Dimensions of specificity in musical memory: Evidence from metrical restoration

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Abstract

How is musical memory organized? While classic studies of music perception appealed to schematic or symbolic knowledge structures, recent work suggests that listeners form highly-detailed auditory representations of music. Studies of *metrical restoration*—memory fill-in of the "beat" of a metrically-ambiguous melody—suggest some organizing dimensions in musical memory. However, many potential dimensions remain unexplored. The current study looked for effects of *mode* (major vs. minor)—a substantial organizing force in Western music—and *timbre* (what instrument is playing) on metrical restoration. Both mode and timbre can signify particular musical styles. In Experiment 1, listeners showed timbre specificity in metrical restoration, but not mode specificity. However, in Experiment 2, when timbres were extremely unique (one per melody), restoration effects were not observed, suggesting that too much variability leads to diffuse representations which are too weak to support metrical restoration. Implications for the nature of musical memory are discussed.

Keywords: perceptual restoration, meter, music perception, metrical restoration

Introduction

Recent research suggests that listeners form rich, detailed representations of perceptual information. These details later facilitate recognition (Creel, Aslin, & Tanenhaus, 2008; Goldinger, 1998; Gjerdingen & Perrott, 2008; Krumhansl, 2010; Schellenberg et al., 1999) and allow fill-in of ambiguous or absent information (Creel, 2011, 2012; Samuel, 1981). In music particularly, Creel (2011, 2012) has shown that listeners who hear particular metrical (or harmonic) information with a melody will later, upon hearing the melody alone, fill in the missing contextual information (harmony or meter) previously heard with that melody.

These findings are interesting in a number of respects. First, meter is a property previously thought to be largely signal-driven, with listeners extracting metrical regularities via statistical analysis of the signal itself. Creel's work suggests that *memory* influences meter perception. Second, these findings suggest that similarity-based organization of detailed auditory-temporal memories can support knowledge of distinct genres, such as different musical styles or different languages.

Yet many questions remain. What factors allow listeners to keep particular musical patterns distinct in memory—what keeps them from bleeding together? Inversely, what factors allow listeners to *generalize* metrical information? On first glance, a simple answer to both questions is *degree of similarity*: listeners generalize to similar musical patterns, and maintain specific representations of less-similar patterns. However, determining equivalent degrees of similarity on varied dimensions is not trivial, as perceivers' use of dimensions can change depending on task and attentional factors (Nosofsky, 1986). That is, we do not know what weights listeners assign to different dimensions in musical memory. Further, some dimensions may be processed integrally, such that their combined effect is not a simple sum of their individual effects. The current study aims to explore the relative strength of various auditory-musical properties on metrical restoration, providing insights into similarity-based organization in musical memory.

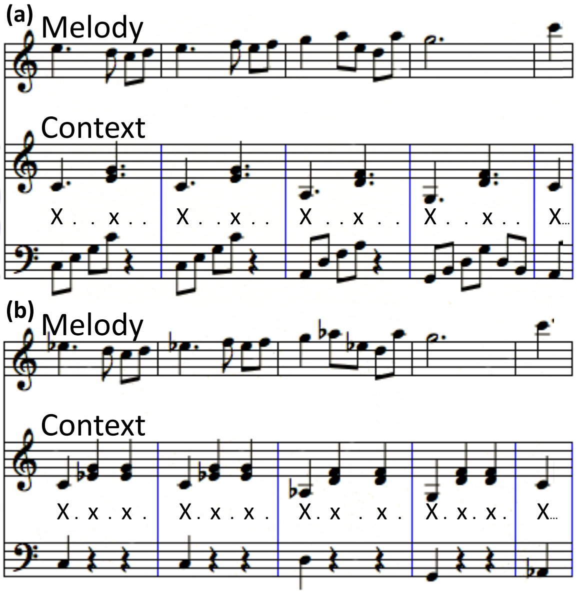

Figure 1. First four measures of a melody, in (a) major key with 6/8 metrical context; (b) minor key with 3/4 metrical context. Metrical grids indicate perceived emphasis in each meter: large X's denote strong beats, small x's weaker beats, and .'s indicate the subdivision of each beat. Beat subdivisions are identical in duration in both versions.

