants were asked to indicate for each trial whether both instances of the melody were presented on the same or on different sides by pressing one of two buttons on the numerical pad of the computer keyboard. The next trial was initiated 500 ms after the response. If no response was given after 10 s, a buzzer signal reminded the participant to respond, and the next trial was initiated 5 s later. In the one-trial condition, the study phase was complete after one block of 24 melodies; in the four-trial condition, the study phase was divided into four blocks, each containing all of the melodies in random order of presentation. In this condition, participants were informed that melodies could repeat during study.

The test phase was identical for the two learning conditions. Each melody was presented once, binaurally. After each melody, participants were asked to press a button to indicate whether the melody was old or new. After each old response, they were asked to additionally indicate via button press whether they actually remembered hearing the melody during learning (remember), just knew the melody was old (know), or guessed (guess; see also Appendix A for a translation of remember/know/guess instructions). The latter response category was included to discourage participants from using the label know whenever they are uncertain. The next trial was initiated 500 ms after the response. If no response was given after 10 s, a buzzer signal reminded the participant to respond, and the next trial was initiated 5 s later.

At the end of the experiment, each participant completed a survey on their musical background and on the strategies they used. The total duration of the experiment was approximately 30 min for the one-trial learning condition and one hour for the four-trial learning condition.

2.1.4. Data analysis.

To assess overall memory performance, we calculated Pr scores (Snodgrass & Corwin, 1988). This measure compares the proportion of old items classified as "old" (p_{hit}) with the proportion of new items falsely classified as being "old" ($p_{false\ alarm}$). To ensure that the pattern of memory performance cannot be attributed to differential tendencies in responding "old", we also compared response bias scores between groups ($Br = p_{false\ alarm} / 1 - (p_{hit} - p_{false\ alarm})$). Note that false alarms cannot be assigned a value of timbre change, i.e. the same values are subtracted for the timbre change and the no timbre change condition.

To test whether a change of timbre between study and test affects recollection, familiarity, or both processes, the influence of timbre change on these measures was separately assessed. Recollection was defined as the proportion of remember-responses to old items minus the proportion of remember-responses to falsely classified new items (i.e. false alarms classified as remember). To calculate the familiarity score, the proportion of know-responses to old items was first compared to the proportion of know-responses to falsely classified new items (i.e. false alarms classified as know). Remember/know- instructions ask participants to respond know only in the absence of recollection, whereas both processes are assumed to be independent. Hence, in a second step, a conditional proportion of know responses relative to possible know responses (i.e. 1 - remember) was calculated (Yonelinas, 2002)[2].

Memory performance measures (Pr, recollection scores and familiarity scores) were subjected to separate mixed ANOVAs with the between-subjects factor learning condition (1 x 2 vs. 4 x 2) and the

[2] Because this formula is not defined for remember rates of 1, both recollection and familiarity scores were based on corrected hit ((p_{hit} + 0.5)/(number of old items + 1)) and false alarm rates (($p_{false\ alarm}$ + 0.5)/(number of new items + 1); see also Hautus, 1995 and Snodgrass & Corwin, 1988 for a similar procedure regarding the calculation of d’). Note that the pattern of results remained the same when uncorrected values were used for all but the twelve participants with perfect remember rates.

within subjects factor timbre change (yes, no). Response bias (Br) was compared between groups. If a significant interaction was found, effects of timbre change were analyzed for each group separately. Partial η^2 is used as a measure of effect size. All analyses were conducted with SAS 9.2.

2.2. Results

2.2.1. Overall memory performance

For Experiments 1 and 2, Table 1 provides an overview of the *absolute* response frequencies of remember, know, guess, and new responses for old melodies with same versus different timbre and for new melodies. These values were used for calculation of both Pr and recollection and familiarity scores, which are displayed in Table 2.

The mixed ANOVA for Pr showed an overall effect of timbre change: Participants gave more old responses to melodies that were presented with the same timbre at both study and test (main effect timbre change: $F(1, 74) = 43.15$, $p < .01$ $\eta^2 = .37$; see also Figure 1). In addition, a main effect of learning condition was observed $F(1, 74) = 48.81$, $p < .01$, $\eta^2 = .40$). No interaction was observed between learning condition and timbre change ($F < 1$). No differences in response bias (Br) were observed ($p > .13$).

**** Figure 1 and Table 1 about here****

2.2.2. Recollection and Familiarity

In the present task, recollection and familiarity scores are based on the remember/know paradigm with an additional guess response category. Consistent with the notion that the participants used these labels as intended, old responses to new melodies (i.e. false alarms) were more often attributed to knowing than to remembering ($F(1, 74) = 79.49$, $p < .01$, $\eta^2 = .52$; see also Figure 1).

Recollection was higher for melodies that were presented with the same timbre during learning and test (main effect timbre change: $F(1, 74) = 89.33$, $p < .01$, $\eta^2 = .55$; Table 2, Figure 2, left) and for the 4 x 2 condition (main effect learning condition: $F(1, 74) = 81.35$, $p < .01$, $\eta^2 = .52$). The effect of timbre change was more pronounced for the 4 x 2 than for the 1 x 2 group, as evident in an interaction of learning condition and timbre change (learning condition x timbre change: $F(1, 74) = 6.13$, $p < .02$; $\eta^2 = .08$; 4 x 2-group: $F(1, 36) = 56.44$, $p < .01$, $\eta^2 = .61$; 1 x 2-group: $F(1, 38) = 31.87$, $p < .01$, $\eta^2 = .53$).

**** Table 2, Figure 2, and Figure 3 about here****

With respect to familiarity, melodies presented in the same timbre during learning and test were perceived as more familiar than melodies that changed timbre between learning and test (main effect timbre change: $F(1, 74) = 12.01$, $p < .01$, $\eta^2 = .14$; Table 2, Figure 3, left). Participants in the 4 x 2 learning condition also classified a higher proportion of non-recognized melodies as familiar compared to participants in the 1 x 2 learning condition (main effect learning condition: $F(1, 74) = 26.50$, $p < .01$, $\eta^2 = .26$). No interaction between learning condition and timbre change interaction was observed, suggesting that effects of timbre change on familiarity were comparable between the groups ($F < 1$).

