

Repetition Priming in Music

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The authors explore priming effects of pitch repetition in music in 3 experiments. Musically untrained participants heard a short melody and sang the last pitch of the melody as quickly as possible. Each experiment manipulated (a) whether or not the tone to be sung (target) was heard earlier in the melody (primed) and (b) the prime–target distance (measured in events). Experiment 1 used variable-length melodies, whereas Experiments 2 and 3 used fixed-length melodies. Experiment 3 changed the timbre of the target tone. In all experiments, fast-responding participants produced repeated tones faster than nonrepeated tones, and this repetition benefit decreased as prime–target distances increased. All participants produced expected tonic endings faster than less expected nontonic endings. Repetition and tonal priming effects are compared with harmonic priming effects in music and with repetition priming effects in language.

Keywords: repetition priming, naming, tonality, music perception

Repetition is ubiquitous in music. Repetition of melodic themes, motives, and rhythms is a fundamental technique in music composition. Furthermore, continuous frequencies are typically categorized into 5 to 12 pitch classes in the musical systems of most cultures, and in Western tonal music, pitches are repeated often within each musical piece. The importance and prevalence of repetition in music leads us to examine the cognitive effects of pitch repetition over short melodic fragments. Usually, repetition facilitates perception. However, it is not clear what happens when repetition is so prevalent. On the one hand, the large rate of repetition in music may aid listeners in expecting repetitions, which can aid perception of repeated events in music. On the other hand, the sheer volume of musical repetition across all pitch categories may serve to make its effects negligible.

Because the structure of music is largely learned and processed implicitly (Krumhansl, 1990; Tillmann, Bharucha, & Bigand, 2000), we examine the effects of repetition in music using a repetition priming paradigm. The priming paradigm is the most common methodology used to study implicit memory (Schacter, 1987). Two main kinds of priming effects have been documented: repetition priming, defined as a processing benefit for previously encountered stimuli (e.g., Brown & Carr, 1993; Church &

Schacter, 1994; Durso & Johnson, 1979; Levy & Begin, 1984; Roediger, 1990; Scarborough, Cortese, & Scarborough, 1977; Schacter, 1987; Tenpenny, 1995), and semantic priming, a processing benefit for stimuli related to those previously encountered (Blaxton, 1989; Freedman & Loftus, 1971; Loftus & Loftus, 1974; McKoon & Ratcliff, 1979; Stanovich & West, 1979). Repetition priming in particular is a very robust effect that occurs in many domains. Previous encounters have been shown to facilitate the processing of words (e.g., Durso & Johnson, 1979; Scarborough et al., 1977), syllables (e.g., Cholin, Schiller, & Levelt, 2004), syntactic structures (e.g., Wheeldon & Smith, 2003), environmental sounds (e.g., Chiu & Schacter, 1995), faces (e.g., Bruce, Carson, Burton, & Kelly, 1998), and visual features (e.g., Huang, Holcombe, & Pashler, 2004). Of these domains, language, and especially individual words, has been the most frequently studied. In language, word frequency has been shown to be an especially important determinant of repetition priming effects. Several studies have shown that high-frequency words do not receive as much of a benefit from prior exposure as low-frequency words (Forster & Davis, 1984; Jacoby & Dallas, 1981; Nevers & Versace, 2003; Scarborough et al., 1977).

Both repetition and semantic priming effects have been documented in language with many tasks. Generality across tasks ensures that priming is not a task-specific effect. Changing the task, however, can have important consequences for both the size and interpretation of the results. Common tasks include making a decision about a feature of the presented stimulus, naming the presented stimulus, and identifying the stimulus presented in noise (see Tenpenny, 1995, for a discussion of tasks used to assess priming in language). In these types of tasks, priming is reflected by faster response latencies and lower error rates for stimuli to which the participant had been previously exposed. Although the naming task is appropriate for material in which items are easily assigned consistent names across individuals, it is not appropriate for music, because most listeners (other than absolute pitch possessors) do not have names for musical pitches. We introduce here a variant on the naming task adapted for music with a nonmusician

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population. This task requires participants to repeat the final tone of a sequence as soon as possible upon hearing it, using a sung response. Latency to sing is measured from the onset of the final tone to the onset of the sung response. The advantage of this methodology is that it allows independent manipulation of pitch repetition, tonal expectancy, and serial position while not requiring musical training.

Priming Effects in Music

Although there is no evidence of repetition priming in music to date, some studies indicate a musical analogue of semantic priming (Tillmann & Bigand, 2002). This effect, termed *harmonic priming*, treats chords (simultaneities of musical pitches) as the basic unit to be primed, and it is defined as the ability of a harmonic context (instantiated by a sequence of chords) to facilitate the processing of related chords. Just as semantic priming in language is theorized to rely on connections within a network of interrelated words, harmonic priming concerns the ability of some musical chords to prime related chords (Bharucha & Stoeckig, 1986, 1987). This effect depends on listeners' knowledge of musical structure, learned over time (Tillmann et al., 2000). Because of their physical-acoustic properties and their statistical co-occurrence, certain tones, chords, and keys are more strongly related to each other. Hearing chords or combinations of chords can evoke the mental representation of the key whose statistical structure they fit best and can create expectations for common events in that key (Krumhansl, 1990; Meyer, 1956). The chord or pitch that is most indicative of a key and most expected in it is generally referred to as the tonic. Several studies have shown that presenting chords within or near a key primes the processing of other chords that are highly expected in that key (Bharucha & Stoeckig, 1986, 1987; Bigand, Madurell, Tillmann & Pineau, 1999; Bigand & Pineau, 1997; Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003).

In early studies of harmonic priming, Bharucha and Stoeckig (1986, 1987) presented primes consisting of one chord. The prime chord was played immediately before the target chord, with no masking between the prime and target. When the prime chord and the target chord were both members of a shared key, and thus closely related to each other, processing of the target was facilitated, compared to when the two chords were not closely related. Subsequent experiments (Tekman & Bharucha, 1992, 1998) showed that this effect was cognitive in nature and not due to overlapping harmonic spectra between primes and targets (i.e., a sensory account), as it could be reproduced without any shared tones.

Harmonic priming has also been demonstrated with longer musical contexts (Bigand et al., 1999, 2003; Bigand & Pineau, 1997). Bigand and Pineau (1997) used a seven-chord context before the target chord, the seventh of which was held constant. The target was either the highly expected tonic chord of the key established by the context or a less expected subdominant chord. This manipulation altered only the global context of the target, while the local context (the immediately preceding chord) was always highly related. Participants were quicker and more accurate on judging whether the target chord had been mistuned when it occurred in a globally expected context versus a globally less expected context. These results proved robust when applied to other decision tasks and musical contexts (Bigand et al., 1999;

Bigand, Tillmann, Poulin, D'Adamo, & Madurell, 2001; Tillmann & Bharucha, 2002; Tillmann & Bigand, 2001). This work was also consistent with Tekman and Bharucha's (1992, 1998) earlier experiments in supporting the cognitive account of harmonic priming over the sensory account, because global context and expectancy accounted for more priming than overlap or repetition of tones, except at the fastest tempi (75 ms per chord; Bigand et al., 2003).

Repetition Priming in Music

Given the strength of the harmonic priming results, as well as the noted similarities between priming in music and language (Tillmann & Bigand, 2002), it is surprising that repetition priming has not been reported in music. Although repetition has been shown to have a facilitative effect on perception of tones in explicit tasks (Deutsch, 1970, 1972), Bigand et al. (2003) saw no benefit on processing of a target chord when the prime context contained a (nonexact) repetition of the target chord; they suggested that music may not support repetition priming. Bigand, Tillmann, Poulin-Charronnat, and Manderlier (2005) used the harmonic priming paradigm to directly compare repetition priming effects with harmonic priming. They compared priming effects on target chords when the prime was an exact repetition, a harmonically related chord, or a harmonically distant chord. They found that exact repetition served as a better prime than a harmonically unrelated chord but was not as effective a prime as a harmonically related chord. In longer contexts, too, direct repetition of chords was not as helpful to a subsequent decision task as were harmonically related chord contexts. The authors suggested that music may be special in not supporting repetition priming, possibly due to expectations for change within music (see Meyer, 1956), and possibly due to the lack of semantics in music as compared with other domains, such as language and environmental sounds.