Known influences on metrical restoration

Previous work in my lab (Creel, 2011, 2012) has examined some factors in memory restoration of meter. In those experiments, as well as the new experiments described here, I exploit the 3/4 – 6/8 ambiguity, a musical "ambiguous figure." Certain musical passages with repeating series of 6 sub-beats can be interpreted as being in 3/4 meter (beats alternating evenly with sub-beats, X . x . x .) or in 6/8 meter (each beat is followed by two sub-beats: X . . x . .). Figure 1 shows examples of each meter.

In my experiments, each listener heard a set of 8-12 melodies. Half were presented in a musical context suggesting 3/4, and half in a context suggesting 6/8. Melodies were constructed to fit either metrical pattern, allowing a carefully counterbalanced design where, across listeners, each melody was heard in each meter equally often (Table 1). A listener heard each melody multiple times during an exposure phase. Next, all listeners heard each melody without its meter-implying context, followed by probe drumbeats in either 3/4 or 6/8. They were asked to rate how well the drumbeats fit with the preceding melody. The question was whether listeners would provide higher ratings for the drumbeats (meters) that matched the contexts that they had previously heard.

Table 1: Example conditions in a metrical restoration experiment. If listeners restore melodies' metrical contexts, then Listener 1 should provide higher probe ratings to the shaded probe trials, and Listener 2 should provide higher probe ratings to the unshaded probe trials.

	Exposure phase		**Test phase**	
Mel-ody	**Listener 1**	**Listener 2**	**All listeners**	
1	3/4 context	6/8 context	melody alone + 3/4 probe	melody alone + 6/8 probe
2	3/4 context	6/8 context	melody alone + 3/4 probe	melody alone + 6/8 probe
3	6/8 context	3/4 context	melody alone + 3/4 probe	melody alone + 6/8 probe
4	6/8 context	3/4 context	melody alone + 3/4 probe	melody alone + 6/8 probe

In Creel (2011, Experiment 2), listeners heard a set of 8 melodies that were very distinct from each other in terms of timbre, note rate (speed), mode (major, minor, other), and rhythmic patterns. Listeners provided higher ratings for drumbeat probes that matched the contexts they had heard with those specific melodies during the exposure phase. This suggests melody-specific memory for meter.

A second study (Creel, 2012) examined the role of cross-melody similarity on metrical restoration, and so presented melodies with a stronger similarity structure: two timbres, a single note rate, and similar rhythmic patterns across melodies. Listeners associated metrical information with timbre: they showed metrical restoration for a melody played in its original timbre, but not when it was played in the other timbre (as long as timbre and meter patterned consistently across melodies). Further, when melodies were constructed from two different sets of motifs (defined in that study as brief rhythm+contour patterns), listeners showed metrical restoration for new melodies with those motifs (Experiment 5).

Interestingly, the magnitude of the metrical restoration effects in the 2011 study was much larger than the effect in Creel (2012). Though there were a number of differences between the two sets of studies, one possibility is that the denser similarity structure of the melodies in the second paper led to greater generalization, but, conversely, less individuation. However, it is not clear which one (or more) of the unique properties of the melodies in the 2011 paper generated such strong restoration effects: rate, timbre, mode, rhythmic patterns. Do all dimensions of variation contribute additively to specificity/individuation in memory, or is one particular factor the "smoking gun"?

Unknown effects on metrical restoration

As seen in Creel (2011, 2012), timbre and motif content seem to be integral to musical memory. That is, metrical restoration shows *timbre specificity* and *motif specificity*. However, numerous dimensions of substantial music-theoretical importance remain untested. First, is there *mode specificity*? Mode, the particular pitch collection used in a musical piece, may be a signature of musical style: in Western music, the most common modes are major and minor. Other musical styles and cultures are characterized by yet other pitch collections (e.g. Castellano et al., 1984). Mode also contributes to emotional processing: Western listeners associate the major mode with happiness, and the minor mode with sadness (e.g. Hunter et al., 2008).