2.3. Discussion of Experiment 1

Timbre change affected overall memory for novel melodies: Consistent with earlier studies (Halpern & Müllensiefen, 2008; Peretz, et al., 1998), a timbre change between study and test reduced overall recognition performance (for related findings, see Cooper, et al., 1992; Schacter & Cooper, 1993; Snodgrass, et al., 1996). As predicted, a timbre change between study and test affected primarily recollection and to a lesser degree also familiarity. Consistent with the findings of Gardiner and colleagues (Gardiner, et al., 1996; Gardiner & Radomski, 1999), increasing the number of listening trials improved overall recognition level. This improvement was found both for recollection and familiarity measures. Notably, increasing the number of learning trials had a larger impact on recollection for melodies with identical timbre at study and test. This suggests an additional retrieval route that is preferentially accessed when a melody has been encountered *repeatedly* with the same timbre. In this case, timbre might additionally serve as a context cue that improves performance when activated during retrieval.

A potential limitation of the remember/ know procedure is that participants might use the labels remember and know as indicating different degrees of certainty rather than applying them to two qualitatively different processes. To counteract such a use of the response categories (answering remember when sure, answering know when unsure), we included a response category for guesses. For old melodies, the proportion of *guess* responses was considerably lower than the proportion of both *remember* and *know* responses. For new melodies, the proportion of *guess* responses was similar to the proportion of *remember*-responses, but lower than the proportion of *know* responses: When a new melody was categorized as *old*, this was mostly attributed to knowing. This pattern of responses strongly suggests that participants used the labels as intended. Relatively high levels of false alarms for *know*-responses have also been reported by Gardiner and colleagues (1996). These authors suggested that feelings of familiarity for new melodies might result from the fact that old and new melodies may contain similar fragments (i.e. short tone sequences), which may evoke feelings of familiarity.

Taken together, the results of Experiment 1 suggest that an identical timbre at study and test facilitates conscious recollection, in particular following repeated encounters with the specific pairing of melody and timbre. To a lesser degree, identical timbre between study and test also enhanced familiarity-based retrieval of a melody. This pattern suggests that timbre indeed facilitates conscious recognition as a context cue, but that it is also an integrated part of the melody's memory trace. To further corroborate this new finding, Experiment 2 was conducted.

In addition to replicating the effects of timbre change on melody recognition, Experiment 1 also showed - in agreement with the earlier findings of Gardiner, et al. (1996) - that increasing the number of melody presentations markedly improves performance. However, in Experiment 1, the total number of melody presentations was confounded by the number of distinct listening episodes: One group heard each melody *twice* in *one* listening episode whereas the other group heard each melody for a total of *eight* times in *four* listening episodes. Thus, the results of Experiment 1 are inconclusive with respect to the question whether the effect of learning condition is due to the total amount of melody presentations or to the number of distinct listening episodes. Earlier research has shown that distributed practice leads to an overall increase in memory performance (Parkin, Gardiner, & Rosser, 1995; Parkin & Russo, 1993). Therefore, we kept the total amount of hearing a melody constant and varied the number of distinct listening episodes in Experiment 2. In the massed learning condition, participants heard each melody four times in one trial. In the distributed learning condition, participants heard each melody only once in a trial and received four trials for each melody.

3. Experiment 2

3.1. Methods

3.1.1. Sample.

Sixty-two participants with normal hearing (self-report) took part in Experiment 2. One participant was excluded because of a negative Pr value. The final sample consisted of 61 participants (18 - 44 years, mean age 23 years, SD= 5; 8 male). Fifty-nine were students of the Heinrich-Heine-University Düsseldorf. Thirty-four participants played or had played a musical instrument, but not at a professional level (between 2 – 27 years; M = 9, SD = 6).

Participants were randomly assigned to the massed learning (N = 29, 17 of which played or had played a musical instrument between 2-15 years, M = 8, SD = 4) or distributed learning condition (N = 32, 17 of which played or had played a musical instrument between 3-27 years, M = 10, SD = 8). Similar to Experiment 1, a positive correlation was observed between musical experience and overall memory performance (r = .35, p = .001). However, the experimental groups differed neither with respect to the number of participants with a formal musical education (χ^2 = 0.19, p > .67) nor with respect to the mean amount of musical experience of those with a formal musical education (t_{32} = -1.02, p > .31).

3.1.2. Material.

The same melodies were used as described above.

3.1.3. Task and procedure.

The procedure was identical to Experiment 1, with the following exceptions: We compared memory for melodies in a massed learning condition (1 x 4) and a distributed learning condition (4 x 1). In the 1 x 4 condition, participants heard each melody four times in one trial. In the 4 x 1 condition, each participant heard one melody per trial, but every to-be-learned melody was presented in four different learning trials. Hence, the total number of presentations was identical between the conditions. Participants were now asked to indicate whether the melody was presented left or right. If a melody was presented four times in a given trial, the same side was used for each presentation.

3.1.4. Data analysis.

Data analysis was identical to Experiment 1.

3.2. Results

3.2.1. Overall memory performance.

The mixed ANOVA for Pr showed an effect of timbre change (see also Table 1 and Figure 1): Participants gave more old responses to melodies that were presented with the same timbre at both study and test (main effect timbre change: $F(1, 59) = 53.18$, $p < .01$, $\eta^2 = .47$). No main effect of learning condition ($p > .20$) nor a reliable interaction between learning condition and timbre change ($F < 1$) was observed. Response bias (Br) did not differ between learning conditions ($p > .12$).

3.2.2. Recollection and familiarity.

Consistent with the notion that participants used the labels as intended, old responses to new melodies (i.e. false alarms) were more often attributed to knowing than to remembering ($F(1, 59) = 61.84$, $p < .01$, $\eta^2 = .51$; see also Figure 1).

Recollection scores were higher for melodies presented with the same timbre during learning and test (main effect timbre change: $F(1, 59) = 60.12$, $p < .01$, $\eta^2 = .50$; see also Table 2, Figure 2, right). Moreover, a learning condition by timbre change interaction was observed for recollection scores

($F(1, 59) = 8.07$, $p < .01$, $\eta^2 = .12$), reflecting a larger timbre change effect for the distributed than the massed learning condition (4 x 1-group: $F(1, 31) = 40.29$, $p < .01$; $\eta^2 = .57$; 1 x 4-group: $F(1, 28) = 23.71$, $p < .01$, $\eta^2 = .45$). The main effect of learning condition was not significant ($p > .15$).

Familiarity scores were also affected by timbre change ($F(1, 59) = 37.05$, $p < .01$, $\eta^2 = .39$), but no reliable effects involving learning condition were observed (all *ps* > .16; see also Table 2 and Figure 3, right).