The nature of repetition priming effects in language is affected by the unit primed and the task used to measure priming effects (e.g., Tenpenny, 1995). Repetition may play more of a role in memory for individual pitches, the fundamental units of music, than it does in harmonic chord sequences. Connectionist models of harmonic priming treat pitches as the basic unit through which perceptual input arrives to the system (Bharucha, 1987; Tillmann et al., 2000). Palmer and van de Sande (1993) provided evidence from musicians' performance errors that pitches are the fundamental unit in production as well. Speech research also suggests that pitch is a good candidate for repetition priming. Church and Schacter (1994) manipulated the fundamental frequency of spoken words; listeners were better able to identify degraded target words when the frequency remained constant between study and test than when it had changed. This result held only for frequency, not for intensity. The authors suggested that the representation of pitch plays an important role in auditory priming (Church & Schacter, 1994). In sum, single pitches may be a natural unit for examining repetition priming in music.

Whereas harmonic priming effects have been measured largely with decision tasks, most of these tasks concern the relationship between certain elements within the chord and thus would not easily apply to individual pitches (but see Bigand et al., 2001, for a task that does not concern intrachordal relationships). Because these decision tasks require combining and comparing input from multiple pitches, an extra step beyond single pitch recognition, this

extra processing may mask repetition priming effects at the level of individual pitches. Furthermore, the transfer-appropriate processing framework (Morris, Bransford, & Franks, 1977) predicts more evidence of repetition priming if the task is more similar to the method of encoding. Indeed, Schacter (1987) and Roediger (1990) show evidence for a priming benefit for task similarity between study and test along several different lines, and Gabrieli et al. (1999) report benefits of other types of study–test similarities. In harmonic priming experiments, decision tasks may be quite dissimilar to the encoding process, because the former involves critical judgments where the latter does not.

In our experimental paradigm, participants sang back the final pitch that they heard in a melodic sequence; this response task is similar to the encoding phase because it does not involve making decisions about the pitch, and it supports a response latency measurement. The pitch reproduction task is similar to a naming task in language, but simpler, in that the participant does not have to convert from a visual to an auditory modality. Because vocalizing pitches is a skill possessed by most of the population, this is a natural task that a majority of people should be capable of performing, which allows us to assess repetition priming across a broad population.

Although repetition priming has not yet been documented in music, one model offers predictions for the time course of repetition priming in a production task (Palmer & Pfordresher, 2003). This model of sequence planning proposes that sequence events are planned continuously throughout a performance, with sequence events becoming more activated the closer they are to the current produced event. As a result of the contextual representation of each sequence event, the model predicts which sequence events will be most active in memory during production; pitches within three to four events from the currently produced event will influence production the most (Palmer & Pfordresher, 2003). Consistent with this prediction, the experiments described here varied the distance between the prime and the target between one and four events—those events predicted to be most active in memory. This model can also be used, as Palmer and Pfordresher (2003) point out, to predict memory for particular pitch sequences, as well as the likelihood of incorrect pitches being produced. It does not, however, deal directly with the question of implicit memory of previously heard tones.

Three experiments used the pitch singing paradigm to examine repetition priming effects on listeners' response latencies to sing a pitch. Participants heard a short melody and sang back the last tone (target) of the melody as soon as they could. We expected that target tones heard earlier in the melody (primed) would be produced more quickly than target tones that were not primed. We also expected this repetition priming effect to diminish as the primes were further distanced from the targets. Pitch repetition and prime–target distance were manipulated in variable-length melodies (Experiment 1) and in fixed-length melodies (Experiments 2 and 3). Experiment 3 changed the timbre of the target so that it differed from the prime. To control for the expectedness of certain pitches in melodic contexts that might influence response latencies, the target tones were also manipulated to represent highly expected (tonic) and less expected (nontonic) tones within each melodic context. Both repetition priming and priming from tonal expectancies represent common implicit processes. Therefore, participants in these experiments represented the general population

of amateur musicians, generally with limited singing experience and little explicit vocal training.

Experiment 1

Experiment 1 investigated the effect of pitch repetition in melodies on listeners' latency to sing the last tone in a musical sequence. Participants heard short melodies of two to five tones and sang the final pitch as quickly as possible. We manipulated whether the final pitch (target) had occurred earlier in the melody as a prime (repetition), as well as the distance between the prime and the target. Because pitch height (Sundberg, 1979) and interval size (Ranvaud, Thompson, Silveira-Moriyama, & Balkwill, 2001) have been shown to affect preparation latencies for singing and decision task latencies, respectively, we controlled for these and other possible confounds by keeping contour, melodic range, and rhythm the same across the melodies. Repeated tones were expected to be sung more quickly than nonrepeated tones; also, repetition at short prime–target distances should benefit response latencies more than at long prime–target distances. Latencies may be faster for more expected pitches, such as the tonic tone; therefore, the target was manipulated to be the tonic or nontonic tone. However, due to the shortness of the melodies used in this experiment, the effects of tonal expectation were expected to be small. A single tone condition was also included in which listeners heard and sang only one tone in each trial, in order to measure any individual differences in people's vocal frequency range, as well as to provide a baseline measurement for latencies to respond in the absence of sequence context.

Method

Participants. Participants were 24 women (only women were selected for this experiment, to control for vocal range) between the ages of 18 and 31 (mean age = 20.46 years). None were chosen for singing ability or prior vocal training. Participants reported a mean of 0.54 years of prior vocal training (range = 0–4 years), 4.65 years of singing in ensembles (range = 0–10 years), and 6.94 years of practice on an instrument (range = 0.5–16 years). Participants were given \$12 or course credit for their participation. All subjects reached a criterion of matching the pitch of the presented tone within less than one semitone (successfully fulfilling the task requirements) in at least 90% of trials or were excluded from the study. Subjects were excluded if they reported having absolute pitch or any diagnosed hearing disorders.

Stimulus materials. Stimuli included two subtypes: single tones and short melodies. There were 12 single-tone stimuli, each consisting of a pitch between B-flat₃ (233.1 Hz) and A₄ (440 Hz). Sixty-four short melodies were created for the experiment; these melodies varied in length between two and five tones. Four different base melody stimuli were created (shown in the Appendix): three in the major mode and one in the minor mode. Each base melody contained five tones, the first and last of which were the tonic. The penultimate tone was higher or lower in pitch than the final tone equally often, to control for direction of melodic contour change.

To confirm that the base stimulus melodies would be interpreted as ending with the tonic tone, we compared them with previously obtained measures of tonal fit. Krumhansl and Kessler's (1982)

listener ratings of fit for pitches from each tonal key were judged on a 7-point scale, where 7 represented a very good fit of a pitch to a key-defining context. These ratings were compiled into tonal profiles, which are a statistical measurement of the typical frequency and expectedness of each pitch class in each of the 24 major and minor keys in Western tonal music. Correlations were computed between the pitches contained in each base stimulus melody and the tonal profile for each of the 24 possible tonal keys. The correlations were highest for the intended key (mean $r = .80$, $p < .01$), which indicates that these melodies are highly likely to be interpreted as being in the intended key and ending on the tonic tone.

The initial and final pitches of the base melodies were manipulated to create nontonic and nonrepetition conditions for each base melody. All pitch changes across stimuli were either up two semitones or down one semitone. The four conditions are shown for one base melody in Figure 1. In the tonic ending conditions, the final tone is a tonic; the nontonic endings were always a pitch member of the dominant chord (the next most likely or expected chord in the stimulus key). In the repetition condition, the final tone was a repetition of a previously sounded tone; the nonrepetition tones were a pitch that did not occur previously in the melody. The factors of repetition and tonic ending were manipulated orthogonally to create four conditions. Because the first four tones in each sequence occurred equally often in either repetition condition and in either tonic ending condition, they set up the same melodic and tonal expectations across all conditions and thus serve as a control for influences of expectancy on response latencies. To check whether tonal strength could account for differences in repetition conditions, we compared average tonal strength (based on Krumhansl–Kessler correlations) between repetition and nonrepetition stimuli. Nonrepetition stimuli had a mean correlation to the intended key of $r = .617$, whereas repetition stimuli had a mean correlation of $r = .475$. Because these run in the opposite direction of the expected repetition priming effect, it is unlikely that differences in tonal strength across melodies or conditions could account for repetition priming benefits.