A second factor not previously examined is *rate*—the speed at which a musical piece is executed. Do listeners store melodies rate-specifically?

Finally, the role of timbre bears further exploration. Is timbre simply one of many cues that differentiate music in memory? If hearing melodies in two timbres allows listeners to keep metrical patterns distinct, then does hearing melodies in even more timbres create even more distinct metrical representations?

The current study

The current study examined influences of mode, rate, and timbre on the metrical restoration effect. Experiment 1 asked whether differences in mode (major or minor), alone or in combination with timbre cues, show specificity effects in metrical restoration. Experiment 2 asked whether maximal differences in timbre (1 vs. 12 timbres), and differences in rate, allow even more specificity in memory.

Experiment 1

The first experiment compares metrical restoration as a function of timbre-specificity (shown in Creel, 2012) and mode-specificity (not yet explored). We know that listeners show timbre-specific metrical restoration when timbre patterns consistently with meter. Does mode serve a similar function? That is, if mode patterns consistently with meter (e.g. major melodies are always heard in 3/4, minor melodies in 6/8), will listeners only restore the meter when a melody is heard in its original mode? Further, do timbre and mode combine additively to provide even more distinct musical memories, and even stronger restoration effects?

Method

Participants *N*=107 participants from the UCSD human participant pool received course credit for participation. Roughly equal numbers of participants took part in Experiments 1a (*n*=36), 1b (*n*=35), and 1c (*n*=36).

Stimuli The 18 melodies used here were originally used in Experiments 1-3 of Creel (2012). Melodies were edited slightly to generate clearer metrical contexts. The originals were all composed in major mode. Minor-mode versions were created by lowering the pitch of scale degree 3, and 6 and 7 in certain contexts, by ½ step, or about 6%. Melodies were exported from Finale software (MakeMusic, Inc.) in the key of C, played both in a vibraphone timbre and a muted-trumpet timbre. These two timbres were chosen to be highly distinct, based on Iverson and Krumhansl's (1993) perceptual scaling study of timbres.

Design Each participant heard only 12 of the 18 melodies during exposure. Test trials presented all 18 melodies, with manipulations as described below (examples in Table 2). All melodies were presented during the test phase followed by metrical probe drumbeats in 6/8 and 3/4.

Experiment 1a: different timbres. There was a consistent mapping of timbre to meter. For example, a participant might hear six major-mode vibraphone melodies in 3/4, and six major-mode muted-trumpet melodies in 6/8. A given participant heard only one mode (major or minor). Test trials presented each melody four times: two probe meters (original meter, other meter) x two timbres (original timbre, other timbre). Mode did not change from training to test.

Experiment 1b: different modes. There was a consistent mapping of mode to meter. For example, a participant might hear six major-mode vibraphone melodies in a 3/4 metrical context, six minor-mode vibraphone melodies in a 6/8 metrical context. Thus, the roles of mode and timbre were reversed relative to Experiment 1a. Test trials presented each melody four times: two probe meters (original meter or other meter) x two modes (original mode or other mode). Timbre did not change from training to test.

Experiment 1c: different mode+timbre combinations. There was a consistent mapping of timbre and mode to meter. For example, a participant might hear six major-mode vibraphone melodies in 3/4, and six minor-mode muted-trumpet melodies in 6/8. Thus, 3/4 melodies all had the same mode and timbre, while 6/8 melodies had the other mode and timbre, giving listeners *two* attributes to link to metrical information. Test trials presented each melody four times: twice for each probe meter, with either the original mode+timbre combination or the opposite mode+timbre combination.

Table 2: Example exposure conditions in Experiment 1.

Melody	Exp. 1a listener	Exp. 1b listener	Exp.1c listener
1	major, vib., 3/4	major, vib., 3/4	major, vib., 3/4
2	major, vib., 3/4	major, vib., 3/4	major, vib., 3/4
3	major, tpt., 6/8	minor, vib., 6/8	minor, tpt., 6/8
4	major, tpt., 6/8	minor, vib., 6/8	minor, tpt., 6/8

Note. Vib. = vibraphone; tpt. = muted trumpet.

