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Global Context Effect in Normal and Scrambled Musical Sequences

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The processing of chords is facilitated when they are harmonically related to the context in which they appear. The purpose of this study was to assess whether this harmonic priming effect depends on the version (normal vs. scrambled) of the context chord sequences. Normal sequences were scrambled by permuting chords two-by-two (Experiment 1) or four-by-four (Experiments 2 and 3). Normal chord sequences were judged less coherent than scrambled sequences. However, normal chord sequences showed facilitation for harmonically related rather than for unrelated targets, and this effect of relatedness did not diminish for scrambled sequences (Experiments 1–3). The data of musicians and nonmusicians were interpreted with Bharucha's (1987) spreading activation framework. Simulations suggested that harmonic priming results from activation that spreads via schematic knowledge of Western harmony and accumulates in short-term memory over the course of the chord sequence.

The effect of context on event processing is a robust phenomenon that has been documented for pictures, faces, environmental sounds, language, and music. In language, it has been shown that the processing of a target word is faster and more accurate when it follows a prime word that is semantically related than when it follows a prime word that is semantically unrelated (Meyer & Schvaneveldt, 1971). Similarly, in music, the processing of a target chord is facilitated when it occurs after a harmonically related prime chord rather than after a harmonically unrelated prime chord (Bharucha & Stoeckig, 1986, 1987; Tekman & Bharucha, 1992, 1998). As priming effects occur for a variety of events, the question arises as to whether processes involved in priming might have domain specificity. Our study relates to this broad issue by assessing the extent to which musical priming in relatively long harmonic contexts (Bigand, Madurell, Tillmann, & Pineau, 1999; Bigand & Pineau, 1997) may rely on processes comparable with processes in semantic priming in sentences (Fischler & Bloom, 1980; Stanovich & West, 1979).

In psycholinguistics, it has been suggested that semantic priming in sentences and discourse may result from two sources. One source is located inside the mental lexicon: Priming is due to fast and automatic activation spreading through the long-term connections between semantically related items *(intralexical spreading activation account of priming)* (Duffy, Henderson, & Morris, 1989; Forster, 1979; Neely, 1991). A second source of priming arises from processes that integrate local structures into a coherent discourse representation *(discourse priming)* (Foss & Ross, 1983; Hess, Foss, & Carroll, 1995; Sharkey & Sharkey, 1987, 1992). One way these two potential sources of priming have been contrasted is by manipulating the temporal order of words in the sentence context (Masson, 1986; O'Seaghdha, 1989; Simpson, Peterson, Casteel, & Brugges, 1989). Simpson et al. (1989) presented sentences visually, either in a normal form (*The auto accident drew a large crowd of <u>people</u>*) or in a scrambled form (*Accident of large the drew auto crowd a <u>people</u>*).[1] A change in the temporal order of words strongly decreased the strength of priming: Normal sentences showed facilitation for related targets and inhibition for unrelated targets, but there was no effect of relatedness for scrambled sentences. Consistent findings were reported with spoken language: Recognition of spoken target words was more difficult for scrambled rather than for normal sentences (Marslen-Wilson & Tyler, 1980). This influence of word order on semantic priming suggests that the effect of global context on word processing results not only from intralexical spreading activation, but also from the ease with which new words are integrated into the current discourse representation (e.g., Hess et al., 1995).

Until now, harmonic priming has been understood as resulting from a single source: the fast and automatic activation of an abstract knowledge of the Western musical system with its tonal and harmonic hierarchies (e.g., Bharucha & Stoeckig, 1987; Bigand et al., 1999). Tonal and harmonic hierarchies refer to a set of constraints, specific to the Western musical idiom, that has been internalized through passive exposure to Western musical pieces (see Tillmann, Bharucha, & Bigand, 2000, for a formal account). In Western music, a restricted set of 12 pitch classes is organized in subsets of seven notes, leading to major and minor musical keys. For each key, seven chords may be defined on the degrees of the

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[1] Sentences were presented by a sequential method in which the words appeared one at a time at a rate of one word each 300 ms, so the sentences unfolded in time on the screen.

seven-note scale.[2] A critical feature of this musical system is that chords built on the first, fifth, and fourth scale degrees (referred to as the *tonic, dominant,* and *subdominant* chords, respectively) usually have more central functions than other chords, with the tonic chord being the most referential one in the key. These differences in musical functions create within-key hierarchies of stability. Stable events induce in listeners a sense of finality or resolution; less stable events need to be anchored to more referential ones and induce the expectation that more stable events will occur (see Krumhansl, 1990, for a review).

Harmonic priming effects are supposed to be strongly related to these harmonic hierarchies (i.e., hierarchies between chords; see Bharucha, 1987; Bigand et al., 1999). A musical context activates listeners' knowledge of harmonic hierarchies in a way that referential stable chords of the key (such as the tonic chord) are the most expected. Chords that do not belong to the context key (Bharucha & Stoeckig, 1987; Schmuckler & Boltz, 1994; Tillmann, Bigand, & Pineau, 1998), or are less referential in the context key (Bigand et al., 1999; Bigand & Pineau, 1997), are less expected, which results in slower and less accurate processing. In Bigand and Pineau's (1997) priming study, expectation for the to-be-processed target chord (the last chord of eight-chord sequences) was varied by changing the harmonic context created by the first six chords (see Figures 1a and 1c, for an example). In the related context, the target was a harmonically stable tonic chord. In the unrelated context, the target was a contextually congruent, but less stable, subdominant chord. Results showed a facilitation effect for the processing of the target when it was the more stable tonic chord in the related context.

The purpose of our study was to investigate whether harmonic priming in chord sequences reported by Bigand and Pineau (1997) showed an effect of temporal order similar to that of semantic priming in sentences. To our knowledge, the potential influence of the temporal order of chords on harmonic priming has never been investigated. The temporal order of sound events was shown to be a main determinant of melodic perception (Butler & Brown, 1984; Deutsch, 1984) and recognition memory (Deutsch, 1980). In Deutsch (1980), unstructured sequences were obtained by a temporal reorganization of the melodic tones. Scrambled tone sequences sound less coherent and are more difficult to recall than normal versions of the same tone sequences. We therefore hypothesized that scrambling the order of chords in a sequence should weaken the perceptual coherence of the musical context. The main issue of our study was to assess whether this change in structural coherence of the context reduces harmonic priming.

There are two possible predictions. On one hand, harmonic expectations that develop during a musically coherent sequence are likely to differ from expectations that develop during an incoherent (or less coherent) sequence. An incoherent musical context should notably disturb the formation of harmonic expectation, resulting in a decrease of the strength of priming in scrambled sequences. This finding would challenge an account that explains harmonic priming as resulting from the sole activation of an abstract knowledge of Western harmonic hierarchies. It would need to consider further sources of priming, for example, the integration of events in an overall coherent pitch–time event structure.

On the other hand, the temporal order of musical events does not usually represent an indispensable feature for the determination of the context key and, accordingly, the harmonic stability of the events. If harmonic priming depends mostly on the harmonic stability of the target chord in the context key, no decrease in priming should be observed in scrambled sequences. Although permuting the temporal order of tones in a melody may sometimes lead to a change in the perceived key (for a discussion, see Bharucha, 1984; Deutsch, 1984), neither music theory analyses nor empirical research have reported an equivalent effect in the case of harmony. Furthermore, it has been shown that a key-finding algorithm (Krumhansl & Schmuckler in Krumhansl, 1990) manages to accurately identify the key of musical excerpts (e.g., single melodic lines, simultaneous sounding tones, or harmonized excerpts) without considering the temporal order of the events (Krumhansl, 1990; Tillmann, Bigand, & Madurell 1998). The algorithm determines the key on the basis of the total duration of tones within a musical selection of predetermined duration (e.g., four notes, one measure [Krumhansl, 1990] or eight measures [Tillmann, Bigand, & Madurell, 1998]).