3.3. Discussion of Experiment 2

Experiment 2 replicates the findings of previous studies (e.g. Halpern & Müllensiefen, 2008; Peretz, et al., 1998) and of Experiment 1 with respect to the effect of timbre change on both overall memory performance and the respective roles of recollection and familiarity for memory retrieval: Again, effects of timbre change were obtained for overall memory performance as well as for both recollection and familiarity. Unlike Experiment 1, Experiment 2 showed a benefit of distributing learning trials only when melodies that were played in the *same* timbre at study and test were *consciously recollected*. The general effect of learning condition on recollection and familiarity of both same and different timbre melodies obtained in Experiment 1 is thus likely to reflect the influence of increasing the overall number of presentations. By contrast, better performance in the distributed compared to the massed learning condition when same-timbre melodies were consciously recollected appears to be associated more specifically with the distribution of learning trials. Encoding each melody in several different learning episodes may promote the formation of associative connections between melody and timbre, which may particularly improve conscious recollection (for related arguments see Litman & Davachi, 2008; de Jonge, Tabbers, Pecher, & Zeelenberg, 2012).

In Experiments 1 and 2, timbre change affected both conscious recollection and familiarity, suggesting a dual role of timbre as a context cue and an integrated part of the memory trace. Because calculation of the familiarity score is based on the subsamples of melodies not consciously recollected, the two measures are not independent, therefore precluding a direct statistical comparison. Nevertheless, at a descriptive level, effects of timbre change were consistently larger for recollection than for familiarity (Experiment 1 η^2 = .55 versus .14; Experiment 2: η^2 = .50 versus .39 for recollection and familiarity, respectively). This pattern of findings suggests that the timbre change effect relies to a large degree on recollection. If this is the case, participants should be able to explicitly verbalize a change in timbre. Thus, in Experiment 3, memory for the timbre of novel melodies was assessed directly. For each melody identified as old, we asked *explicitly* whether it was presented in the same or in a different timbre than in the study phase. Based on Experiments 1 and 2, we expected participants to be able to indicate whether or not timbre changed between study and test.

4. Experiment 3

4.1. Methods

4.1.1. Sample.

Sixty-four participants with normal hearing (self-report) took part in Experiment 3. One participant was excluded because of hearing problems (Tinnitus). One participant was excluded because of a negative Pr value. The final sample consisted of sixty-two participants (16-44 years, mean age 25 years, SD = 5; 16 male). Fifty-eight were students of the Heinrich-Heine-University Düsseldorf. Fourty-one played or had played a musical instrument, but not at a professional level (between 1-27 years, M = 9, SD = 6).

Participants were randomly assigned to the massed or distributed learning condition. In the massed learning condition, participants heard each melody in one learning trial (N = 30, 20 of which played or had played a musical instrument between 1-27 years, M = 9, SD = 7); In the distributed learning condition, participants heard each melody in four learning trials (N = 32, 21 of which played or had played a musical instrument between 2-21 years, M = 9, SD = 5). The correlation between musical experience and overall memory performance was not significant for Experiment 1 (r = .19, p = .13). The groups differed neither with respect to the number of participants with a formal musical education ($\chi^2 = 0.008$, $p > .93$) nor with respect to the mean amount of musical experience of those with a formal musical education ($t_{32} = -0.01$, $p > .99$).

4.1.2. Material.

The same melodies were used as described above.

4.1.3. Task and procedure.

Everything was as described for Experiment 2, with the following exception: At test, participants were now asked to indicate after each old response whether the melody had been presented with the same timbre during learning (same), had been played with the other timbre (different), or whether they did not know and had to guess (guess).

4.1.4. Data analysis.

For Pr and Br, data analysis was identical to Experiment 2. In addition, we identified how many *same* and *different timbre* melodies were both correctly identified as old and categorized with the correct timbre (i.e. *timbre-recognition scores)*: First, we calculated the proportion of same responses relative to all old responses to *same* timbre melodies ($p_{\text{hit timbre same}}$) and the proportion of different responses relative to all old responses to *different* timbre melodies ($p_{\text{hit timbre different}}$). To estimate whether there was an overall bias to respond same or different, the proportions of same and different responses relative to all old responses to new melodies were also calculated ($p_{\text{false alarm timbre same}}$, $p_{\text{false alarm timbre different}}$). These proportions were combined into timbre-recognition scores, separately for same and different responses (i.e. $\text{timbre-recognition}_{\text{same}} = p_{\text{hit timbre same}} - p_{\text{false alarm timbre same}}$; $\text{timbre-recognition}_{\text{different}} = p_{\text{hit timbre different}} - p_{\text{false alarm timbre different}}$). These scores were submitted to a mixed ANOVA with between subjects factor learning condition (1 x 4 vs. 4 x 1) and within subjects factor timbre change (yes, no).

4.2. Results

4.2.1. Overall memory performance.

For Experiment 3, Table 1 provides an overview of the *absolute* response frequencies of same timbre, different timbre, guess, and new responses for old melodies with same versus different timbre and for new melodies. These values were used for calculation of the timbre recognition scores, which are displayed in Table 3.

The mixed ANOVA for Pr showed an overall effect of timbre change (see also Table 1 and Figure 1), which was qualified by learning condition (timbre change, $F(1, 60) = 51.84$, $p < .01$, $\eta^2 = .46$; timbre change x learning condition, $F(1, 60) = 5.34$, $p = .02$, $\eta^2 = .08$). Changing the timbre between study and test had a larger effect on melody recognition for the distributed learning condition than for the massed learning condition (distributed: $F(1, 31) = 43.42$, $p < .01$, $\eta^2 = .58$; massed: $F(1, 29) = 12.61$, $p < .01$, $\eta^2 = .30$). A main effect of learning condition was not observed ($F < 1$). Response bias (Br) did not differ between learning conditions ($F < 1$).

4.2.2. Timbre recognition.

**** Table 3 about here****

Timbre recognition for same timbre melodies was significantly above chance level (one-sample t-test, $t_{61} = 13.63$, $p < .0001$) – both for the distributed and for the massed learning condition (distributed: $t_{31} = 13.19$, $p < .0001$; massed: $t_{29} = 7.37$, $p < .0001$). By contrast, timbre recognition for different timbre melodies did not differ significantly from chance ($t_{61} = -0.35$, $p > .73$; distributed: $t_{31} = -0.77$, $p > .44$; massed: $t_{28} = 0.28$, $p > .78$).

Analyzing timbre recognition scores for same and different responses showed a main effect of timbre change ($F(1, 60) = 61.95$, $p < .01$, $\eta^2 = .51$): Timbre recognition was better for melodies presented in the same versus a different timbre. No main effect of learning condition was observed ($p > .16$). However, a trend for the learning condition by timbre change interaction was observed ($F(1, 60) = 2.83$, $p < .10$, $\eta^2 = .06$). Consistent with Experiment 2, the timbre change effect was larger for the distributed than for the massed learning condition (4 x 1-group: $F(1, 31) = 62.07$, $p < .01$; $\eta^2 = .67$; 1 x 4-group: $F(1, 29) = 14.76$, $p < .01$, $\eta^2 = .35$; see also Table 3 and Figure 4).