Melodic sequences were then adjusted to create different prime–target distance conditions. The distance between the target (last)

* = prime, O = target to be sung

Figure 1. Example stimuli used in Experiment 1 for each repetition and tonic ending condition, with prime–target distance of four events. Asterisks indicate the prime (or nonprime controls), and circled notes indicate the target tone to be sung.

* = prime, O = target to be sung

Figure 2. Example stimuli used in Experiment 1 for each prime–target distance, from the repeated, tonic ending condition. Asterisks indicate the prime, and circled notes indicate the target tone to be sung.

tone and its prime (first tone) was manipulated by reducing the length of the five-tone melodies, as shown in Figure 2. Intermediate tones were removed; this manipulation created stimuli of length four, three, and two tones, which have prime–target distances of three, two, and one tone, respectively. The total number of stimuli in the experiment was 4 (base melodies) \times 2 (repetition) \times 2 (tonic ending) \times 4 (length) = 64 melodic stimuli. Sixteen additional stimuli similar in design to the stimulus materials served as practice melodies. All melody tones lasted 350 ms with an interonset interval of 500 ms, to ensure that the sound had completely decayed before the following tone’s onset.

Four pitch masks were created to minimize carryover between trials. Each pitch mask lasted 2.25 s and contained 72 tones, consisting of quick pitch runs up and down the two octaves from C3 to C5, first as an upwards glissando, then as three downwards arpeggiated diminished seventh chords, and finally in four different nonrepeating random orders. Each tone duration was 31 ms with no intervening silence between tones.

Equipment. All stimuli were constructed from midi files and were sounded with the harpsichord patch (#007) from the “SB Live! Synth A” midi sound bank (Creative Technology, Milpitas, CA), which was chosen because of its quick onset and quick decay. All stimuli were presented over AKG-K271 headphones (AKG Acoustics, Vienna, Austria), and participants’ voices were recorded through an AKG-C420 head-mounted microphone (AKG Acoustics, Vienna, Austria) at a sampling rate of 44.1 kHz.

Design. All participants heard all combinations of each factor: pitch repetition (whether the last tone was repeated earlier in the melody), prime–target distance (one to four tones), and whether the last tone was the tonic (yes/no), yielding a $2 \times 2 \times 4$ within-subjects design. The single-pitch stimuli were presented in four pseudorandom orders. Each of the 12 single tones occurred four times within each ordering, leading to 48 total trials, with the condition that stimuli could not repeat until each member of the set had been used.

Trials of multiple-tone stimuli were blocked by prime–target distance. Four pseudorandom trial orderings were created for each block, such that there could not be two melodies in a row created from the same base melody and that trials from the repetition or nonrepetition condition could not occur more than three times

consecutively. Each stimulus was presented twice during the experiment, once during the first half of the block and once during the second half. Participants heard 32 trials in each of the four prime–target distance blocks, for a total of 128 total trials. The presentation order of the four blocks was counterbalanced with a Latin square based on the ordering 1-3-2-4 (numbers refer to the distance between the prime and the target in that block). Participants were randomly assigned to block orders.

Procedure. Participants first completed a questionnaire about their musical background. They were then given approximately 5 min of experimenter-guided vocal warm-up, in which they matched pitches and sang parts of musical scales. After this, participants were given the instructions and donned the head-mounted microphone and headphones.

In the first block, participants heard single-tone stimuli and were told to sing the tone as quickly as possible as soon as they heard it. Participants sang /ba/, which was chosen for its distinct onset and voiced quality, as well as its common vowel. They were told to sing at a comfortable volume and to hold the tone for about a second. Participants were informed that they would hear pitch masks between trials and that they were not going to be judged on their vocal performance quality, only on their pitch and timing. Participants received five practice trials before the first block; if they did not perform the task correctly (sang the wrong syllable, etc.), they received another five practice trials. In the short melody trial blocks, participants were told that they would hear short melodies and to sing the last tone of the melody as soon as possible upon hearing it. They were told how long each stimulus in that particular block would be, and they received four practice trials before each of these blocks.

All practice and experimental trials had the following structure (see Figure 3): One of the four pitch masks, chosen randomly, was presented, followed by a 1.75-s pause, and then the stimulus began. The time from the end of one melody to the beginning of the next pitch mask was 3.5 s, during which participants sang their response. Each block lasted about 5 min. Participants were offered a short break halfway through each block, during which they were reminded to sing as quickly as possible. The experiment lasted about 50 min.

Results

Latency to respond was measured from the time of the onset of the final stimulus tone (the target) to the first pitched part of the

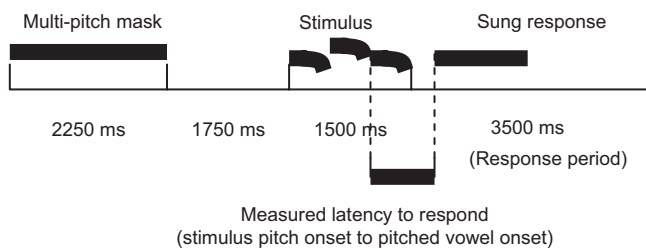


Figure 3. A sample trial with a prime–target distance of five events. Time is indicated on the x axis. This figure shows both what the participant hears (the pitch mask and the stimulus melody) and what she sings. The circled tone is the target tone. The bracket indicates the response latency, which is the time between the onset of the final stimulus tone and the onset of the participant’s singing.

sung tone that continued for at least 50 ms, determined by an algorithm that found the first zero crossing in the midfrequency range. This corresponded to the beginning of an audible pitch in the range of the final pitch of the melody. Thus, this measurement captures the time that participants began singing, rather than when they reached the correct pitch (see Murry, 1990, for a similar measurement of vocal recordings). Two types of production errors occurred: pitch errors, in which the participants sang a pitch other than the one presented (pitch difference of a semitone or more), and vocal errors, which included all other types of singing errors (e.g., singing before the stimulus was presented, singing a syllable other than /ba/, coughing while singing, etc.). Trials with either kind of error (less than 2% of all trials) were excluded from response latency analyses.

Single-tone trials. A one-way analysis of variance (ANOVA) on the response latencies in the single-note condition revealed no main effect of which pitch was sung. This control condition demonstrated that all pitches used in the experiment were within the vocal range of the participants.

Multiple-tone trials. The top panel of Figure 4 shows a histogram of response latencies across all conditions. A $2 \times 2 \times 4$ repeated-measures ANOVA on the response latencies by the factors of repetition, tonic ending, and prime–target distance revealed a main effect of repetition, $F(1, 23) = 12.92, p < .01$. Response latencies were shorter for pitches that had been sounded earlier in the stimulus melody (primed; $M = 711$ ms) than for those that had not ($M = 731$ ms). The main effect of distance approached significance, $F(3, 69) = 2.52, p = .065$; latencies were largest at Distance 4 in both repetition and nonrepetition conditions. Although the interaction between repetition and prime–target distance (shown in Figure 5) was not significant, the differences between response latencies for repetition and nonrepetition conditions were greatest at Distance 1 and smallest at Distance 4. Finally, the main effect of tonic ending approached significance, $F(1, 23) = 2.98, p = .098$; mean latencies for tonic endings (717 ms) were slightly faster than for nontonic endings (725 ms). There were no significant interactions among variables.

An analysis of the 40 total errors in participants’ responses (28 pitch errors, 12 vocal errors) showed significantly more errors on nonrepetition trials than on repetition trials, $F(1, 23) = 8.02, p < .01$, and more errors on nontonic-ending trials than on tonic-ending trials, $F(1, 23) = 8.77, p < .01$. Thus, conditions in which response latencies were slower also tended to contain more errors; there was no evidence of a speed–accuracy tradeoff. Of the pitch errors, 89% (25 of 28) were less than two semitones from the target pitch. Further analysis of the error types was not supported, due to the small number of errors.