To address the potential effect of the temporal order of chords, we conducted three experiments using the harmonic priming task, subjective coherence judgments, and a recognition task. Following previous research on chord sequence priming (Bigand et al., 1999; Bigand & Pineau, 1997; Tillmann, Bigand, & Pineau 1998), half of the target chords were rendered acoustically dissonant by adding a nondiatonic tone, which is a semitone above a chord component tone (e.g., C, E, G, C, and C#). Participants were required to make a fast consonant–dissonant judgment on the target. This task mirrors the lexical decision task (i.e., word–nonword judgments) used in semantic priming paradigm. If the coherence of the musical context is the main source of harmonic priming, the harmonic context effect should be reduced or eliminated in scrambled sequences compared with normal sequences. In addition, testing of harmonic context and scrambling of chords provided an opportunity to investigate the influence of musical training. Until now, harmonic priming has been shown to weakly depend on the extent of musical expertise. According to Bharucha and Stoeckig (1986), this finding emphasizes the robustness of the processes into which priming taps. The present study permits further examination of this issue. As musicians are usually supposed to be more sensitive to the global coherence of musical pieces and to changes in musical structure, stronger effects of scrambling were expected to occur in musicians than in nonmusicians.

Experiment 1

In Experiment 1, chord sequences ending on either a tonic or a subdominant target chord were presented in either a normal or scrambled order (see Figure 1). In the normal version, the presentation order of chords adhered to transition rules of Western harmony. In the scrambled version, the temporal order was manipulated by scrambling the chords two by two.

Method

Participants. There were 24 participants in this experiment: 12 students in psychology with no formal musical training or any practice of a

[2] A chord is a simultaneity of three tones usually called the root, third, and fifth. In the C major key for example, the tonic chord C major is constructed by combining the notes E and G to the root note C.

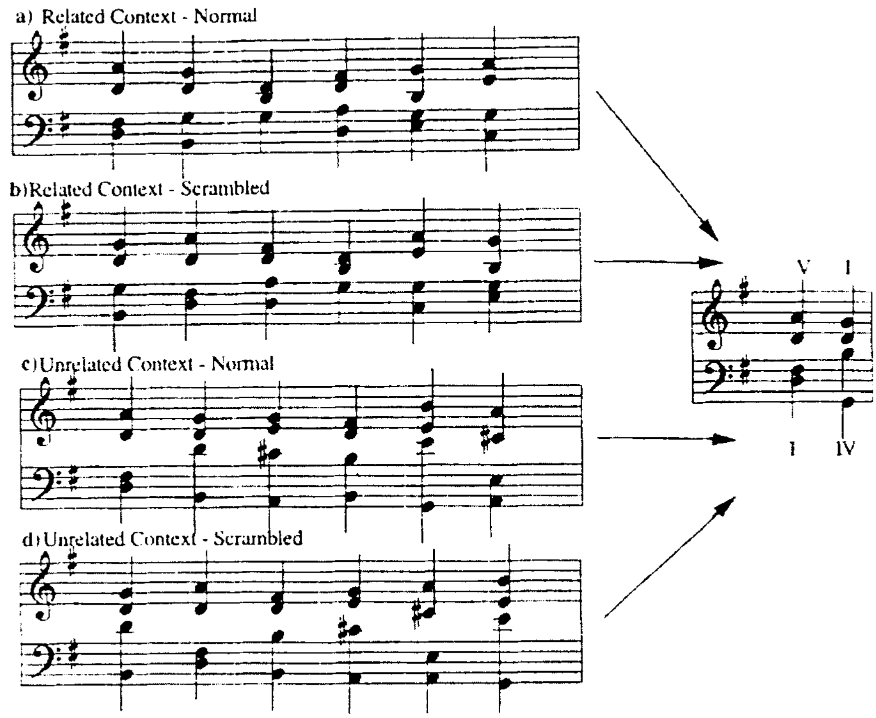

Figure 1. Examples of the normal (related [a] and unrelated [c]) sequences used in Bigand and Pineau (1997) and the present study. Examples of the scrambled (related [b] and unrelated [d]) sequences used in Experiment 1. Tonic, dominant, and subdominant chords are designated by I, V, and IV, respectively.

musical instrument (referred to below as *nonmusicians*) and 12 graduate students of the music department of the University of Dijon (referred to below as *musicians*).

Material. The 40 chord sequences of Bigand and Pineau (1997) and Pineau and Bigand (1997) were used: 20 sequences represented the related condition and 20 sequences represented the unrelated condition. The related sequences differed in several aspects, including the melodic contour of highest and lowest voices and the voicing (the specific pitch height of component tones). Given these variations, each sequence sounded different from the others. Beyond these differences, all of the sequences contained eight chords and were closed by a dominant-to-tonic cadence (i.e., an authentic cadence). For the unrelated sequences, the first six chords were systematically varied in such a way that the sequences were in the dominant key of the related sequences (i.e., the dominant chord in the related sequences defined the tonic chord for the key of the unrelated sequences). The last two chords were kept acoustically identical (see Figures 1a and 1c for an example). Because of changes in the first six chords, the last chord functioned as a tonic, part of an authentic cadence, in the related context and as a subdominant in the unrelated context.

A scrambled sequence was defined for each of the 40 normal sequences (i.e., 20 related and 20 unrelated sequences), resulting in 80 experimental sequences. The first six chords were permuted two by two, resulting in the chord order 2–1–4–3–6–5–7–8. The order of the last two chords was kept identical for all sequences (see Figures 1b and 1d). To create the dissonant targets for the priming task, we altered the sensory consonance of all targets by adding an augmented octave (C#4) to the root (i.e., C2–E3–G3–C4–C#4). This added tone was played more quietly than the other tones to make this dissonance only moderately salient.

Apparatus. All the stimuli were played with sampled piano sounds produced by a Yamaha Sound Expander (EMT10). Velocity, a parameter related to the force with which a key is struck, was constant for all tones except the added augmented octave for dissonant targets, which was played at half velocity. The sound stimuli were captured by SoundEditPro software (Macromedia, San Francisco, CA) at CD quality (16 bits and 44 kHz), and the experiment was run on PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Reaction times were recorded using PsyScope's button box, with an accuracy of 1 ms. The tempo of the sequences was 90 quarter notes/min (666 ms/chord).

Procedure. The experimental procedure was split into two phases. During the first phase, participants were trained to differentiate between consonant and dissonant chords with 40 isolated chords presented in random order. They had to make a consonant–dissonant judgment as quickly and accurately as possible by pressing one of two keys of the PsyScope button box. During the second phase, the eight-chord sequences were presented and participants made the consonant–dissonant judgment for the last chord of the sequences. In both phases, the next trial began when the participant pressed a button on the button box. In an effort to encourage participants to answer as quickly and accurately as possible, the target chord stopped sounding after a correct response (i.e., allowing participants to continue with the next trial), but not after an incorrect response, which in addition was accompanied by an alerting feedback signal.

Design. The within-subject factors were version (normal vs. scrambled), harmonic context (related vs. unrelated), and target type (consonant vs. dissonant). The between-subjects factor was musical expertise (nonmusicians vs. musicians). Crossing version, harmonic context, and target type produced eight possible versions for each sequence. The 20 original (related) sequences were split into two groups of 10. One group of sequences was presented with consonant targets and the other group of sequences with dissonant targets for half of the participants. The type of target (consonant vs. dissonant) for each group of sequences was reversed for the other half of the participants. Each participant heard 80 sequences presented in random order.