Procedure The experiment was run in Matlab using Psychtoolbox3 (Brainard, 1997; Pelli, 1997). Sounds were presented via Sennheiser HD 280 headphones. Before the experiment proper, listeners completed a questionnaire on their academic and performing music experiences. They then went on to an exposure phase, followed by a test phase.

The exposure phase presented each of 12 melodies 6 times each (72 trials total). On each trial, listeners were asked to rate, by clicking in a 2-dimensional grid, the melody's affective quality (sad to happy, on the x-axis) and their subjective judgment of it (like to dislike, on the y-axis). This cover task aimed to keep participants attentive without alerting them to attend specifically to the meter. They were not told that they would later be tested on their knowledge of the melodies.

After exposure, participants were asked to rate drumbeats following each melody. Before beginning the test, they were presented with four example drumbeat probe trials, in order: four bars of Happy Birthday (3/4 meter) followed by "good" drumbeats (in 3/4); Happy Birthday followed by "bad" drumbeats (in 6/8); four bars of Greensleeves (6/8 meter) followed by "good" drumbeats (in 6/8); Greensleeves followed by "bad" drumbeats (in 3/4). They were prompted to consult the experimenter if they had any questions. After this, they proceeded to the test phase.

The test phase presented all 12 melodies that the participant had heard during learning, plus the 6 held-out melodies. Each melody was presented four times: once in the original mode and timbre followed by 3/4 probe drumbeats (4 measures plus a downbeat, or 13 beats); once in original mode and timbre with 6/8 drumbeats (4 measures plus a downbeat, or 9 beats); once in the other mode and/or timbre with 3/4 drumbeats; and once in the other mode and/or timbre with 6/8 drumbeats. For each participant, the mode/timbre and meter either matched or mismatched the contexts they had heard at training.

Results

All ratings were converted from raw pixel values to a scale ranging from -1 to +1 to allow easier interpretation.

Cover task Participants rated liking and affective content during exposure. Participants rated major melodies happier than minor melodies (1a: between-participants: $t(33)=4.79$, $p<.0001$; 1b: $t(35)=15.07$, $p<.0001$; 1c: $t(35)=11.30$, $p<.0001$). These ratings differences suggest that participants were attentive during exposure, and further, that they readily distinguished major and minor modes from each other.

Probe ratings

Experiment 1a. To determine whether probe ratings differed as a function of prior exposure and instrument match, an analysis of variance (ANOVA) on probe ratings was conducted with Exposure Meter (3/4 or 6/8), Probe Meter (3/4 or 6/8), and Timbre (original, switched) as within-participants factors. Bear in mind that, if there is a metrical restoration effect, then the interaction of Exposure Meter x Probe Meter should be significant. If restoration was timbre-specific—that is, if restoration was stronger when the melody was presented in the original timbre—then there should be a three-way interaction. For ease of interpretation, the restoration effect (Figures 2 and 3) is plotted in this paper as the average difference between the exposed probes (Exposure=3/4, Probe=3/4; 6/8, 6/8) and the unexposed probes (Exposure=3/4, Probe=6/8; 6/8, 3/4).

An Exposure Meter x Probe Meter interaction (*F*(1,34)= 5.30, *p*=.03) verified an overall metrical restoration effect. An interaction of Exposure Meter x Probe Meter x Timbre (*F*(1,34)=4.57, *p*=.04) suggested differences in metrical restoration as a function of timbre match. Considering each timbre individually, the Exposure Meter x Probe Meter interaction was only significant for original-timbre trials (*F*(1,34)=9.29, *p*=.004), but not for switched-timbre trials (*F*(1,34)=.06, *p*=.80). This replicates previous work (Creel, 2012) suggesting that, when meter and timbre covary, listeners do not generalize metrical restoration across a timbre change. Data from "new" melodies (heard for the first time at test) are not discussed due to space restrictions.