Discussion

Repeated pitches were sung back with shorter latencies than nonrepeated pitches, despite intervening items between the prime and target. To our knowledge, this is the first demonstration of repetition priming of pitches in a music production task. Hearing the pitch beforehand may have led to more activation of that pitch, which made it easier to sing than other pitches nearby in frequency. There was a trend toward faster response latencies for tones repeated at shorter distances than at farther distances. However, in this experiment, the prime was always in the first sequen-

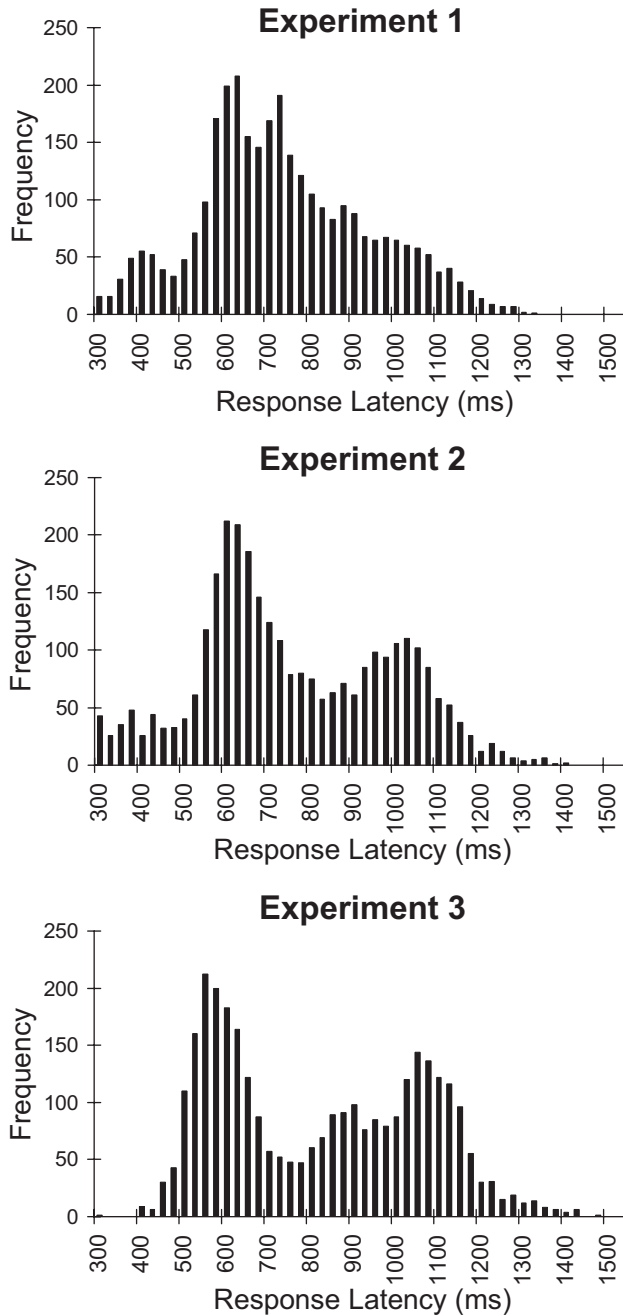


Figure 4. Histograms of the response latencies for Experiments 1, 2, and 3.

tial position of each stimulus melody; it never suffered any proactive interference. This may contribute to a primacy effect for the primes, which may weaken or override prime–target distance effects. We address this possibility in the next experiment.

The fact that small benefits were found in response latencies for tonic endings is not surprising, considering the overall shortness of the melodies used in Experiment 1. Because there was only a short time for tonal expectations to build, there was little chance for benefits of tonality to arise. Experiment 2 addressed the issues of

prime–target distance and tonal expectancies with longer melodies, in which larger tonal expectancies might facilitate response latencies.

Experiment 2

Experiment 2 presented longer melodies in which pitch primes were embedded within the melodies. The stimulus length and the prime–target distance were dissociated by presenting fixed-length melodies of five tones and manipulating the position of the prime within each melody. Embedding the primes within a longer melody ensured that primes did not benefit in salience over other pitches due to serial position effects; however, more tones occurred before or after the prime, depending on its serial position, than in Experiment 1. Lengthening these melodies should also have the effect of making the stimulus tonality more salient, as it allows more pitch events and more time to contribute to the formation of tonal expectancies. We expected larger effects of tonic ending on response latencies and that pitch repetition may most benefit the pitches that were less tonally expected.

Method

Participants. Participants were 24 women between the ages of 18 and 30 ($M = 20.88$ years). These subjects reported a mean of 0.5 years of vocal training (range = 0–3 years), 4.9 years of singing in ensembles (range = 0–15 years), and 6.44 years of practice on an instrument (range = 0–13 years), and they met the same pitch-matching requirements as participants in Experiment 1.

Stimulus materials and equipment. Stimuli and equipment in Experiment 2 were the same as in Experiment 1, except that the length of the multiple-tone melodies was held constant at five tones. The prime–target distance was manipulated by embedding the prime closer to the target within the five-tone sequences. Primes could occur in one of the first four serial positions of the melody, yielding prime–target distances of one to four tones. An example of this prime–target manipulation is shown in Figure 6. All other stimulus pitches were kept the same. This distance manipulation manipulates only the order of the tones. Correlations between the stimulus melodies and the tonal profiles based on listeners' ratings (Krumhansl & Kessler, 1982) of the intended key

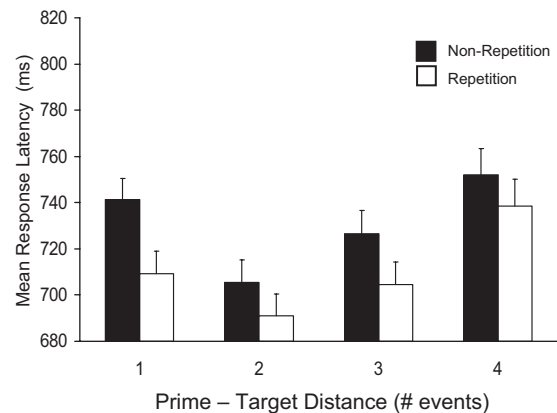


Figure 5. Mean response latencies by repetition condition and prime–target distance in Experiment 1, with standard error bars.

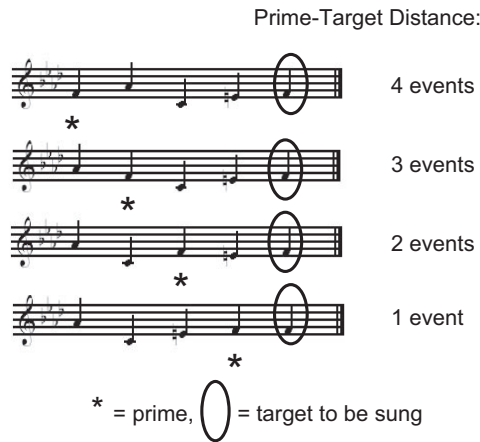


Figure 6. Example stimuli used in Experiment 2 for each prime-target distance, from the repeated, tonic ending condition. Asterisks indicate the prime, and circled notes indicate the target tone to be sung.

are the same as reported in Experiment 1, because the tonal profiles only take frequency of occurrence (and not serial order) into account.

Design and procedure. The design and procedure were the same as in Experiment 1, except that there was only one set of eight practice trials before the first block and no practice trials between experimental blocks (because melodies were of the same length).

Results

Response errors were coded the same way as in Experiment 1; they were less than 2% of the data and were excluded from response latency analyses.

Single-tone trials. A one-way ANOVA on response latencies in the single-tone condition revealed no main effect of pitch to be sung. Thus, the mean response latencies were equivalent across pitches.

Multiple-tone trials. The middle panel of Figure 4 shows a histogram of response across all conditions. Figure 7 shows the mean response latencies for repetition conditions by prime-target distance. A $2 \times 2 \times 4$ repeated-measures ANOVA on the response latencies by repetition, tonic ending, and prime-target distance indicated that the main effect of repetition was not significant, but there was a main effect of prime-target distance, $F(3, 69) = 6.59, p < .01$, as well as a significant interaction between pitch repetition and prime-target distance, $F(3, 69) = 12.49, p < .01$. Post hoc tests showed longer response latencies for Distance 1 than for other distances (Tukey's honestly significant difference [HSD] = 44.7, $p < .05$), and repetition trials had significantly shorter latencies than nonrepetition trials at Distance 1 (Tukey's HSD = 19.1, $p < .05$). Latencies were longer for repetition trials than nonrepetition trials at Distance 2 (Tukey's HSD = 19.1, $p < .05$). The fact that nonrepetition stimuli were matched to repetition stimuli at each prime-target distance (i.e., different stimuli represented each prime-target distance) may have contributed to the uneven nonrepetition bars shown in Figure 7.