Preliminary tests. Ten musicians and 10 nonmusicians participated in a first preliminary test but not in the experiment. Normal and scrambled versions of related and unrelated sequences were played and participants were required to evaluate, on a subjective scale, how coherent the flow of the sequences sounded. The scale varied from 0 (*weakly coherent*) to 6 (*strongly coherent*). Ratings were analyzed in a 2 × 2 × 2 analysis of variance (ANOVA) with version and harmonic context as within-subject factors and musical expertise as the between-subjects factor. The normal sequences received significantly higher ratings of coherence than the scrambled ones, $F(1, 18) = 24.95$, $MSE = 0.173$, $p < .001$, even if this difference remained small (4.16 vs. 3.69). Because of their less natural ending, unrelated sequences were judged as less coherent (3.41) than related ones (4.44), $F(1, 18) = 34.74$, $MSE = 0.61$, $p < .001$. There was no other significant effect. A second pretest was conducted to further investigate nonmusicians' ability to differentiate between normal and scrambled sequences. Another group of 10 nonmusicians was required to evaluate, on a subjective scale, how pleasant the sequences sounded. The scale varied from 0 (*unpleasant*) to 9 (*very pleasant*). The normal sequences were rated as slightly (6.0 vs. 5.7) but significantly more pleasant than the scrambled sequences, $F(1, 9) = 5.37$, $MSE = .157$, $p < .05$. Unrelated sequences were judged as less pleasant than related sequences, but this difference did not reach statistical significance. The findings of these preliminary tests suggest that even nonmusicians reacted differently to normal versus scrambled versions.

Results

Response accuracy. Percentages of errors (see Table 1) were analyzed in a 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVA. There was a main effect of harmonic context, $F(1, 22) = 14.26$, $MSE = 1.94$, $p < .01$, and a significant two-way interaction between harmonic context and target type, $F(1, 22) = 18.44$, $MSE = 2.24$, $p < .001$. For consonant targets, the error rates were lower for the related than for the unrelated context, $F(1, 22) = 32.64$, $MSE = 2.09$, $p < .001$. For dissonant targets, the difference between related and unrelated contexts was smaller and did not reach significance. In addition, percentages of errors were significantly higher for nonmusicians (28.94%) than for musicians (3.02%), $F(1, 22) = 142.59$, $MSE = 2.26$, $p < .001$. The effect of harmonic context and its interaction with target type were more pronounced for nonmusicians than for musicians, $F(1, 22) = 6.96$, $MSE = 1.95$, $p < .05$; and $F(1, 22) = 9.24$, $MSE = 2.24$, $p < .01$, respectively.

Table 1
Error Rates (in Percentages) as a Function of Version (Normal–Scrambled), Harmonic Context (Related–Unrelated), Target Type (Consonant–Dissonant), and Musical Expertise (Musicians–Nonmusicians) in Experiment 1

	Consonant		Dissonant	
Condition	Related	Unrelated	Related	Unrelated
Musicians				
Normal	.83 (.83)	7.5 (2.79)	2.5 (1.79)	3.3 (1.42)
Scrambled	.80 (.83)	4.2 (2.59)	3.3 (2.56)	1.7 (1.12)
Nonmusicians				
Normal	17.5 (5.09)	45.0 (6.45)	28.3 (6.49)	25.8 (5.57)
Scrambled	10.8 (2.59)	40.8 (5.14)	33.3 (5.27)	30.0 (4.77)

Note. Standard errors are in parentheses.

The primary point of interest was related to the influence of version (normal vs. scrambled). There was no main effect of version, nor any significant two-way interaction between version and harmonic context. There were no other significant effects.

Two further 2 × 2 × 2 (Version × Harmonic Context × Musical Expertise) ANOVAs were performed on sensitivity (d') and response criterion (c), respectively, as dependent variables.[3] Results of the signal–detection parameters confirmed the influences of harmonic context and musical expertise, but did not reveal any significant influence of version nor of an interaction between version and harmonic context. The main effect of harmonic context was significant for d' and for c: $F(1, 22) = 19.04$, $MSE = 1.25$, $p < .001$, and $F(1, 22) = 10.97$, $MSE = .45$, $p < .01$, respectively; d' was higher for the related context (3.98) than for the unrelated context (2.99), and a small tendency to respond "consonant" was observed in the related context ($c = -.23$) and to respond "dissonant" in the unrelated context ($c = .22$). This type of response bias has also been reported by Bharucha and Stoeckig (1987) for single chord primes. Furthermore, the effect of musical expertise was significant for d', $F(1, 22) = 163.05$, $MSE = 1.99$, $p < .001$; d' was higher for musicians than for nonmusicians.

Response times. Response times for correct responses (see Figure 2) were analyzed in a 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVA. The analysis of response times confirmed the main effect of harmonic context, $F(1, 22) = 52.90$, $MSE = 18{,}137.0$, $p < .001$, and the two-way interaction of Harmonic Context × Target Type, $F(1, 22) = 7.35$, $MSE = 15{,}884.3$, $p < .05$. Response times were shorter in the related condition (867.36 ms) than in the unrelated condition (1,008.75 ms). This difference was more pronounced for consonant targets, though still significant for dissonant targets, $F(1, 22) = 24.69$, $MSE = 8{,}239.2$, $p < .01$.

There was no main effect of version on response times, nor was there a significant two-way interaction between version and harmonic context. However, the effect of version was expressed in a two-way interaction with target type, $F(1, 22) = 7.44$, $MSE = 8{,}303.1$, $p < .05$. Response times were longer in scrambled than in normal versions for consonant targets, but slightly longer in normal than in scrambled versions for dissonant targets. This interaction was stronger for nonmusicians than for musicians. In addition, musicians responded faster than nonmusicians (727.97 ms vs. 1,148.14 ms), $F(1, 22) = 30.31$, $MSE = 279{,}625.9$, $p < .001$, and the effect of harmonic context was more pronounced in nonmusicians, $F(1, 22) = 7.69$, $MSE = 18{,}137.0$, $p < .05$. Finally, the main effect of target type was significant, $F(1, 22) = 40.39$, $MSE = 16{,}548.3$, $p < .001$, with shorter response times for dissonant targets.

Discussion

The present results obtained with the normal versions of the chord sequences replicated Bigand and Pineau's (1997) findings. Participants were more accurate and took less time to decide whether the target chord was acoustically consonant or dissonant

[3] The parameters d' and c were calculated for each participant separately. In cases without false alarms, the proportion of false alarms was set to .001. The possible range of d' scores was from 0 to 6.18.

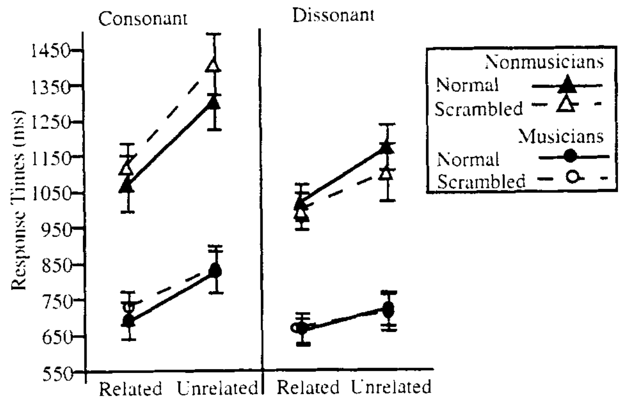

Figure 2. Correct response times averaged across the chord sequence set as a function of version, harmonic context, target type, and musical expertise in Experiment 1.

when it was the more stable tonic chord in the related context. The purpose of Experiment 1 was to study how the temporal order of chords influences harmonic priming. The effect of harmonic relatedness was unaffected by the scrambling of the sequences: Normal sequences showed facilitation for harmonically related targets, but this effect of relatedness was almost identical in the normal and the scrambled conditions. This finding suggests that the stability of chords in the harmonic hierarchy of the context key influences processing in the priming task.