Experiment 1b. An ANOVA was conducted on probe ratings with Exposure Meter, Probe Meter, and Mode (original or switched) as factors. The ANOVA showed an Exposure Meter x Probe Meter interaction (*F*(1,35) = 6.84, p = .01), consistent with metrical restoration. If restoration was mode-specific, there should be a significant Exposure Meter x Probe Meter x Mode interaction. However, this interaction did not approach significance (*F*(1,35)=0.00, *p*=.98), implying that there was no decrement in metrical restoration when a melody was presented in the opposite mode as in training. Bearing this out, the Exposure Meter x Probe Meter interaction was significant for original-mode (*F*(1,35)=4.76, *p*=.04) and switched-mode (*F*(1,35)=4.66, *p*=.04) trials individually. This suggests that, in contrast to timbre specificity, listeners do not show mode specificity, but rather *mode generality*, in meter perception.

Experiment 1c. One might wonder if mode, while not showing specificity effects alone, might augment a timbre-specificity effect. An ANOVA with Exposure Meter, Probe Meter, and Mode+Timbre Combination (original, switched) was conducted on probe ratings. An Exposure Meter x Probe Meter interaction (*F*(1,35)=4.44, *p*=.04) suggested an overall metrical restoration effect. The Exposure Meter x Probe Meter x Mode+Timbre Combination interaction did not approach significance (*F*(1,35)=0.68, *p*=.42). However, considering each mode+timbre combination individually suggested that the metrical restoration effect was carried by original mode+timbre trials (significant Exposure Meter x Probe Meter interaction, *F*(1,35)=4.65, *p*=.04), rather than switched mode+timbre trials (not significant; *F*(1,35)=0.46, *p*=.50). This is numerically consistent with timbre specificity, as in Experiment 1a and Creel (2012). However, it is not at all consistent with stronger specificity effects when both mode and timbre pattern with meter.

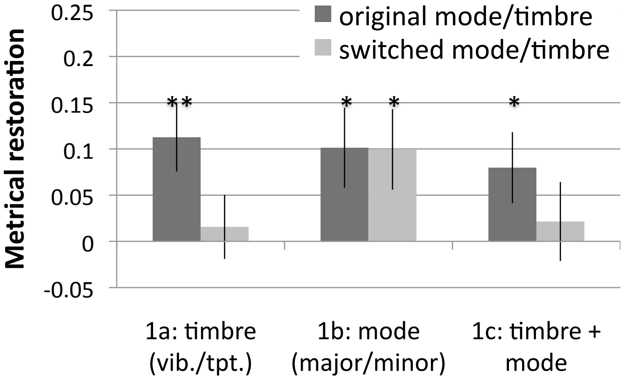

Figure 2: Experiment 1, metrical restoration as a function of whether the melody was presented in its original mode and timbre, or in a different mode and/or timbre.

Discussion

Experiment 1 replicated previous findings of timbre-specific metrical restoration (Creel, 2012). However, metrical restoration seems to generalize readily across a change in mode. Given the theoretical and affective importance of the major/minor mode distinction, and listeners' demonstrated sensitivity to the affective connotations of mode in the affect-rating cover task, this is somewhat surprising. One possible explanation is that, while harmonic cues to mode in the context were quite strong, cues to mode in the melody alone were weaker. (Note that timbre cues were still available in the melody alone.) If so, stronger harmonic contexts might reveal evidence of mode-specific metrical restoration. Another possibility is that in real musical styles, other factors that covary with mode carry the weight of mode's apparent stylistic impact. For instance, minor-mode melodies might use particular note sequences that are rare in major-mode melodies, and vice versa. Because the melodies used here were changed to minor mode simply by shifting certain pitches down by a small amount, no such stylistic differences were evident here.

Experiment 2

While Experiment 1 found no effects of mode on metrical restoration, there were effects of timbre: listeners did not generalize metrical restoration across a change in timbre. One might take this to imply that timbre differences alone could be used to keep different musical styles separate from one another. If this were true, then even more diversity should lead to highly-specific metrical storage. The current experiment addressed this hypothesis.