Figure 8 shows mean response latencies for repetition condi-

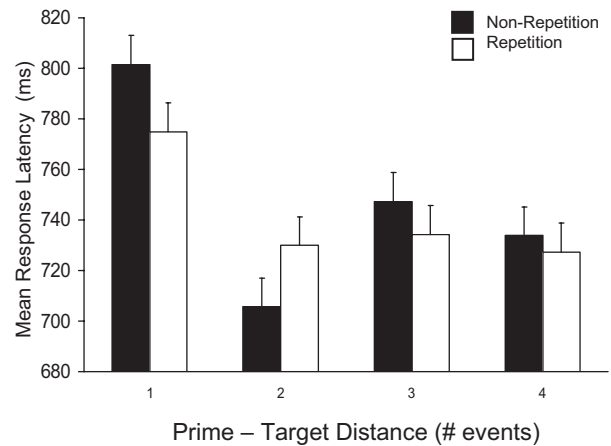


Figure 7. Mean response latencies by repetition condition and prime-target distance in Experiment 2, with standard error bars.

tions by tonic ending condition. There was a main effect of tonic ending, $F(3, 69) = 15.44, p < .01$; tonic endings were sung faster than nontonic endings, as expected for the longer stimuli. This factor interacted with pitch repetition, $F(1, 23) = 4.34, p < .05$, such that the tonic advantage was greater for nonrepetition tones than for repetition tones (Tukey's HSD = 14.72, $p < .05$), and the pitch repetition advantage was greater for nontonic endings than for tonic endings ($p = .06$).

An analysis of the 51 errors (39 pitch errors, 12 vocal errors) in participants' responses showed significantly more errors for nontonic-ending trials than for tonic-ending trials, $F(1, 23) = 5.28, p = .03$. Again, there was no evidence of a speed-accuracy tradeoff. Of the pitch errors, 74% (29 of 39) were less than two semitones from the target pitch. The small number of errors did not support further analyses.

Discussion

Experiment 2 replicated the finding of repetition priming with longer melodies. Listeners produced pitches faster when they were

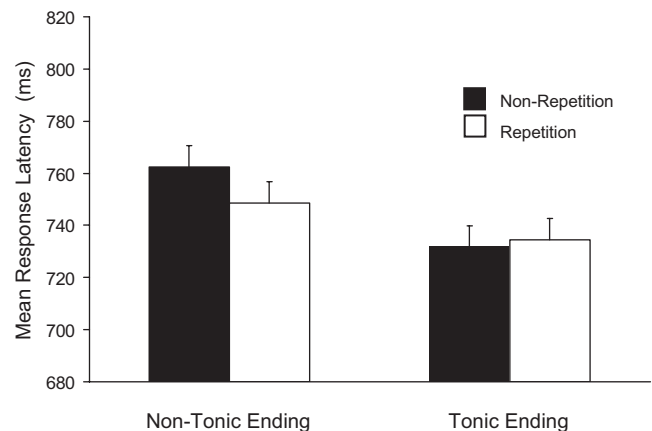


Figure 8. Mean response latencies by repetition condition and tonic ending in Experiment 2, with standard error bars.

heard earlier (repeated), and this effect was mediated by the prime–target distance. This experiment removed the potential confound in Experiment 1 between prime–target distance and total stimulus length; pitch primes occurred at different serial positions embedded within a melody. Repetition primes were most effective at short distances from the target and did not give much benefit at longer distances beyond three events from the target, consistent with Palmer and Pfordresher's (2003) predictions of the sequence range over which performers' contextual representation of musical sequences is active.

Pitches that formed tonic endings were produced faster than nontonic endings, as expected for the longer melodic stimuli in Experiment 2, which give more time and pitch information for tonal expectations to arise. Pitch repetition decreased response latencies more for nontonic endings than for tonic endings, which may be a floor effect; the tonic endings may have been so highly expected that repetition priming added little beyond tonal priming, similar to diminishing priming effects seen for more frequent words in language (Forster & Davis, 1984; Jacoby & Dallas, 1981; Nevers & Versace, 2003; Scarborough et al., 1977). Tonic pitches are the most frequently occurring tones in Western tonal music and might be predicted to be less influenced by repetition priming than nontonic tones. Participants' verbal reports suggested that repeated tones were overtly no more expected than nonrepeated tones but that tonic ending tones were more expected than nontonic ending tones, even for those participants without explicit musical knowledge.

Experiment 2 showed slowest latencies to respond to stimuli at prime–target distances of one tone. Distance 1's slower latencies are reminiscent of repetition blindness effects (e.g., Kanwisher & Potter, 1989; Miller & MacKay, 1994); satiation effects (e.g., MacKay, 1987; MacKay, Wulf, Yin, & Abrams, 1993); and a psychological refractory period (e.g., Miller & Alderton, 2006; Pashler, 1994), in which the similarity of two successive items can slow reaction times. The faster response latencies at a prime–target distance of two tones for nonrepeated pitches than for repeated pitches were, however, unexpected. If this reversal of the priming effect and the increased response latencies at Distance 1 are due to repetition of physical characteristics of the prime and target, then changing the physical characteristics of the target relative to the prime should yield similar responses across Distance 1 and Distance 2 conditions. If repetition priming effects are solely sensory in basis, then a physical difference between prime and target should remove the repetition priming effects. We explore this rationale in the next experiment.

Experiment 3

Experiment 3 employed the same priming paradigm as Experiment 2, but the timbre of the target tone differed from the timbre of the preceding melodic sequence (including the prime). Thus, the prime and target were no longer physically identical, and priming that may have occurred in Experiment 3 should not have been due solely to sensory similarity between the prime and the target. Comparisons of these findings with Experiment 2 indicate how much of the priming effect is due to cognitive versus sensory priming, and to what extent timbral change affects the magnitude of repetition priming. We expected to find similar priming effects as in Experiment 2 with faster response latencies for short prime–

target distances and less benefit at longer prime–target distances. We also expected to find a tonic effect, as the same long sequences were employed as in Experiment 2.

Method

Participants. Participants were 24 women between the ages of 16 and 30 ($M = 21.96$ years). These subjects reported a mean of 0.93 years of vocal training (range = 0–5 years), 6.25 years of singing in ensembles (range = 2–15 years), and 6.68 years of practice on an instrument (range = 0–13 years), and they met the same pitch-matching requirements as participants in the previous experiments.

Stimulus materials and equipment. Stimulus materials and equipment were the same as in Experiment 2, except that the timbre of the final tone of each melody was different from the timbre of the tones preceding it. The first four tones were sounded with the harpsichord patch (#007) from the "SB Live! Synth A" midi sound bank, as in the previous experiments. The final tone was sounded with the acoustic guitar (steel) patch (#026), which was chosen because of its similar amplitude envelope (especially the short onset) but dissimilar spectral content, giving it similar timing properties but a dissimilar sound. In order to allow for comparisons between multitone and single-tone stimuli, the single-tone stimuli were also sounded with the acoustic guitar timbre.

Design and procedure. The design and procedure were the same as in Experiment 2.

Results

Response errors were coded the same way as in the previous experiments; they formed less than 1% of the total data and were excluded from response latency analyses. The total number of errors ($N = 10$) was too small to support error analyses.

Single-tone trials. A one-way ANOVA on response latencies in the single-tone condition revealed a main effect of pitch to be sung, $F(11, 253) = 3.12, p < .01$. Subjects showed increasing mean response latencies across higher-pitched tones. A reanalysis of this data over only the range of tones used in the multiple-tone trials (excluding responses for the highest two and lowest two tones) showed no effect of pitch to be sung, $F(7, 161) = 1.33, ns$, indicating that pitch height did not affect mean response latency over the pitches used in the multitone trials.

Multiple-tone trials. A $2 \times 2 \times 4$ repeated-measures ANOVA on the response latencies by the factors of repetition, tonic ending, and prime–target distance showed a main effect of tonic ending, $F(1, 23) = 11.51, p < .01$; tonic endings were produced with a faster latencies than nontonic endings. There was also a main effect of prime–target distance, $F(3, 69) = 3.56, p = .02$; response latencies for prime–target distances of one or four were longer than those for prime–target distances of two or three. Surprisingly, there was no main effect of repetition, nor did it interact with any other variables.