However, one possible explanation for the lack of an observed difference between the two versions might be that permuting the chords two by two did not sufficiently alter the structure of the sequence to have a significant impact on participants' responses to the target chords. Participants actually managed to differentiate both versions of the sequences on the basis of the structural coherence and pleasantness judgments, but the differences in ratings remained small, even for musicians (cf. preliminary tests). The main purpose of Experiment 2 was to increase the incoherence of scrambled sequences and to further investigate its influence on the global relatedness effect.

Experiment 2

In the 2-by-2 scrambling method (2–1–4–3–6–5–7–8) of Experiment 1, adjacent chords of the original sequence remained close to each other in time. The mean distance m between neighboring chords inside the sequence can be calculated with the help of the chords' position in the original normal sequence. For example, the chaining of ex-chord #2 to #1 represents a distance of $m = 1$, that of ex-chord #1 to #4 represents a distance of $m = 3$. The mean distance over the whole scrambled sequence is $m = 1.8$ (a stronger temporal distance than in the normal sequence with $m = 1$). The purpose of Experiment 2 was to choose a new scrambling method that increased the temporal distance between chords so that chords that were adjacent in the normal sequence were separated in time in the scrambled sequence. Random reorganizations of chords in the sequence led to a mean distance between chords of $m = 2.4$ (calculated over a set of 80 random orders). A stronger mean distance, $m = 3.4$, could be obtained by permuting chords 4 by 4 (i.e., 4–1–5–2–6–3–7–8). This 4-by-4 scrambling method was chosen for Experiment 2.

Experiment 2 was conducted with two further changes in procedure. Participants were required to perform the priming task and to judge the coherence of the sequences on a subjective scale. An accuracy criterion was added in the training phase of consonant–dissonant judgments, as prolonged training might increase nonmusicians' performance.

Method

Participants. There were 20 participants in this experiment: 10 students in psychology with no formal musical training or any practice of a musical instrument (referred to below as *nonmusicians*) and 10 students of composition at the music department of the University of California at San Diego (referred to below as *musicians*). None had participated in Experiment 1.

Material. The material was identical to that of Experiment 1, with the exception that scrambled sequences were now defined by permuting the temporal order of the first six chords 4 by 4 (4–1–5–2–6–3–7–8) instead of 2 by 2 (2–1–4–3–6–5–7–8). The last two chords were kept identical for all sequences.

Procedure. The experimental procedure was split into three phases. The first two phases were the same as described in Experiment 1, with the exception that participants were required to achieve an accuracy of at least 70% to proceed to the second phase. They were permitted to repeat this training session until the criterion was reached. In the third phase, participants were asked to evaluate, on a subjective scale, how coherent the flow of the chord sequences sounded in comparison with what they were used to hearing. The scale varied from 0 (*weakly coherent*) to 6 (*strongly coherent*). The sequences were presented in random order for each participant.

Design. The within-subject factors were version (normal vs. scrambled), harmonic context (related vs. unrelated), and target type (consonant vs. dissonant). The between-subjects factor was musical expertise (nonmusicians vs. musicians). Each participant made the consonant–dissonant judgments for 80 sequences (see Experiment 1) and the coherence judgments for 40 sequences. All 40 sequences ended on a consonant target. For half of the participants, one group of 10 sequences was presented in the related versions (both normal and scrambled) and the other group of sequences was presented in the unrelated versions (both normal and scrambled). The group of sequences was reversed for the other half of the participants.

Results

Response accuracy. Percentages of errors (see Table 2) were analyzed in a 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVA. Nonmusicians committed fewer errors than in Experiment 1, though still more than musicians (10.6% vs. 4.6% in musicians), $F(1, 18) = 3.32$, $MSE = 4.34$, $p = .08$. The main effect of target type was significant, $F(1, 18) = 8.82$, $MSE = .64$, $p < .01$, with more errors for consonant targets than for dissonant targets. An effect of harmonic context was observed in a marginally significant two-way interaction with target type in nonmusicians, $F(1, 18) = 3.20$, $MSE = 1.43$, $p = .09$. For consonant targets, the error rate was lower in the related condition (11%) than in the unrelated condition (15%). For dissonant targets, the error rate was higher in the related condition (11%) than in the unrelated condition (5.5%). There were no other significant effects.

Two further 2 × 2 × 2 (Version × Harmonic Context × Musical Expertise) ANOVAs were performed on sensitivity (d')

Table 2
Error Rates (in Percentages) as a Function of Version (Normal–Scrambled), Harmonic Context (Related–Unrelated), Target Type (Consonant–Dissonant), and Musical Expertise (Musician–Nonmusician) in Experiment 2

	Consonant		Dissonant	
Condition	Related	Unrelated	Related	Unrelated
Musicians				
Normal	5.0 (1.67)	7.0 (2.61)	2.0 (1.33)	1.0 (1.00)
Scrambled	7.0 (3.00)	5.0 (3.07)	6.0 (3.39)	4.0 (1.63)
Nonmusicians				
Normal	11.0 (5.86)	14.0 (4.76)	12.0 (4.89)	6.0 (3.06)
Scrambled	11.0 (3.14)	16.0 (3.71)	10.0 (5.37)	5.0 (2.24)

Note. Standard errors are in parentheses.

and response criterion (c). The factor version was expressed only on the response criterion c in an interaction with musical expertise, $F(1, 18) = 9.56$, $MSE = 0.18$, $p < .01$. Both groups of participants had a weak tendency to respond "consonant" ($c = .18$ for musicians, $c = .27$ for nonmusicians), but this bias was slightly stronger for normal sequences in musicians and for scrambled sequences in nonmusicians. For d', the main effect of musical expertise was marginally significant, $F(1, 18) = 3.91$, $MSE = 5.55$, $p = .06$: d' was higher for musicians (4.86) than for nonmusicians (3.82). There were no other significant effects.

Response times. Correct response times (see Figure 3) were analyzed in a 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVA. There was a main effect of harmonic context, $F(1, 18) = 29.95$, $MSE = 16{,}504.5$, $p < .001$, and a two-way interaction Harmonic Context × Target Type, $F(1, 18) = 17.37$, $MSE = 7{,}575.8$, $p < .001$. Response times were shorter in the related condition (684.4 ms) than in the unrelated condition (795.5 ms). This difference was less pronounced for dissonant targets, although it was significant, $F(1, 18) = 9.75$, $MSE = 5{,}936.01$, $p < .01$. The effect of harmonic context was more pronounced for nonmusicians than for musicians, $F(1, 18) = 8.17$, $MSE = 16{,}504.5$, $p < .05$.

There was no main effect of version, but there was a significant three-way interaction between Version × Harmonic Context × Musical Expertise, $F(1, 18) = 9.05$, $MSE = 1{,}801.3$, $p < .01$. For musicians, the difference between related and unrelated contexts was slightly, but not significantly, stronger for normal (65.96 ms) than for scrambled versions (40.24 ms), $F(1, 18) = 1.83$, $MSE = 1{,}801.3$. For nonmusicians, however, the effect of harmonic context was stronger for scrambled (196.7 ms) than for normal versions (141.7 ms), $F(1, 18) = 8.4$, $MSE = 1{,}801.3$, $p < .01$.