Listeners were exposed to 12 3/4 and 6/8 melodies either in a single timbre, or in 12 different timbres (one per melody). If more timbres yields more distinct melody representations, then twelve-timbre listeners should show stronger metrical restoration than one-timbre listeners. Crossed with this was a rate-variability manipulation: listeners heard melodies at a single presentation rate, or in three different rates (consistent for a particular melody). If listeners store melodies rate-specifically, then multiple rates should yield more distinct representations, and hence, stronger metrical restoration.

Method

Participants N=72 listeners from the UCSD human participant pool took part in the experiment.

Stimuli Stimuli were 12 major-mode melodies, a subset of those in Experiment 1. The 12 timbres were selected to be discriminable (Iverson & Krumhansl, 1993) and to span multiple instrument families (percussion, strings, brass, woodwinds) which have timbres similar to each other. For a given participant, each melody had a single rate and timbre.

Design Participants were randomly assigned to one of four combinations of timbre variability (1 timbre or 12) and rate (1 rate or 3). Timbres and rates were counterbalanced such that each timbre, rate, and timbre-rate combination occurred roughly equally across participants and melodies.

Procedure The procedure was identical to that in Experiment 1, except for differences in the stimuli heard.

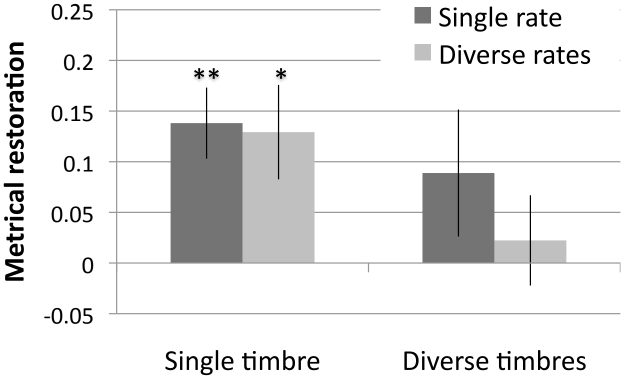

Figure 3: Experiment 2, metrical restoration effect as a function of timbre and rate variability.

Results

Metrical restoration (Figure 3) was assessed in an ANOVA on probe ratings with Exposure Meter and Probe Meter as within-participants factors, and Timbre (one or twelve) and Rate (one or three) as between-subjects factors. As in Experiment 1, an Exposure Meter x Probe Meter interaction (*F*(1,68)=14.52, *p*=.0003) indicated a metrical restoration effect overall.

However, none of the higher-level interactions—which would indicate timbre diversity or rate diversity effects—were significant: Exposure Meter x Probe Meter x Timbre (*F*(1,68)=2.47, *p*=.12), Exposure Meter x Probe Meter x Rate (*F*(1,68)=0.58, *p*=.45), or Exposure Meter x Probe Meter x Timbre x Rate (*F*(1,68)=0.34, *p*=.56). Further, the direction of the Timbre interaction effect was numerically opposite that predicted: metrical restoration was more robust for listeners who heard a single timbre than for those who heard 12 different timbres. Individually, metrical restoration was significant only in the two single-timbre conditions (no-variability: *F*(1,17)=14.64, *p*=.001; rate-variability: *F*(1,17) =7.25, *p*=.02). Thus, the strongest evidence for metrical restoration was carried by the low-diversity conditions.

Discussion

The results of Experiment 2 were counter to predictions of timbre specificity and rate specificity. There was no effect of rate diversity, which one might think would be closely linked to meter as both properties emerge from musical timing. Further, instead of stronger metrical restoration when each melody had a unique timbre, metrical restoration was numerically smaller—absent—when each melody had a unique timbre. Why wouldn't 12 more-distinct melodies (12 unique timbres) generate stronger metrical restoration, due to specificity, than 12 less-distinct (identical-timbre) melodies?