As shown in the bottom panel of Figure 4, the histogram of all response latencies in Experiment 3 indicated a bimodal distribution with a trough at 750 ms and peaks near 550 ms and 1000 ms (one to two interonset intervals [IOIs] past the stimulus ending at 0 ms). As seen in trends in Experiment 2, the longer stimuli used in Experiment 3 caused some participants to respond around one or

two beats (stimulus IOIs) after the end of the stimulus. The combined bimodal groups in Experiment 3 yielded average response latencies slower than in Experiment 1 (94 ms slower), $t(6142) = 16.53, p < .01$, and in Experiment 2 (65 ms slower), $t(6142) = 10.83, p < .01$.

Differences in repetition priming between the bimodal populations were evaluated in an ANOVA that added a factor that grouped participants into slow and fast responders based on their average response latency, using a threshold of 750 ms (the halfway point between two stimulus IOIs, which corresponds to the peaks in the histogram in Figure 8). We refer to the factor henceforth as *speed*. Besides the main effect of speed, $F(1, 22) = 88.17, p < .01$, this reanalysis revealed an interaction between speed and repetition, $F(1, 23) = 9.61, p < .01$, such that fast-responding participants showed a significant repetition effect (Tukey's HSD = 11.22, $p < .05$), whereas slow-responding participants showed no repetition effect. Nine of the 10 fast-responding participants in Experiment 3 showed a positive repetition priming effect, whereas only 5 of the 14 participants with average response latencies over 750 ms showed this effect. Examination of musical background questionnaires indicated that fast-responding participants had more

years of experience singing in ensembles (7.95 years) than slow-responding participants (5.04 years), though this difference did not reach significance, $t(22) = 1.76, p = .09$.

There was also a three-way interaction between prime-target distance, repetition, and speed, $F(3, 66) = 3.50, p = .02$. As shown in Figure 9, fast-responding participants showed a benefit of repetition effect that decreased as prime-target distance increased; the largest repetition effect was at Distance 1 and the smallest effect at Distance 4. Due in part to the reduced power of the smaller sample size, only the fast-responding participants at Distance 1 showed a significant difference between nonrepetition and repetition conditions (Tukey's HSD = 22.37, $p < .05$). Slow-responding subjects showed no reliable differences between repetition and nonrepetition conditions at any prime-target distance.

Combined Reanalysis

To examine effects of individual differences in response speed across the three experiments, the analyses were conducted on the combined data from Experiments 1–3, adding speed (greater than or less than 750 ms average response latency) as a between-subjects factor. Experiment 1 had 15 fast-responding participants and 9 slow-responding participants, and Experiment 2 had 14 and 10, respectively. Overall there were 39 fast-responding participants and 33 slow-responding participants. Eighty-five percent of fast-responding participants produced faster responses for repetition trials than nonrepetition trials, compared with 45% of slow-responding participants. Fast-responding participants showed significantly more years of singing in ensembles, $t(70) = 2.33, p = .02$, and practicing other instruments, $t(70) = 2.64, p = .01$, than slow-responding participants.

A mixed-design ANOVA on the response latencies across the three experiments revealed main effects of repetition, $F(1, 70) = 13.38, p < .01$, tonic ending, $F(1, 70) = 26.30, p < .01$, and prime-target distance, $F(3, 210) = 8.09, p < .01$, as well as speed, $F(1, 70) = 228.58, p < .01$. There were also significant interactions between repetition and prime-target distance, $F(3, 210) = 4.92, p < .01$, and between repetition and tonic ending, $F(1, 70) = 5.75, p = .02$. Response speed interacted with repetition, $F(1, 70) = 19.61, p < .01$, and also with tonic ending, $F(1, 70) = 7.16, p < .01$. Fast-responding participants showed larger repetition priming and larger tonic priming effects than slow-responding participants. The only significant higher-order interaction was between repetition, prime-target distance, and speed, $F(3, 210) = 3.43, p = .02$, shown in Figure 10. Post hoc comparisons showed significantly faster responses for repetition conditions over nonrepetition conditions at prime-target distances of one event, $t(1246) = 5.46, p < .01$, and three events, $t(1246) = 3.05, p < .01$, among fast-responding participants, and marginally significant effects at Distance 4, $t(1246) = 1.76, p = .08$. A follow-up ANOVA including the factor of Experiment found no effect of repetition among slow-responding participants at any prime-target distance across experiments or within experiments.

We examined further the repetition priming effect at prime-target distance of two events by contrasting that data from the fast-responding subjects in each of the three experiments. The ANOVA on fast-responding participants' data by repetition, tonic, distance, and experiment was conducted. Along with the same main effects and significant interactions as before for repetition,

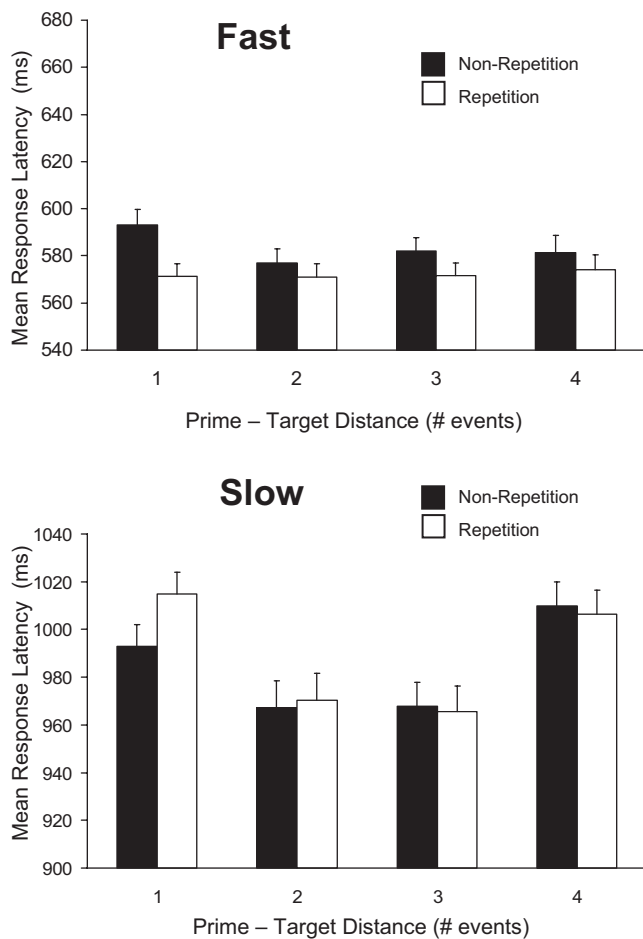


Figure 9. Mean response latencies by repetition condition and prime-target distance for fast- and slow-responding participants in Experiment 3, with standard error bars.

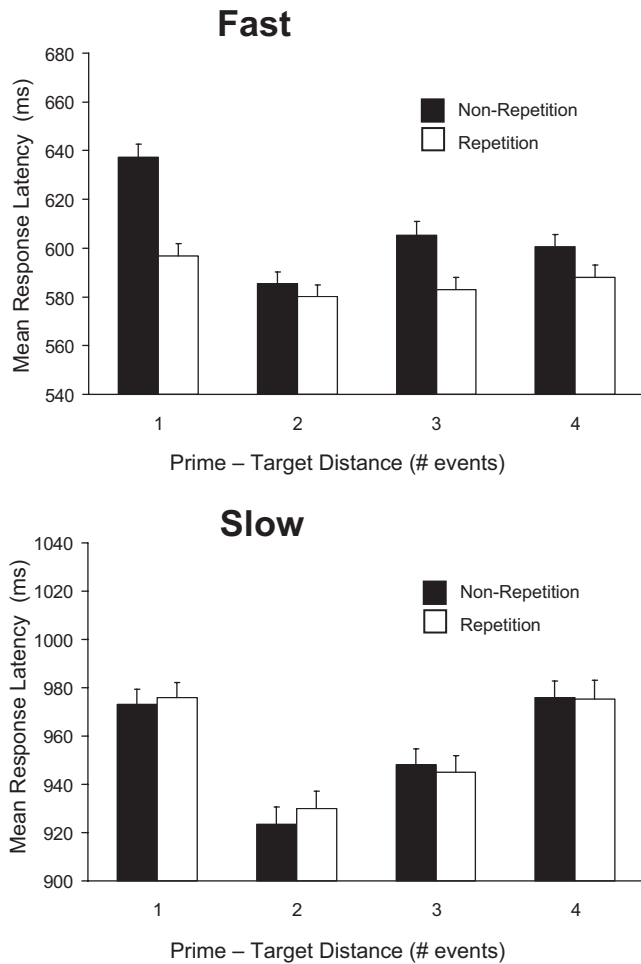


Figure 10. Mean response latencies by repetition condition and prime-target distance for fast- and slow-responding participants across all experiments, with standard error bars.

tonic ending, and prime-target distance, we found a significant interaction between repetition and experiment, $F(2, 36) = 4.18$, $p = .02$. In addition, the three-way interaction between experiment, repetition, and prime-target distance (shown in Figure 11) approached significance, $F(6, 108) = 2.14$, $p = .055$. Planned comparisons on the data at prime-target Distance 2 indicated a significant interaction between repetition and experiment across Experiments 1 and 2, $F(1, 27) = 11.04$, $p < .01$, and across Experiments 2 and 3, $F(1, 27) = 6.12$, $p = .02$, and no differences between Experiments 1 and 3, $F(1, 27) = .986$, *ns*. Thus, the priming effect at prime-target Distance 2 was different in Experiment 2 (repetition effect = -19 ms), when compared with Experiment 1 (repetition effect = 21 ms) or Experiment 3 (repetition effect = 11 ms).