In addition, musicians responded faster than nonmusicians (513.15 ms compared with 966.69 ms), $F(1, 18) = 63.46$, $MSE = 129{,}650.6$, $p < .001$, and response times were shorter for dissonant targets than for consonant ones, $F(1, 18) = 33.43$, $MSE = 17{,}019.6$, $p < .001$. This effect of target type was more pronounced in nonmusicians, $F(1, 18) = 17.37$, $MSE = 7{,}575.8$, $p < .001$.

Coherence judgments. Coherence judgments were analyzed in a 2 × 2 × 2 (Version × Harmonic Context × Musical Expertise) ANOVA. The judgments of one musician were excluded because of a change in the use of the scale during the course of this phase of the experiment. Coherence judgments reflected that participants were sensitive to the experimental manipulations of chord order (see Figure 4). Despite the fact that scrambling order had no effect on priming, the scrambled sequences were judged as being less coherent than the normal sequences, $F(1, 17) = 24.12$, $MSE = 0.33$, $p < .01$. The subjective judgments confirmed an effect of harmonic context, $F(1, 17) = 40.98$, $MSE = 0.38$, $p < .01$. Because of their less natural ending, unrelated sequences received smaller ratings of coherence than did related sequences. More important, the two-way interaction between version and harmonic context was significant, $F(1, 17) = 8.3$, $MSE = 0.11$, $p < .05$. The difference in coherence judgments between related and unrelated sequences was stronger for the normal sequences than for the scrambled sequences. Finally, there was also a two-way interaction between Version × Musical Expertise, $F(1, 17) = 8.27$, $MSE = 0.33$, $p < .05$. The difference between normal and scrambled sequences was more pronounced in musicians than in nonmusicians.

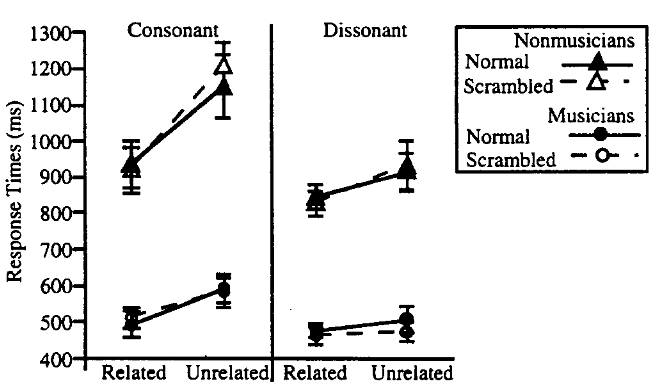

Figure 3. Correct response times averaged across the chord sequence set as a function of version, harmonic context, target type, and musical expertise in Experiment 2.

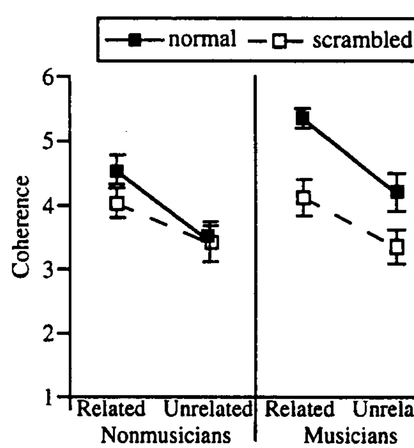

Figure 4. Coherence judgments averaged across the chord sequence set as a function of version, harmonic context, and musical expertise in Experiment 2.

The influence of the factor version on the coherence judgments was further shown in a 2 × 2 × 2 (Version × Harmonic Context × Musical Expertise) ANOVA performed with items as a random variable. The outcome confirmed the main effect of version, $F_2(1, 38) = 27.79$, $MSE = 0.58$, $p < .001$, the main effect of harmonic context, $F_2(1, 38) = 41.05$, $MSE = 0.07$, $p < .001$, and the interaction between version and harmonic context, $F_2(1, 38) = 5.15$, $MSE = 0.47$, $p < .05$.

Discussion

When required to evaluate the musical coherence of the chord sequences, participants were shown to differentiate normal versus scrambled sequences and to more strongly distinguish related versus unrelated sequences in the normal than in the scrambled versions. However, when required to perform a fast consonant–dissonant judgment on the target, the processing of the target was faster in the related context than in the unrelated context, irrespective of the version (normal vs. scrambled). The effect of harmonic context did not vanish in the scrambled condition, and it was even stronger in the scrambled condition for nonmusicians.

To investigate the difference between coherence judgments and priming data, we conducted further analyses. We first studied an eventual link between rated coherence and response times of normal and scrambled sequences. The correlations were not significant for musicians and nonmusicians in the unrelated context: musicians, $r(38) = -.17$, $p = .30$; nonmusicians, $r(38) = .10$, $p = .52$. In the related context, the correlation was not significant for nonmusicians, $r(38) = -.06$, $p = .72$, but was significant for musicians, $r(38) = -.32$, $p = .045$: The more a sequence was judged coherent, the faster was the response in the priming task. Though this correlation in musicians' data remained weak, it might be argued that the scrambling of chords created stronger incoherence for some of the sequences and that the influence of scrambling on priming would be stronger for these sequences.

This possible link between strength of coherence modification and the strength of priming was further investigated by selecting those sequences for which the coherence judgments were the most affected by the scrambling. On the basis of coherence judgments for normal and scrambled versions (averaged over related and unrelated contexts), a subset of six sequences was selected for which the difference in coherence between normal and scrambled versions was the strongest among all sequences.[4] A 2 × 2 × 2 × 2 ANOVA on response times of the subset sequences confirmed previously observed effects of harmonic context, $F(1, 18) = 18.27$, $MSE = 26{,}864$, $p < .001$, target type, $F(1, 18) = 16.36$, $MSE = 21{,}502$, $p < .001$, the interaction between these factors, $F(1, 18) = 5.23$, $MSE = 34{,}412$, $p < .05$, the main effect of musical expertise, $F(1, 18) = 54.46$, $MSE = 154{,}927$, $p < .001$, and its interaction with harmonic context, $F(1, 18) = 5.16$, $MSE = 26{,}864$, $p < .05$. However, the interaction between version and harmonic context was not significant, $F(1, 18) = 1.34$. Separate analyses for the two levels of musical expertise revealed that the interaction was not significant for nonmusicians or musicians. In summary, these supplementary analyses on the basis of most and least coherent sequences confirmed the previous outcome of the entire sequence set. Scrambling the chords of the sequences 4 by 4 did not decrease the effect of harmonic context, even if it decreased the perceived coherence of these sequences as well as the difference between related and unrelated contexts in the coherence ratings.

Experiment 3

Experiment 2 suggests that manipulating the temporal order of chords taps into cognitive processes that do not seem to be involved in harmonic priming. It might be argued, however, that a coherence judgment explicitly demands participants to focus their attention on the overall structure of the chord sequence. By contrast, the consonant–dissonant judgment required participants to pay attention to only the target. This difference in attentional demands of the tasks might potentially explain why participants reacted to the order manipulation in one task but not in the other. To address this issue, in Experiment 3 we added a supplementary recognition task to the priming task that forced participants to carefully attend to the entire chord sequence.

Method

Participants. There were 30 participants in this experiment: 15 students in psychology with no formal musical training or any practice of a musical instrument (referred to below as *nonmusicians*) and 15 graduate students of the music department of the University of Dijon (referred to below as *musicians*). None had participated in the previous experiments.