**** Figure 4 about here****

4.3. Discussion of Experiment 3

Experiment 3 suggests that explicit retrieval of timbre information is possible, at least when timbre is identical between study and test. Notably, this effect cannot be attributed to a bias to respond *same*, since this was already accounted for in the timbre recognition scores. In Experiment 2, the timbre change effect was larger in the distributed than the massed learning condition, but only for conscious recollection. In Experiment 3, larger timbre change effects for distributed than massed learning were also observed for conscious recollection, but were additionally present for overall memory performance. Due to the test requirements at retrieval (remember/know versus same/different timbre), timbre information was more relevant in Experiment 3 compared to Experiments 1 and 2. Thus, these different test requirements might have influenced the processing of timbre information during encoding.

5. General Discussion

In three experiments, we both replicated and extended earlier research on episodic memory for melodies. Consistent with the few existing studies, which assessed the effects of timbre change on recognition memory for melodies (Halpern & Müllensiefen, 2008; Peretz, et al., 1998), a change in timbre had a negative impact on recognition performance in all three experiments. Extending earlier findings, we more specifically examined how timbre change affected familiarity and recollection. Experiments 1 and 2 demonstrate that the detrimental effect of timbre change was present for retrieval both based on conscious recollection and on familiarity, suggesting that a feature like timbre can influence memory for melodies even in the absence of conscious recollection. Hence, the role of timbre in recognition of melodies seems not to be restricted to the role of a context feature. Rather, timbre information appears to be an integrated part of a melody's memory trace, i.e. the internal representation of a melody *in memory* may not be completely separable from timbre.

However, although familiarity ratings were subject to a change in timbre between study and test in Experiments 1 and 2, timbre change effects were larger for conscious recollection. Previous research suggests that familiarity can be sufficient to retrieve the different components of a memory representation when the formation of a unitized memory trace is promoted by task-instructions during encoding (Diana et al., 2008, 2011; Opitz & Cornell, 2006). The present study did not use any explicit encoding manipulation. Nevertheless, participants might have spontaneously formed a unitized memory trace because musical material inherently calls for integration. Alternatively, the effect may be due to a subsample of participants employing an encoding strategy favoring unitization (this could also explain the smaller effect of timbre change on familiarity). The two alternatives will be addressed in the following.

Data obtained in perceptual tasks suggest that timbre and pitch are automatically processed in an integrated fashion (see also Melara & Marks, 1990; Pitt & Crowder, 1992). As for the integration of separate features *in memory*, behavioral performance for visual material varies considerably between investigations (e.g. Piekema, Rijpkema, Fernandez, & Kessels, 2010; Zimmer & Ecker, 2010), depending on the specific type of material (e.g. words, objects, faces, or geometric shapes) and the features specifying context (e.g. color, location). The heterogeneous results can be accounted for by distinguishing between different types of associations: Inter-item associations can consist between any pair of items, within the same or different modalities (e.g. word-word, word-object). Intra-item associations may be for instance objects presented at a particular location (i.e. an extrinsic feature) or objects painted in a particular color (i.e. an intrinsic feature). Different patterns of neurophysiological activity suggest that inter-item bindings and extrinsic intra-item bindings rely on hippocampal activation and are supported exclusively by recollection, whereas intrinsic intra-item bindings can also be supported by familiarity (Piekema, et al., 2010). Thus, the existing evidence on visual information suggests that the type of information to be recalled plays a major role for the type of binding to occur – and hence for the memory process that may be involved in the retrieval of the association. Whether a related distinction applies to auditory information in general - or melodies in particular - remains open so far. Consistent with the finding that timbre change affected familiarity in addition to recollection, timbre might be considered both an intrinsic feature of a melody (comparable to an item's color) and an extrinsic feature (comparable to an item's spatial location). Future studies are needed to further explore whether other aspects of a melody might potentially correspond to purely extrinsic features.

As detailed in the previous section, the effect of timbre change on familiarity may be explained by assuming that presenting a melody in a specific timbre promotes the formation of intrinsic intra-item bindings. Alternatively, the effect may be due to a number of individual participants who spontaneously adopted an encoding strategy favoring unitization. With respect to differences in processing musical material, it may be particularly fruitful to consider the degree of musical expertise. The present study was not designed to investigate this issue, but exploratory analyses showed that the effects of timbre change on overall memory, as well as on recollection and familiarity were independent of musical expertise (for related data on overall recognition see also Radvansky, Fleming, & Simmons, 1995; but see Wolpert, 1990). However, the participants categorized as musicians in the present study played music only at a recreational level. Poulin-Charronnat et al., (2004, Experiment 3) showed that a change in timbre affected melody recognition both for expert musicians and non-musicians – if both were familiar with the melody's genre. Future studies may recruit *professional* musicians to clarify whether the effects of timbre change on familiarity and recollection, and thus the specific role of timbre as an intrinsic or extrinsic feature, depends on musical expertise.

Across experiments, the effect of timbre change on conscious recollection was further modulated by the distribution of learning episodes: The effect of timbre change on conscious recollection was particularly large when item presentations were distributed over several distinct learning episodes during the study phase. Consistent results were obtained with different estimates of recollection (Experiments 1 and 2: based on remember judgments; Experiment 3: based on explicit timbre recognition), suggesting that a common retrieval mechanism was involved across experiments:

Repeating a specific combination of timbre and melody particularly enhanced conscious recollection when learning episodes were distributed. This pattern of results is consistent with the notion that associative memory in particular benefits from distributed learning (Litman & Davachi, 2008; see also O'Reilly & Norman, 2002). Associations between potentially many individual features may become stronger when the same sensory features are re-activated in the same ensemble repeatedly. In line with this idea, when a melody is associated with the same timbre in separate learning episodes, timbre may become a particularly effective context cue.

In sum, distributed learning specifically enhanced recollection for same-timbre melodies. By contrast, a timbre change decreased overall memory performance and was observed for both recollection and familiarity. This pattern of findings suggests that timbre is stored in memory both as a context cue and as part of an integrated representation, presumably depending on the degree to which melody encoding promotes unitization. Thus, the distinction between recollection and familiarity can contribute to our understanding of how complex auditory stimuli are transformed into a memory representation that is later retrieved (in part) from episodic memory.

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7. References

Church, B. A., & Schacter, D. L. (1994). Perceptual specificity of auditory priming: Implicit memory for voice intonation and fundamental frequency. *Journal of Experimental Psychology: Learning Memory and Cognition, 20*, 521-533.