Discussion

Experiment 3 showed that repetition priming effects extend to targets that differ in timbre from primes, but only for those participants whose average response latencies were less than 750 ms after the target tone. For the fast responders, the priming

benefit decreased as prime-target distance increased, whereas slow responders showed no benefit of repetition. The delayed responses of the slow responders may be outside the limited range of repetition priming effects. The effects of prime-target timbre differences were most apparent at Distance 1 response latencies, which were relatively shorter in Experiment 3 compared with other distances, than in previous experiments; these findings suggest that perception of the second stimulus onset for immediately repeating prime-target frequencies (at Distance 1) may have taken longer in previous experiments due to failure to discriminate the first (repeated) pitch from the onset of the second (same) pitch.

Experiment 3 also replicated the tonic priming benefits, with faster responses to tonic ending tones than nontonic ending tones for all participants. Notably, the fast-responding participants (who showed larger repetition effects) showed the same repetition benefits across all prime-target distances, in contrast to the reversal at Distance 2 seen in Experiment 2. Comparisons across experiments among fast-responding subjects indicated similar repetition priming effects at Distance 2 in Experiments 1 and 3, suggesting that the timbre change in Experiment 3 increased the repetition effect for prime-target pairs that are separated by only one tone. We return to explanations of this finding in the next section.

General Discussion

Three experiments documented priming effects from pitch repetition in music, a domain in which natural pitch repetition is ubiquitous. Participants with little singing experience sang back the final tone of short melodies faster when it was a repetition of a previously heard tone in that melody. Although previous work suggested that repetition might not facilitate perceptual processing of music (Bigand et al., 2003, 2005), the studies reported here showed a benefit for previously heard pitches. The size of the repetition priming effect (~ 20 ms) was consistent with effect sizes for repetition priming in language (Balota, Boland, & Shields, 1989; Bodner & Masson, 2001; McLennan & Luce, 2005). The first experiment documented pitch repetition priming at all prime-target distances in short melodies, with larger benefits at shorter distances; the second experiment showed benefits of repetition priming only at short prime-target distances in longer musical sequences. A weakened repetition benefit across longer prime-target distances is consistent with constraints on the time course of repetition priming in memory tasks (Ebbinghaus, 1885; Forster & Davis, 1984; Jacoby & Dallas, 1981) as well as response preparation tasks (Palmer & Pfordresher, 2003; Pfordresher & Palmer, 2006). The third experiment showed repetition priming even when primes and targets differed in timbre, suggesting that sensory priming alone could not account for the pitch repetition advantage. All experiments showed that repetition priming effects were modulated by overall response speed; fast-responding participants showed consistent repetition priming benefits, whereas slow-responding participants did not.

Priming benefits for tonic tones (the most stable and expected tones in Western tonal music) were found for all participants and were stronger in long melodic contexts than in short ones. Participants were able to produce tonic tones faster than less expected nontonic tones, consistent with previous findings of harmonic priming (Bharucha & Stoeckig, 1987; Bigand et al., 1999) and findings that listeners will most strongly expect the

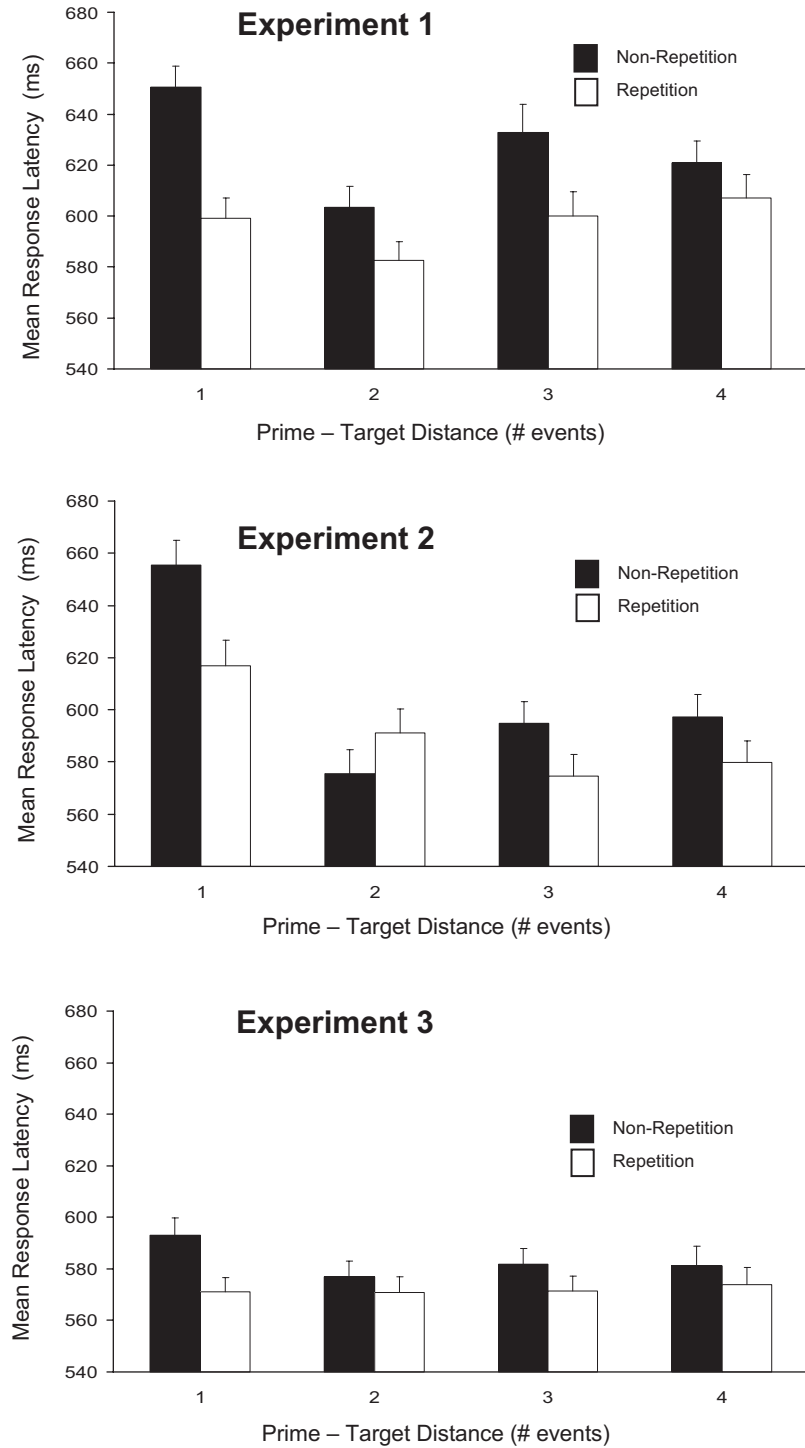


Figure 11. Mean response latencies by repetition condition and prime–target distance for fast-responding participants in Experiments 1, 2, and 3, with standard error bars.

tonic tone in tonal melodies (Krumhansl & Kessler, 1982). Because a melodic context is required to establish the tonic (key) of a melodic sequence (Bharucha & Stoeckig, 1986; Krumhansl, 1990; Tillmann et al., 2000), the longer melodies of Experiments 2 and 3 may have more strongly activated a tonal

representation and thus generated stronger tonal expectations, consistent with perceptual models of tonality (Bharucha, 1987; Tillmann et al., 2000). The fact that the nontonic ending in these experiments was chosen to be close in frequency, as well as a member of the next-most expected (dominant) chord, makes the

tonal priming benefits documented here especially strong; tonal priming differences may have been larger if less expected pitches were used in the nontonic ending conditions. The stability of the tonic tones may also convey a memory advantage compared with nontonic tones.