Material. Experiment 3 was conducted with the normal and scrambled sequences used in Experiment 2. For the recognition test, 16 of these sequences were followed by a short excerpt of four chords. In half of the cases, the excerpts were either Chords 1–4 or Chords 2–5 (*target excerpts*). In the other half, the excerpts did not belong to the sequences (*foil excerpts*). Foil excerpts were chosen in the related or in the unrelated counterpart version of the same sequence. For example, when a sequence of the related condition was presented, the foil excerpt corresponded to a set of four chords taken from the unrelated version of the same sequence, and vice versa. The recognition test was performed after 16 sequences randomly chosen among the 80 of the experiment. They were chosen in such a way that each experimental condition (i.e., Related vs. Unrelated × Normal vs. Scrambled) was represented by four sequences.

Procedure. The experimental procedure was split into two phases. The first phase was identical to the one described in Experiment 2. During the second phase, participants were required to quickly and accurately judge whether the last chord of the sequence was consonant or dissonant. They were asked to pay great attention to the overall sequence and were informed that some of the sequences would be followed by a recognition test. In such a case, an excerpt of four chords was presented after the consonant–dissonant judgment. Participants were then asked to indicate whether or not this excerpt belonged to the sequence they had just heard by pressing one of two keys of the button box; they were allowed to take their time for the recognition answer. In both the consonant–dissonant judgment and the

[4] The selection was made separately for musicians and nonmusicians, on the basis of their respective coherence judgments. For musicians, the mean coherence ratings of the subset were 5.08 for the normal and 3.29 for the scrambled versions (mean ratings of the total set = 4.82 and 3.76, for normal and scrambled sequences, respectively). For nonmusicians, the mean coherence ratings of the subset were 4.31 for the normal and 3.04 for the scrambled sequences (mean ratings of the total set = 3.78 and 3.59, for normal and scrambled sequences, respectively). The change in coherence difference between normal and scrambled versions from the entire sequence set to the subset was significant for both nonmusicians, $t(5) = 4.48$, $p < .01$, and musicians, $t(5) = 3.15$, $p < .05$.

recognition task, participants were alerted by a feedback signal if they gave an incorrect response.

Design. The within-subject factors were version (normal vs. scrambled), harmonic context (related vs. unrelated), and target type (consonant vs. dissonant). The between-subjects factor was musical expertise (nonmusicians vs. musicians). Eighty sequences were presented to each participant, as described in Experiment 1.

Results

Response accuracy. Percentages of errors (see Table 3) were analyzed in a 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVA. The effect of harmonic context was significant, $F(1, 28) = 24.64$, $MSE = 0.41$, $p < .01$, with more numerous errors in the unrelated condition (9.16%) than in the related condition (5.08%). The effect of harmonic context was, on average, more pronounced for consonant than for dissonant targets, but the two-way interaction of Harmonic Context × Target Type failed to reach statistical significance. There were no other significant effects, except for a main effect of musical expertise, $F(1, 28) = 10.14$, $MSE = 3.55$, $p < .01$, with more errors for nonmusicians (11.0%) than for musicians (3.25%).

A 2 × 2 × 2 (Version × Harmonic Context × Musical Expertise) ANOVA performed on sensitivity (d') confirmed the previously reported main effects of harmonic context and musical expertise: $F(1, 28) = 23.26$, $MSE = 1.03$, $p < .01$, and $F(1, 28) = 13.23$, $MSE = 3.88$, $p < .01$, respectively; d' was higher in the related context (4.96) than in the unrelated context (4.07), and it was higher for musicians (5.16) than for nonmusicians (3.86). The effect of version was expressed only in a marginally significant interaction with harmonic context and musical expertise, $F(1, 28) = 3.73$, $MSE = 0.95$, $p = .064$: For nonmusicians, the effect of harmonic context tended to be stronger for scrambled than for normal sequences; for musicians it was as strong for normal as for scrambled sequences. A 2 × 2 × 2 (Version × Harmonic Context × Musical Expertise) ANOVA performed on response criterion (c) did not show any significant effects, except for a marginally significant main effect of musical expertise, $F(1, 28) = 3.49$, $MSE = 0.52$, $p = .07$, with nonmusicians being slightly more subject to a response bias ($c = .39$) than were musicians ($c = .15$).

Response times. Correct response times (see Figure 5) were analyzed in a 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVA. There was a main effect of harmonic context, $F(1, 28) = 45.72$, $MSE = 17{,}820.3$, $p < .001$, and a significant two-way interaction between harmonic context and target type, $F(1, 28) = 12.03$, $MSE = 12{,}264.6$, $p < .01$. Response times were shorter in the related condition (893.94 ms) than in the unrelated condition (1,010.47 ms). This difference was more pronounced for consonant targets, although still significant for dissonant targets, $F(1, 28) = 26.73$, $MSE = 5{,}028.9$, $p < .01$. The main effect of version and its interaction with harmonic context was not significant. However, planned comparisons indicated that the two-way interaction between Version and Harmonic Context was marginally significant in nonmusicians for consonant targets, $F(1, 28) = 4.05$, $MSE = 9{,}471.33$, $p < .06$. As illustrated in Figure 5, response times tended to be longer for unrelated than for related targets, and this difference was more pronounced for scrambled sequences. In addition, the factor version interacted with target type, $F(1, 28) = 5.11$, $MSE = 6{,}858.6$, $p < .05$. For consonant targets, response times were longer for scrambled than for normal versions. This two-way interaction was stronger for nonmusicians.

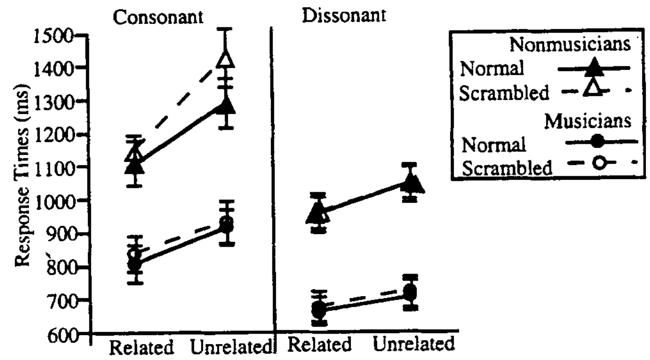

Figure 5. Correct response times averaged across the chord sequence set as a function of version, harmonic context, target type, and musical expertise in Experiment 3.

As in Experiment 2, musicians responded faster than nonmusicians, $F(1, 28) = 22.54$, $MSE = 308{,}984.4$, $p < .001$, and the effect of harmonic context was more pronounced for nonmusicians than for musicians, $F(1, 28) = 6.07$, $MSE = 17{,}820.3$, $p < .05$. There was also a main effect of target type, $F(1, 18) = 33.43$, $MSE = 17{,}019.6$, $p < .001$, with shorter response times for dissonant targets than for consonant targets. There were no other significant effects.

Response time analysis restricted on most and least coherent sequences. As in Experiment 2, an additional analysis addressed the argument that the effect of scrambling on priming might be stronger for sequences for which coherence decreased the strongest in the scrambled version. An ANOVA on response times for the subset sequences (cf. Experiment 2) confirmed the outcome of the entire sequence set reported above: a main effect of harmonic context, $F(1, 28) = 20.45$, $MSE = 486{,}435$, $p < .001$, musical expertise, $F(1, 28) = 19.02$, $MSE = 341{,}324$, $p < .001$, and target type, $F(1, 28) = 58.57$, $MSE = 44{,}473$, $p < .001$. The interaction Harmonic Context × Version × Musical Expertise was marginally significant, $F(1, 28) = 3.21$, $MSE = 19{,}093$, $p = .08$, because (as already reported for the entire set of sequences) for nonmusicians,

Table 3
Error Rates (in Percentages) as a Function of Version (Normal–Scrambled), Harmonic Context (Related–Unrelated), Target Type (Consonant–Dissonant), and Musical Expertise (Musicians–Nonmusicians) in Experiment 3

	Consonant		Dissonant	
Condition	Related	Unrelated	Related	Unrelated
Musicians				
Normal	2.7 (1.18)	3.3 (1.26)	.67 (.67)	5.3 (2.15)
Scrambled	3.3 (1.59)	6.7 (1.87)	1.3 (1.33)	2.7 (1.53)
Nonmusicians				
Normal	10.0 (2.18)	20.0 (4.88)	9.3 (5.56)	7.3 (4.40)
Scrambled	8.7 (2.91)	17.3 (2.48)	4.7 (2.36)	10.7 (3.45)

Note. Standard errors are in parentheses.

the effect of context tended to become stronger for scrambled than for normal sequences.