Cooper, L. A., Ballesteros, S., Schacter, D. L., & Moore, C. (1992). Priming and Recognition of Transformed 3-Dimensional Objects - Effects of Size and Reflection. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*, 43-57.

de Jonge, M., Tabbers, H. K., Pecher, D., & Zeelenberg, R. (2012). The Effect of Study Time Distribution on Learning and Retention: A Goldilocks Principle for Presentation Rate. *Journal of Experimental Psychology-Learning Memory and Cognition, 38*, 405-412.

Diana, R. A., Van den Boom, W., Yonelinas, A. P., & Ranganath, C. (2011). ERP correlates of source memory: Unitized source information increases familiarity-based retrieval. *Brain Research, 1367*, 278-286.

Diana, R. A., Yonelinas, A. P., & Ranganath, C. (2008). The effects of unitization on familiarity-based source memory: Testing a behavioral prediction derived from neuroimaging data. *Journal of Experimental Psychology-Learning Memory and Cognition, 34*, 730-740.

Eldridge, L. L., Knowlton, B. J., Furmanski, C. S., Bookheimer, S. Y., & Engel, S. A. (2000). Remembering episodes: a selective role for the hippocampus during retrieval. *Nature Neuroscience, 3*, 1149-1152.

Gardiner, J. M., Kaminska, Z., Dixon, M., & Java, R. I. (1996). Repetition of previously novel melodies sometimes increases both remember and know responses in recognition memory. *Psychonomic Bulletin and Review, 3*, 366-371.

Gardiner, J. M., & Radomski, E. (1999). Awareness of recognition memory for Polish and English folk songs in Polish and English folk. *Memory, 7*, 461-470.

Gregg, V. H., & Gardiner, J. M. (1994). Recognition Memory and Awareness - a Large Effect of Study Test Modalities on Know Responses Following a Highly Perceptual Orienting Task. *European Journal of Cognitive Psychology, 6*, 131-147.

Halpern, A. R., & Bartlett, J. C. (2010). Memory for Melodies. In M. R. Jones, R. R. Fay & A. N. Popper (Eds.), *Music Perception* (pp. 233-258). New York: Springer.

Halpern, A. R., & Müllensiefen, D. (2008). Effects of timbre and tempo change on memory for music. *Quarterly Journal of Experimental Psychology, 61*, 1371-1384.

Hautus, M. J. (1995). Corrections for Extreme Proportions and Their Biasing Effects on Estimated Values of D'. *Behavior Research Methods, Instruments, and Computers, 27*, 46-51.

Java, R. I., Kaminska, Z., & Gardiner, J. M. (1995). Recognition Memory and Awareness for Famous and Obscure Musical Themes. *European Journal of Cognitive Psychology, 7*, 41-53.

Litman, L., & Davachi, L. (2008). Distributed learning enhances relational memory consolidation. *Learning and Memory, 15*, 711-716.

McAuley, J. D., Stevens, C., & Humphreys, M. S. (2004). Play it again: did this melody occur more frequently or was it heard more recently? The role of stimulus familiarity in episodic recognition of music. *Acta Psychologica, 116*, 93-108.

Melara, R. D., & Marks, L. E. (1990). Interaction among auditory dimensions: Timbre, pitch, and loudness. *Perception & Psychophysics, 48*, 169-178.

Opitz, B., & Cornell, S. (2006). Contribution of familiarity and recollection to associative recognition memory: insights from event-related potentials. *Journal of Cognitive Neuroscience, 18*, 1595-1605.

O'Reilly, R. C., & Norman, K. A. (2002). Hippocampal and neocortical contributions to memory: advances in the complementary learning systems framework. *Trends in Cognitive Sciences, 6*, 505-510.

Parkin, A. J., Gardiner, J. M., & Rosser, R. (1995). Functional aspects of recollective experience in face recognition. *Consciousness and Cognition, 4*, 387-398.

Parkin, A. J., & Russo, R. (1993). On the origin of functional differences in recollective experience. *Memory, 1*, 231-237.

Peretz, I., Gaudreau, D., & Bonnel, A. M. (1998). Exposure effects on music preference and recognition. *Memory & Cognition, 26*, 884-902.

Piekema, C., Rijpkema, M., Fernandez, G., & Kessels, R. P. C. (2010). Dissociating the Neural Correlates of Intra-Item and Inter-Item Working-Memory Binding. *PLoS ONE, 5*, -.

Pitt, M. A., & Crowder, R. G. (1992). The role of spectral and dynamic cues in imagery for musical timbres. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 728-738.

Poulin-Charronnat, B., Bigand, E., Lalitte, P., Madurell, F., Vieillard, S., & McAdams, S. (2004). Effects of a change in instrumentation on the recognition of musical materials. *Music Perception, 22*, 239-263.

Radvansky, G. A., Fleming, K. J., & Simmons, J. A. (1995). Timbre Reliance in Nonmusicians' and Musicians' Memory for Melodies. *Music Perception, 13*, 127-140.

Rajaram, S. (1996). Perceptual effects on remembering: Recollective processes in picture recognition memory. *Journal of Experimental Psychology-Learning Memory and Cognition, 22*, 365-377.

Ranganath, C., Yonelinas, A. P., Cohen, M. X., Dy, C. J., Tom, S. M., & D'Esposito, M. (2004). Dissociable correlates of recollection and familiarity within the medial temporal lobes. *Neuropsychologia, 42*, 2-13.

Schacter, D. L., & Cooper, L. A. (1993). Implicit and explicit memory for novel visual objects: Structure and Function. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*, 995-1009.

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

Semal, C., & Demany, L. (1991). Dissociation of pitch from timbre in auditory short-term memory. *Journal of the Acoustical Society of America, 89*, 2404-2410.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of Measuring Recognition Memory - Applications to Dementia and Amnesia. *Journal of Experimental Psychology: General, 117*, 34-50.

Snodgrass, J. G., Hirshman, E., & Fan, J. (1996). The sensory match effect in recognition memory: Perceptual fluency or episodic trace? *Memory & Cognition, 24*, 367-383.

Spencer, W. D., & Raz, N. (1995). Differential effects of aging on memory for content and context: a meta-analysis. *Psychology and Aging, 10*, 527-539.

Trainor, L. J., Wu, L. A., & Tsang, C. D. (2004). Long-term memory for music: infants remember tempo and timbre. *Developmental Science, 7*, 289-296.

Tulving, E. (1985). Memory and Consciousness. *Canadian Psychology-Psychologie Canadienne, 26*, 1-12.

Warker, J. A., & Halpern, A. R. (2005). Musical stem completion: Humming that note. *American Journal of Psychology, 118*, 567-585.