One possible answer is that listeners were not associating timbres themselves with meter, but were associating timbre-specific motifs with meters. That is, listeners were aggregating traces that grouped according to perceptual similarity. Recall that Creel (2012) showed that motif similarity influenced metrical restoration. Suppose that listeners in the current experiment also associated meter with motif-like rhythmic patterns. The melodies in the current study were built from a small set of moderately-ambiguous rhythmic patterns, many of which occurred across multiple melodies. If the same rhythmic patterns were stored separately for separate timbres, then listeners who heard few timbres (Experiment 1; one-timbre condition of Experiment 2) might build up relatively strong motif representations. On the other hand, listeners who heard multiple timbres (the 12-timbre condition of Experiment 2) would store a larger number of timbre-specific motif representations, but these would be weaker because they had been exposed too few times. Thus, the 12-timbre condition may have yielded motif representations that were too weak to generate significant metrical restoration.

General Discussion

I began by asking what factors influence metrical restoration. Experiment 1 suggests that timbre may be a stronger influence than mode (major vs. minor), at least in listening situations with limited harmonic information. Further, Experiment 2 suggests that similarity-based grouping of musical memory by timbre may decrease metrical restoration due to too little representational overlap.

Listeners may need many repetitions of motifs in a given timbre (and perhaps in a given rate) for metrical restoration to occur. As shown in Creel (2012), too *much* motif overlap between two meters blocks metrical restoration. The current study suggests that too *little* timbre-specific motif overlap in melodic patterns may also thwart metrical restoration. However, I hypothesize that this occurs for two different reasons: too much motif+timbre overlap *between* meters causes interference, while too little timbre-specific motif overlap *within* a meter yields representations too weak to generate restoration.

Ongoing work explores the roles of pattern (motif) overlap in metrical restoration. When Experiment 2 presented listeners with multiple rhythmic motifs in diverse timbres—i.e., rhythmic motifs were scattered across melodies and timbres—no metrical restoration was found. A new experiment (*N*=96 participants) again uses multiple timbres, but each rhythmic motif is in the *same* timbre, which should boost representation strength by increasing representational overlap. The magnitude of metrical restoration is .23, far exceeding (nonsignificant) diverse-timbre restoration observed in Experiment 2. This suggests that timbre uniqueness does not inhibit metrical restoration as long as timbres and motifs consistently cooccur. Whether distinct timbres *facilitate* motif encoding is still unknown.

The nature of musical memory

These results speak not only to restoration of metrical information, but also to the organization of musical memory itself. I have argued previously (Creel, 2012) that fine auditory detail in musical memory is not an epiphenomenon, but an organizing force, where similarity-based grouping leads to emergent clusters in memory which shape recognition and processing. Like the "phoneme restoration effect" (Samuel, 1981), metrical restoration and other varieties of musical restoration (harmonic; Creel, 2011) indicate the strength of memory in the processing of auditory events. While the incoming signal itself certainly shapes music processing, memory too is a sizable influence on perception. My studies thus far suggest that musical memory is organized along at least two dimensions: timbre and motif. Future work should assess additional factors in metrical restoration, and also whether metrical restoration and other types of musical restoration—particularly, harmonic restoration—are influenced by the same musical dimensions. If they are not, this might suggest differing attentional weights across dimensions (Nosofsky, 1986) for processing of metrical vs. harmonic information.

An additional question concerns the nature of motifs. Motif structure appears to be a strong organizing force in musical memory, but it is unclear what, functionally, counts as a motif. Creel (2012) defined it as a rhythmic pattern with a particular pitch contour, but many other possibilities are equally consistent with the data: a rhythmic pattern alone; clusters of similar but not identical rhythmic patterns.

Finally, these investigations have implications for other temporal perception phenomena. For instance, Brochard et al. (2003) showed an ERP signature of listeners' illusory perception of strong-weak alternations in a series of tones of equal amplitude. The research described here suggests that this effect may arise from memory activation of duple meters, the most common meter in Western music. Future studies of restoration effects should continue to reveal how temporal events are represented in the mind.

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