Recognition data. Overall percentages of correct performance were above chance for both musicians (75.5%), $\chi^2(1)=31.01$, $p < .001$, and nonmusicians (75%), $\chi^2(1)=30$, $p < .001$. Recognition data were analyzed in terms of hits and false alarms (see Table 4): Hits were defined as correct responses given when the target excerpt appeared; false alarms were defined as incorrect responses given when the foil appeared. A 2 × 2 × 2 ANOVA was performed with version (normal vs. scrambled) and response category (hits vs. false alarms) as within-subject factors and with musical expertise as the between-subjects factor. Hits were more numerous than false alarm rates, indicating that participants differentiated target excerpts from foils, $F(1, 28) = 168.0$, $MSE = 0.045$, $p < .001$. This finding suggests that participants focused not only on the target chords, but also paid attention to the entire sequence. In addition, there was a main effect of version, $F(1, 28) = 18.99$, $MSE = 0.048$, $p < .001$, with less numerous hits and false alarms for the scrambled version. When presented with scrambled sequences, participants tended to favor the "no" response.

Discussion

Experiment 3 replicated the main outcome of Experiments 1 and 2: Normal chord sequences showed facilitation for harmonically related rather than for unrelated targets, and this effect of relatedness did not diminish for scrambled sequences. In comparison with Experiment 2, Experiment 3 provided further evidence that attracting participants' attention toward the entire sequence by adding a recognition task did not increase the effect of the factor version. Recognition data demonstrated that participants did actually pay attention to the entire sequences because they managed to differentiate target excerpts from foil excerpts. The new attentional demand resulted in longer response times for the priming task in Experiment 3 than in Experiment 2, but had no reliable effect on the overall pattern of the data.

In Experiments 1–3, no significant interaction between version and harmonic context was found for musicians in the priming task. The sole evidence for an interactive effect between version and harmonic context was observed in nonmusicians for response times: The effect of harmonic relatedness was stronger in the scrambled version for only consonant targets, but not systematically in all experiments. This outcome suggests that the effect of version might require a more powerful statistical test to be consistently revealed. To address this issue, we performed further statistical analyses combining the 74 participants of Experiments 1–3. Results on error rates and response times did not provide a different light on the data.[5] For error rates, there was no evidence for an effect of version or for any interactive influences of this factor. For response times, there was a significant four-way interaction of Version × Harmonic Context × Target Type × Musical Expertise, $F(1, 72) = 5.45$, $MSE = 6{,}934.3$, $p < .05$. Planned comparisons indicated that only for nonmusicians did the interaction Version × Harmonic Context × Target Type reach significance, $F(1, 72) = 6.65$, $MSE = 6{,}934.33$, $p < .05$. Response times for consonant targets were longer in the unrelated than in the related condition, and this difference was more pronounced for scrambled sequences, $F(1, 72) = 8.07$, $MSE = 8{,}433.07$, $p < .01$. For musicians, the difference in response times between related and unrelated sequences was slightly stronger in normal sequences (115.8 ms) than in scrambled sequences (88.3 ms) for consonant targets, but this interaction did not reach significance. For musicians, the effect size (i.e., a measure of the degree to which the means differ in terms of standard deviation) of the interaction between version and harmonic context for consonant targets was calculated over the three experiments. Following the definition of Cohen (1988), this effect size was considered to be small ($d = .13$). Given this effect size and an alpha level of .05, a large subject pool would be necessary to obtain a test power of 0.8 (464 musicians).

Table 4
Hit and False-Alarm Rates for Normal and Scrambled Versions for Both Musicians and Nonmusicians in Experiment 3

	Response category	
Condition	Hit	False alarm
Musicians		
Normal	.90	.57
Scrambled	.78	.17
Nonmusicians		
Normal	.92	.43
Scrambled	.82	.30

General Discussion

The present study confirmed the importance of contextual information for the processing of chords reported in previous studies (Bigand et al., 1999; Bigand & Pineau, 1997; Tillmann, Bigand, & Pineau, 1998). Although the difference in harmonic relationship manipulated in related and unrelated conditions was small (with the tonic and subdominant chords being among the three most stable chords of a key), targets were processed more accurately and quickly in the related condition. The fact that this harmonic context effect was consistently observed for music students and for participants without musical training or formal tonal knowledge suggests that harmonic priming is a subtle phenomenon that is based on quite a robust cognitive process that does not require explicit knowledge of musical structure (for converging evidence, cf. Bharucha & Stoeckig, 1986, 1987; Bigand & Pineau, 1997; Bigand et al., 1999; Tillmann, Bigand, & Pineau, 1998).

[5] Error rates and correct response times for the three experiments were analyzed separately in two 2 × 2 × 2 × 2 (Version × Harmonic Context × Target Type × Musical Expertise) ANOVAs. For both error rates and response times, the combined analyses confirmed the effect of harmonic context. There were fewer errors and shorter response times for related conditions: $F(1, 72) = 23.10$, $MSE = 1.1607$, $p < .0001$, and $F(1, 72) = 126.69$, $MSE = 17{,}822.7$, $p < .0001$, respectively. Harmonic context effects were found to be more pronounced in nonmusicians: error rate, $F(1, 72) = 6.34$, $MSE = 1.1607$, $p < .02$; response time, $F(1, 72) = 22.36$, $MSE = 17{,}822.7$, $p < .0001$; and for consonant targets: error rate, $F(1, 72) = 15.45$, $MSE = 1.7360$, $p < .0001$; response time, $F(1, 72) = 32.62$, $MSE = 12{,}919.5$, $p < .0001$. In addition, there was a main effect of musical expertise, with more errors and longer response times in nonmusicians: error rate, $F(1, 72) = 43.11$, $MSE = 6.019$, $p < .0001$; response time, $F(1, 72) = 63.28$, $MSE = 339{,}584.6$, $p < .0001$; and a main effect of target type, with fewer errors and shorter response times for acoustically dissonant targets: error rate, $F(1, 72) = 4.95$, $MSE = 2.4049$, $p < .05$; response time, $F(1, 72) = 176.81$, $MSE = 21{,}442$, $p < .0001$.

The purpose of the present study was to investigate whether this process is sensitive to the temporal order of events in the context. The critical finding was to show that listeners exhibited a sensitivity to the temporal order of events with musical coherence judgments but not with a priming task. Perceptual coherence ratings were lower for scrambled than for normal sequences, and the difference between related and unrelated contexts was less pronounced for scrambled than for normal sequences. In contrast, harmonic priming did not significantly decrease for scrambled sequences in comparison with normal sequences. Moreover, harmonic priming tended to be more pronounced in the scrambled condition for nonmusicians. Taken together, these findings confirm the common intuition that the temporal order of events does actually affect the perceived coherence of musical pieces, a finding consistent with previously reported effects of temporal order on melodic perception (Bharucha, 1984; Deutsch, 1980, 1981, 1984), and provide preliminary evidence that the temporal order of chords only weakly contributes to harmonic priming effects. The fact that changing the temporal order never significantly decreased the strength of priming suggests that harmonic priming may be understood in light of a theoretical framework that is based on tonal stability and does not confer a strong importance on the temporal order of musical events.