Wolpert, R. S. (1990). Recognition of Melody, Harmonic Accompaniment, and Instrumentation: Musicians vs. Nonmusicians. *Music Perception, 8*, 95-106.

Yonelinas, A. P. (1997). Recognition memory ROCs for item and associative information: The contribution of recollection and familiarity. *Memory & Cognition, 25*, 747-763.

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46*, 441-517.

Yonelinas, A. P., & Jacoby, L. L. (1995). The relation between remembering and knowing as bases for recognition: Effects of size congruency. *Journal of Memory and Language, 34*, 622-643.

Zimmer, H. D., & Ecker, U. K. (2010). Remembering perceptual features unequally bound in object and episodic tokens: Neural mechanisms and their electrophysiological correlates. *Neuroscience and Biobehavioral Reviews, 34*, 1066-1079.

8. Tables

Table 1. Average frequencies of responses in the different response categories (Experiment 1 and 2: $Old_{Remember}$, Old_{Know}, Old_{Guess}, New; Experiment 3: Old_{same}, $Old_{different}$, Old_{guess}, New), separately for old melodies with the same timbre (old_{same}), old melodies with a different timbre ($old_{different}$) and new melodies and for the three Experiments. The standard error of the mean is given in parentheses.

		Experiment 1		**Experiment 2**			**Experiment 3**	
		1 x 2	**4 x 2**	**1 x 4**	**4 x 1**		**1 x 4**	**4 x 1**
same-timbre melody								
correct	**remember**	5.44 (0.43)	9.59 (0.35)	5.79 (0.51)	7.50 (0.55)	**same timbre**	7.80 (0.40)	8.94 (0.41)
	know	3.74 (0.38)	1.70 (0.31)	3.66 (0.29)	2.22 (0.30)	**different timbre**	1.33 (0.23)	0.97 (0.19)
	guess	0.79 (0.17)	0.35 (0.10)	1.00 (0.31)	0.69 (0.20)	**guess**	1.13 (0.22)	1.16 (0.21)
incorrect	**new**	2.03 (0.27)	0.35 (0.11)	1.55 (0.26)	1.59 (0.39)	**new**	1.80 (0.30)	1.00 (0.23)
different-timbre melody								
correct	**remember**	3.33 (0.24)	6.00 (0.42)	4.07 (0.35)	3.78 (0.38)	**same timbre**	4.70 (0.43)	3.91 (0.40)
	know	4.23 (0.22)	3.65 (0.32)	3.14 (0.31)	3.44 (0.31)	**different timbre**	3.30 (0.38)	3.50 (0.41)
	guess	0.95 (0.15)	0.73 (0.19)	1.34 (0.26)	1.13 (0.28)	**guess**	0.93 (0.28)	1.06 (0.23)
incorrect	**new**	3.49 (0.29)	1.62 (0.23)	3.45 (0.36)	3.66 (0.42)	**new**	3.17 (0.40)	3.53 (0.43)
new melody								
incorrect	**remember**	1.97 (0.33)	0.84 (0.21)	1.24 (0.32)	1.00 (0.27)	**same timbre**	3.57 (0.63)	2.47 (0.30)
	know	4.97 (0.34)	3.73 (0.40)	4.14 (0.45)	3.50 (0.44)	**different timbre**	2.77 (0.41)	3.13 (0.37)
	guess	2.05 (0.30)	1.70 (0.29)	2.41 (0.31)	1.53 (0.35)	**guess**	1.47 (0.27)	1.47 (0.29)
correct	**new**	15.00 (0.53)	17.73 (0.62)	16.21 (0.68)	17.97 (0.71)	**new**	16.03 (0.74)	16.88 (0.62)

Table 2. (Overall) Pr and Br, and Pr, Recollection and familiarity scores for same timbre and different timbre trials as a function of learning condition, separately for Experiments 1 and 2 (the standard error of the mean is given in parentheses)

	Experiment 1		**Experiment 2**	
	1 x 2	**4 x 2**	**1 x 4**	**4 x 1**
Pr	.41 (.02)	.65 (.03)	.47 (.03)	.54 (.04)
Br	.60 (.03)	.66 (.03)	.58 (.03)	.49 (.04)
Pr_{same}	.46 (.03)	.70 (.03)	.55 (.03)	.61 (.04)
$Pr_{different}$	.35 (.03)	.60 (.03)	.40 (.03)	.46 (.04)
$Recollection_{same}$	.36 (.03)	.72 (.03)	.41 (.04)	.56 (.04)
$Recollection_{different}$	.20 (.02)	.45 (.03)	.28 (.03)	.27 (.03)
$Familiarity_{same}$	.38 (.04)	.61 (.04)	.48 (.04)	.44 (.06)
$Familiarity_{different}$	.28 (.03)	.48 (.04)	.25 (.05)	.30 (.04)

Table 3. Proportions of correctly recognized timbre ($p_{hit\ timbre\ same}$, $p_{hit\ timbre\ different}$), proportions of false alarms ascribed to same or different timbre ($p_{false\ alarm\ same}$, $p_{false\ alarm\ different}$), and timbre recognition scores ($\text{timbre-recognition}_{same}$, $\text{timbre-recognition}_{different}$). The standard error of the mean is given in parentheses.

	1 x 4	**4 x 1**
timbre-recognition$_{same}$	.29 (.04)	.41 (.03)
timbre-recognition$_{different}$	.01 (.04)	-.03 (.04)

9. Figure Captions

Figure 1. Overview of "old" responses for each Experiment and learning condition. Each bar represents the proportion of "old" responses given for old melodies presented with the same or a different timbre and to new melodies, respectively. Within each bar, different shadings of gray indicate "remember" (dark gray), "know" (light gray) and "guess" responses (medium gray) for Experiments 1 and 2 and "same instrument" (dark gray), "different instrument" (light gray) and "guess" responses for Experiment 3. Error bars represent the standard error of the mean. Since corrected proportions are displayed (see Footnote 2 for details) values can exceed 1.

Figure 2. Recollection scores ($p_{Remember|old}$ - $p_{Remember|new}$) of same timbre (dark gray) and different timbre melodies (light gray), separately for the different learning conditions of Experiment 1 (left) and 2 (right). The error bars represent the standard error of the mean.

Figure 3. Familiarity scores ($p_{Know|old}/(1-p_{Remember|old})$ - $p_{Know|new}/(1-p_{Remember|old})$) of same timbre (dark gray) and different timbre melodies (light gray), separately for the different learning conditions of Experiment 1 (left) and 2 (right). The error bars represent the standard error of the mean.