Repetition priming and tonal priming tended to have separate effects overall on response latencies. The experimental design, which balanced repetition and tonic ending against each other, ensured that these were separable effects; tonal priming was not responsible for repetition priming or vice versa. Moreover, the nonrepetition stimuli had stronger tonal strengths than the repetition stimuli. Thus, an account of repetition priming in terms of tonal priming would actually predict faster responses for nonrepetition stimuli, which was not found overall. Repetition priming may be a basic function of how individual pitches are represented in memory, regardless of prior knowledge or experience, whereas tonal priming may reflect specific knowledge of relationships among pitches that get established over larger sequence contexts. In addition, these processes operate over different timescales. Repetition priming appears to be temporally constrained to short prime–target distances, whereas tonal priming appears to require longer stimulus contexts. Thus, when prime–target distances are short, repetition priming can be the stronger process, whereas when melodic contexts are long, tonal priming can be the stronger process.

Interestingly, response latencies indicated two groups of responders: fast responders, whose mean latency tended to center around one interonset interval after the target, and slow responders, whose mean latency centered around two interonset intervals. Entrainment to the time course of the stimulus melodies may have affected response latencies in these experiments. Furthermore, fast-responding participants showed larger benefits of repetition priming than slow-responding participants. Although participants with more musical experience tended to respond more quickly, prior musical experience was not as effective of a predictor of repetition priming as was mean response latency. Despite the instructions, slow-responding participants may not have responded as quickly as possible to the stimulus, and priming effects may have been lost while those participants waited to produce their responses. A related explanation is that some participants may have delayed their responses more than necessary to avoid the possibility of an incorrect response. If the slow-responding participants were induced to respond more quickly, they might show the same pattern of repetition priming benefits as the fast-responding participants. Inducing faster responses, however, may prove difficult if entrainment effects increase with stimulus length for temporally predictable stimuli, as in Experiments 2 and 3. Overall, these findings suggest that stimulus properties should be considered in measurement of response latencies to event sequences.

Fast responders also showed temporal constraints on the course of repetition priming across prime–target distances. Across the three experiments, fast-responding participants showed largest repetition priming effects for prime–target distances of one event; these effects decreased across increasing prime–target distances (with one exception). In Experiment 1, participants showed significant repetition priming at all prime–target distances, with greatest repetition priming benefits at Distance 1 and smallest benefits at Distance 4. In Experiment 2, fast-responding subjects still showed largest repetition priming benefits at Distance 1, but there was a reversal in the repetition priming effect at a prime–target distance of two events. Experiment 3

examined the hypothesis that this reversal at Distance 2—as well as the repetition priming effect itself—was a result of an exact repetition of the physical stimulus by changing the timbre of the target tone. Fast-responding subjects still showed repetition priming effects, indicating that this effect was not solely due to timbral match of prime and target. The priming reversal at a prime–target distance of two events disappeared in Experiment 3; although the priming benefit was not as large at Distance 2 as at other prime–target distances, it was still greater than zero.

This pattern of results suggests that the increased similarity of primes and targets was responsible for the Distance 2 reversal in Experiment 2. Prime and target tones in this condition shared the most acoustic features (had the greatest similarity) across all experiments: They were similar not only in pitch but also in timbre and in metrical accent. The stimuli in this condition only took the form A-B-A as the final three tones, in which production of the target A may have been influenced by weakened postoutput suppression of the first A, as noted in other production tasks with music and language (Palmer & Drake, 1997; Shattuck-Hufnagel, 1979), based on their similarity. Prime–target similarity was lower in this condition in Experiment 1; the prime and target differed in metrical strength because the stimuli were of different lengths, causing the prime and target to occur in different metrical positions, and the normal repetition benefit was found. Prime–target similarity was also lower in this condition in Experiment 3, due to different prime and target timbres, and the repetition priming effect was revealed again at Distance 2. Although these experiments did not directly test how postoutput suppression or similarity influenced response latencies, the combined findings across experiments suggest that prime–target similarity influenced the repetition reversal at Distance 2.

Perception and Production

The experiments demonstrated repetition priming from a perception of a stimulus to a subsequent production, which could entail perceptual priming, production priming, or both. If we assert that the same conceptual system underlies perception and production (e.g., Fowler, Brown, Sabadini, & Weihing, 2003; Liberman & Mattingly, 1985; MacKay, 1987; Pfordresher & Palmer, 2006; Prinz, 1997), then a perceptual task can prime a production response, and vice versa. Similar to effects of comprehension priming on subsequent language production (Bock, Dell, Chang, & Onishi, in press; Branigan, Pickering, & Cleland, 2000) and music performance (Jungers, Palmer & Speer, 2002), the experiments reported here demonstrated priming from a perceived stimulus to a produced response; it is parsimonious to assume that there is some overlap between the two systems. Evidence that priming benefits continue to aid later production was addressed in a delayed pronunciation task (Balota et al., 1989). After delays of over 1000 ms, primed words were still shown to have shorter response latencies and production durations than unprimed words, suggesting that priming benefits were not constrained to perceptual processes.

Comparisons With Harmonic Priming Studies

Although repetition priming is robust in many domains with different tasks, Bigand et al. (2003, 2005) found only weak evidence for repetition priming in music, and claimed that “chord

processing was not facilitated by repetition" (Bigand et al., 2005, p. 1347). We account for the apparent discrepancy by noting some important methodological differences in the findings reported here. First, we employed a different musical unit to be primed (individual pitches instead of chords). Models of harmonic priming (Bharucha, 1987; Tillmann et al., 2000) treat tones as the basic unit of sensory input and chords as units that must be cognitively derived from our knowledge of combinations of tones, as well as top-down knowledge about keys. Thus, it is not surprising that chords would show strong evidence of cognitive harmonic priming, whereas tones would more readily show evidence of repetition priming. Experiments by Deutsch (1970, 1972), too, showed that in an explicit memory test individual pitches were aided by repetition. Although the typical harmonic priming paradigm is useful for measuring effects of tonality, it may be less suitable for measuring effects of repetition.

Second, we employed a different task to measure repetition priming: sung reproduction. The harmonic priming paradigm uses a decision task concerning relationships between tones in a chord, such as an in-tune or out-of-tune decision. Such tuning tasks are not applicable to single pitches, and therefore a singing production task was chosen, most akin to a naming task in language priming. This task does not require participants to be able to name or label which properties of the stimulus they are hearing. Whereas other experiments require subjects to be able to explicitly identify properties such as in-tune versus out-of-tune, major versus minor (Bharucha & Stoeckig, 1986, 1987; Bigand et al., 1999; Bigand & Pineau, 1997), or whether a tone fits in well with a previously heard context (Krumhansl, 1990), the pitch reproduction task does not rely on explicit judgments. Thus, the use of a reproduction task may serve as a more direct measure of listeners' implicit knowledge and offers a way to study the musical knowledge of people without such experience.

Possible limitations of the paradigm reported here concern the roles of stimulus rate and metrical accent. Because stimuli were presented at only one tempo, the factors of elapsed time and number of intervening items were not separated independently. The finding that repetition priming decreases over increasing prime-target distances may be due to interference from intervening items (as suggested by experiments on explicit short-term pitch memory, e.g., Deutsch, 1972, 1975; Massaro, 1970; Wickelgren, 1966) or of decay over time. In future experiments, we hope to address whether priming effects are influenced by the tempo of the melodies. Also of interest is the difference in priming between fast-responding and slow-responding participants, and whether it is possible to induce those who naturally respond slowly to quicken their response times in order to examine effects of response time on the time course of priming in a more controlled manner.

In sum, these experiments provide a new methodology for studying implicit memory and implicit musical knowledge in a music performance task that does not require specific musical training. We found consistent repetition priming effects as well as tonality effects on latencies to produce individual pitches, in contrast to previous findings on chord repetition. The frequency of pitch repetition that naturally occurs in music makes these findings important for understanding the largely implicit cognitive processes that underlie our memory for musical structure.

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Appendix



Figure A1. The four base melodies used in the experiments.

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