Bharucha's (1987) connectionist model, MUSACT, offers one possible formal account of these findings. In this model, tonal knowledge is conceived of as an atemporal pattern of interconnected units. Once learning has occurred (Tillmann et al., 2000), these units are organized in three layers corresponding to tones, chords, and keys. Western tonal and harmonic relations are not stored explicitly but emerge from activation reverberating via connected links between layers. After the presentation of a single chord, the activation pattern of chord units reflects the harmonic hierarchy of the context: Units of harmonically related, stable chords are more strongly activated than units of unrelated, unstable chords. Although MUSACT is based on an atemporal pattern of connections, it nevertheless manages to capture some dynamic characteristics of harmonic expectations as they develop over time. When a chord sequence is played, activation that is due to each chord is accumulated in the network and weighted according to recency. At the end of a chord sequence, the activation of a unit depends as much on the activation spreading in the network that is due to the last event as it does on the decayed activation caused by previous events of the sequence. The MUSACT model thus represents a source of harmonic priming consisting of tonal knowledge activation and accumulation of activation patterns over time. As shown in Bharucha (1987), Bigand et al. (1999), Tekman and Bharucha (1998), and Tillmann, Bigand, and Pineau, (1998), the model provides a possible account of local and global context effects on chord processing.

To assess whether MUSACT accounts for the present findings, we performed simulations with the eight-chord sequences used in the present study (Figure 6).[6] The activation of the target chord unit accumulated after the seven chords was interpreted as how strongly this chord was expected to follow next (see Bharucha, 1987; Bigand et al., 1999). The spreading activation model anticipated no main effect of the version (the activation level remained unchanged for normal and scrambled versions), nor a decrease of harmonic relatedness in the scrambled version. As illustrated in Figure 6, the target chord unit always received stronger activation

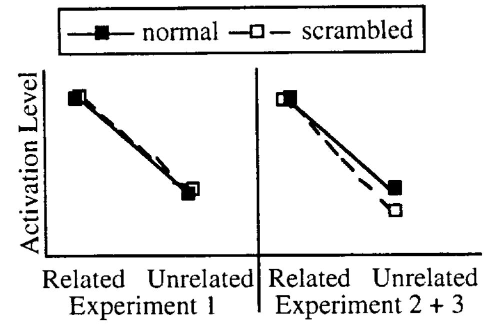

Figure 6. Relative activation observed for target chord units averaged over the sequence set as a function of version and harmonic context for Experiments 1, 2, and 3.

in the related context than in the unrelated context, independent of the version (normal vs. scrambled) of the sequences: material of Experiment 1, $F(1, 19) = 72.66$, $p < .0001$; material of Experiments 2 and 3, $F(1, 19) = 135.53$, $p < .0001$. In the 4-by-4 scrambled sequences used in Experiments 2 and 3, the model even anticipated an opposite effect of version (with a stronger effect of harmonic relatedness for scrambled sequences).[7] This interaction between harmonic context and version did not reach significance in the model, $F(1, 19) = 1.87$, $p = .19$, but the slightly stronger effect of harmonic relatedness mirrored nonmusicians' priming data. Supplementary simulations were run with the experimental material by using different values for the temporal decay of activation in the model. The outcome showed that increasing the decay parameter (from .4 to .6) always resulted in stronger priming for scrambled sequences. By contrast, reducing the decay parameter caused the influence of scrambling on the context effect to become less strong.

In summary, the overall pattern of activation in the MUSACT model provides a rather good fit with the pattern of priming data. This outcome suggests that harmonic priming may result from tonal knowledge activation and the accumulation of activation patterns in short-term memory over the course of the chord sequence.

[6] Simulations were run for all 40 normal and scrambled sequences used in Experiment 1 (2-by-2 scrambling) and in Experiments 2 and 3 (4-by-4 scrambling). They were run with an implementation of Bharucha's model on MATLAB (see Bigand et al., 1999). The rate at which activation decays (d) was .04 as in Bharucha (1987). Given that the interstimulus interval between chords was set to 0 and that all chords were played with the same duration, the time transpired since the last offset (t) was identical for each chord and was set to 1 (as in Bharucha, 1987, and Bigand et al., 1999).

[7] With the stronger 4-by-4 scrambling and because of the temporal decay of activation in the model, some activation patterns became more or less influential than in the normal versions, causing a decrease of activation in the unrelated scrambled condition (e.g., in some of the unrelated scrambled sequences, the subdominant chord occurs in an earlier position and the tonic chord in a later position than in the unrelated normal sequences, which (in combination with other features) might instill more strongly the key of the unrelated context and decrease the activation of the subdominant target in the scrambled version).

Conclusion

Semantic and harmonic priming illustrates the influence of a previous context on the processing of events. Because music and language evolve over time, a fundamental question is to understand the processes governing priming in long contexts and whether or not they are domain specific. Music and language have been compared in numerous ways by both music theorists (Bernstein, 1976; Deliège, 1984; Lerdahl & Jackendoff, 1983) and cognitive psychologists (Clarke, 1989; Sloboda, 1985; Trehub & Trainor, 1993). Although clear differences exist between them (e.g., music does not have the same type of syntactical organization that language has), it has been argued that music and language rely on shared processes and a common pool of neural resources (Besson & Friederici, 1998; Besson & Macar, 1987; Patel, Gibson, Ratner, Besson, & Holcomb, 1998; Patel & Peretz, 1997). The present study contributes to this debate by shedding some light on priming processes occurring in extended temporal contexts in music in comparison with language. In psycholinguistics, it has been shown that sentence priming results from both activation spreading inside the mental lexicon and integrative processes that organize words in meaningful sentences. Evidence for integrative processes was provided by experiments that have manipulated the temporal order of the words. Scrambling words in a sentence generally weakened (Masson, 1986; O'Seaghdha, 1989) or eliminated (Simpson et al., 1989) the semantic relatedness effects observed in normal sentences. The decrease of semantic priming that is due to scrambling highlights the role of syntactic connectedness and suggests that semantic and syntactic knowledge combine to build a conceptual representation of the sentence, which is then used to guide the search for upcoming words (e.g., Foss & Ross, 1983; Hess et al., 1995; Sharkey & Sharkey, 1987, 1992). Evidence for integration was, nevertheless, not always reported in psycholinguistics research. In Faust, Babkoff, and Kravetz (1995), participants were required to perform a lexical decision task on a target word that followed either a neutral, normal, or scrambled sentence of five words presented in either the right or the left visual field. When stimuli were presented in the left visual field, no effect of scrambling on semantic priming was reported. An effect of scrambling occurred only for stimuli presented in the right visual field. According to the authors, this suggests that integrative processes specifically involved the left hemisphere, whereas the right hemisphere was limited to semantic relations between words, that is, intralexical associations that might arise from the automatic spread of activation in the semantic network.

Our present study points to a similar weak effect of temporal order on priming effects in music. The manipulation of chords' order decreased the perceived coherence of sequences, but not the effect of harmonic relatedness on priming. This outcome suggests that harmonic priming primarily results from a fast and automatic activation that spreads via the long-term connections between harmonically related tones and chords as simulated by Bharucha's (1987) spreading activation model. A further stage of processing that consists of integrating the musical events in an overall coherent structure seems not necessary to account for harmonic priming effects. Combined with Faust et al. (1995), the findings underline the fact that the role played by temporal order on priming remains a matter of debate in both music and language domains and that contrary to what we might have expected, scrambling the order of events does not systematically affect priming in either domain.

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