Figure 4. Timbre-recognition scores ($p_{hit\ timbre}$ – $p_{false\ alarm\ timbre}$) of same timbre (dark gray) and different timbre melodies (light gray), separately fo the different conditions. The error bars represent the standard error of the mean.

10. Appendix

Appendix A

Instructions for Remember-Know-Guess

[….]. Please indicate after each melody whether it is "old" or "new" for you. For each melody classified as "old" you will be also asked to indicate whether you consciously recollect having heard the melody in the study phase or whether the melody merely seems familiar. You can also indicate that you guessed the melody was "old".

Differentiating recollection and familiarity

If you recollect having heard a melody before, you can remember details from the study episode (e.g. that the melody was played by a guitar or a specific thought that occurred to you while listening). If asked whether you recognize the name John Kerry*, you might remember that you heard the name on the evening news yesterday. This is an instance of conscious recollection.

If you find something is familiar, you simply know that you have encountered an item before. However, you can't recall any details from a previous encounter. You might simply know that you have heard the name John Kerry previously, without consciously recollecting a specific episode. In this instance the name is familiar to you.

*John Kerry was the presidential nominee of the Democratic Party in the 2004 presidential election [when the data were collected in 2010-2011, his name was rarely mentioned in German news].

Appendix B

Melody 8 (95 bpm)

Melody 21 (85 bpm)

Melody 28 (110 bpm)

Melody 37 (100 bpm)

Melody 43 (85 bpm)

Figure 1

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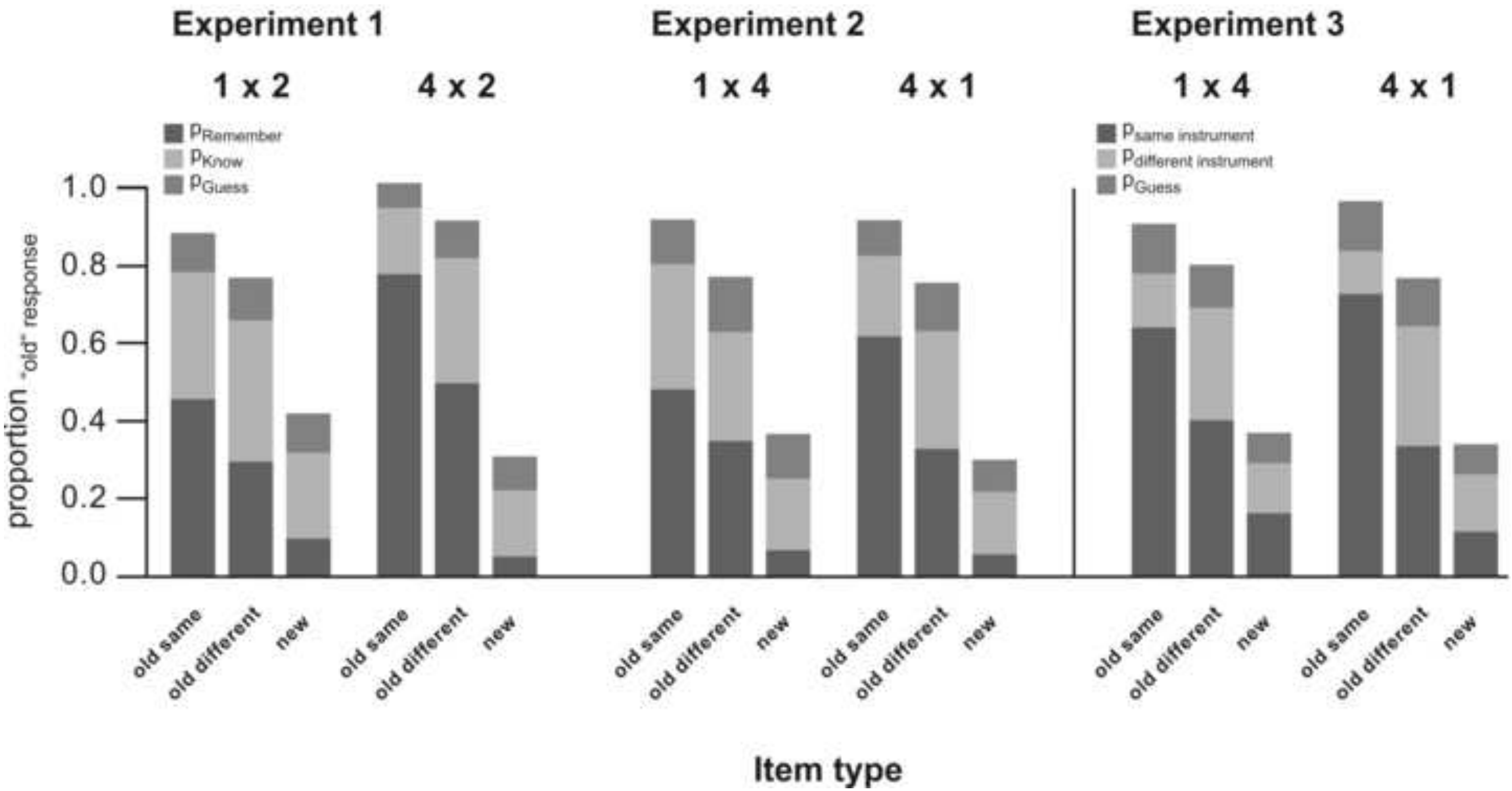

Figure 2
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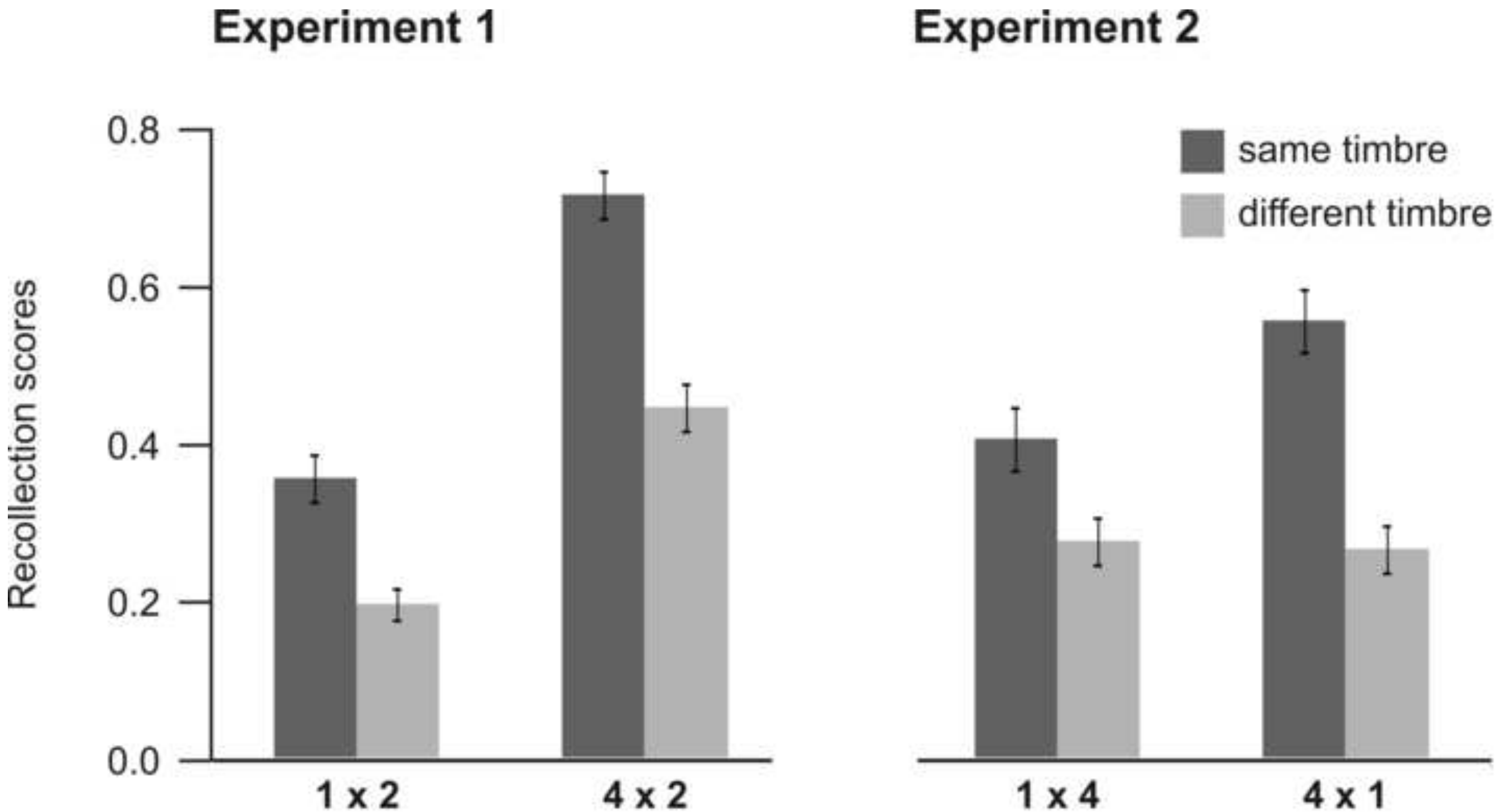

Figure 3
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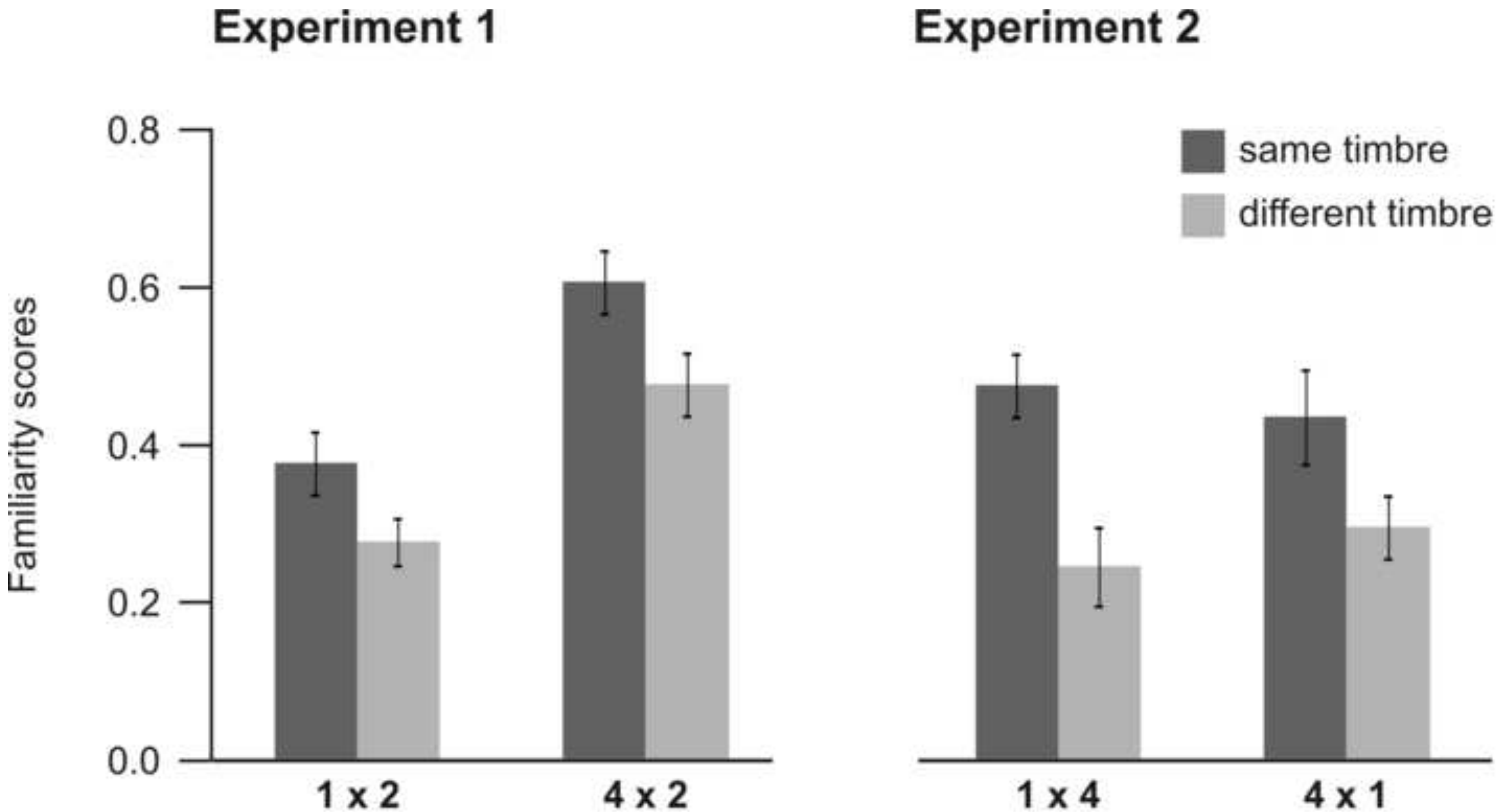

Figure 4
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