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Effects of Global and Local Contexts on Harmonic Expectancy

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Several psycholinguistic studies have investigated the influence of local and global semantic contexts on word processing. The first aim of the present study was to examine local and global level contributions to harmonic priming. The second was to test a spreading-activation account of harmonic context effects (Bharucha, 1987). The expectations for the last chord (the target) of eight-chord sequences were varied by simultaneously manipulating the harmonic relationship of the target to the first six chords (global context) and to the seventh chord (local context). Human performances demonstrated that harmonic expectancies are derived from both the global and local levels of musical structure. Bharucha's connectionist model provides a possible account of local and global context effects. In isochronous chord sequences, harmonic priming seems to result from activation spreading via a schematic knowledge of tonal hierarchies.

SEMANTIC and harmonic priming research illustrates the general influence of a previous context on the processing of upcoming events. Meyer and Schvaneveldt (1971) have established, for example, that the processing of a target word (*nurse*) is faster and more accurate when it follows a prime word that is semantically related (*doctor*) than when it follows a prime word that is semantically unrelated (*bread*). Similarly, it has been established in music that the processing of a target chord (say C major) is facilitated when this chord occurs after a chord belonging to the same musical key (*B♭ major*) rather than another key (*F♯ major*). In harmonic priming studies (Bharucha & Stoeckig, 1986, 1987; Tekman & Bharucha, 1992, 1998), participants heard a prime chord followed by a target chord. On half of the trials, the target chord was slightly mistuned, and participants were asked to make a speeded intonation judgment, that is, to decide as quickly as possible whether the target chord was in tune. The priming effect was shown by (1) a bias to judge targets to be in tune when they were related to the prime, and (2) shorter response times for in-tune targets when

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they were related to the prime, and for out-of-tune targets when they were unrelated to the prime. A preceding musical context (one chord in these experiments) generates the expectancy that related chords will follow, resulting in greater consonance and faster processing for expected chords.

In both language and music research, a key concern remains to understand how such priming effects occur in more ecologically valid situations involving larger contexts than one word or one chord. In psycholinguistics, several empirical studies have been devoted to the analysis of semantic priming in sentences and discourses. In such situations, two potential sources of priming have been identified. One source is located inside the mental lexicon, termed *intralexical priming* (Forster, 1979). Priming is due to the fast and automatic activation that spreads via the long-term connections between semantically related items (Duffy, Henderson, & Morris, 1989; Neely, 1991). A second source of priming arises from the processes that integrate local structures within a coherent whole (Hess, Foss, & Carroll, 1995; Sharkey & Sharkey, 1987, 1992). Facilitation occurs for target words that are easily integrated into the ongoing discourse representation (*discourse priming*). In particular, this second source explains why the effects of global context persist after a semantically unrelated word interposed before the target (Sharkey & Sharkey, 1992). For example, in the study by Hess et al. (1995), the relationship between the target and the general topic of the discourse (*global context*) was crossed with the relationship between the critical word and the sentence prior to it (*local context*). The processing of the target word was facilitated when it was semantically related to the global topic of the discourse, regardless of the local context (see also Foss, 1982; Foss & Ross, 1983).

In music, the simultaneous effect of global and local contexts on harmonic expectancy remains to be studied. Preliminary harmonic priming experiments have shown that one chord can prime another when both are harmonically related (Bharucha & Stoeckig, 1986, 1987; Tekman & Bharucha, 1992, 1998). Given that the prime and target chords were played without any context, these studies provide evidence for local context effects, but not for the possible role played by higher levels of harmonic structure. In some studies, long chord sequences were used as the prime, and the target chord was either at the end of the sequence (Janata, 1995; Schmuckler & Boltz, 1994) or in the middle of the sequence (Patel, Gibson, Ratner, Besson, & Holcomb, in press). However, these studies do not allow distinction between the possible influences of global and local structures because the harmonic expectation for the target was varied by using different final events.

In order to disentangle global and local context effects, Bigand and Pineau (1997) manipulated the global harmonic context of eight-chord sequences while holding the chord preceding the target and the target itself constant.

Expectations for the last chord (the target) were varied by changing the harmonic context created by the first six chords. In the *expected context*, the first six chords of the sequences created a key context (e.g., C major) in which the target chord was a harmonically stable tonic chord, part of an authentic cadence (V-I, or G-C in this example). In the *unexpected context*, slight changes in pitch were introduced in the first six chords so that the sequences created a new key context (G major in this example) in which the target chord took the form of a less stable fourth harmonic degree following an authentic cadence (V-I-IV, or D-G-C).[1] Given this change in harmonic function, the target chord was assumed to be less expected in the latter context. Support for the effect of global harmonic context was provided by the fact that participants were more accurate and took less time to decide whether the last chord was acoustically consonant or dissonant when it was expected. This finding suggests that harmonic priming not only occurs from chord to chord but also involves higher levels of structure.

Bigand and Pineau's findings have been extended to wider harmonic contexts (i.e., 14-chord sequences), defined at three hierarchical levels (Bigand, Madurell, Tillmann, & Pineau, in press). All the sequences used contained two sections delineated by a fermata. In the *highly expected condition*, both sections were in the same key, and the target chord was part of an authentic cadence (V-I) that closed the overall structure. In the *unexpected condition*, both sections were in the dominant key and the target chord was a fourth harmonic degree following an authentic cadence (V-I-IV). In the *middle expected condition*, the first section was harmonically identical to that of the highly expected condition and the second section was identical to that of the unexpected condition. Although the chords of the second section were strictly identical, the target chord in the middle expected condition was no longer a fourth harmonic degree following an authentic cadence. In this context, it may be analyzed as part of an authentic cadence (V-I) that returns to the main key. In all the conditions, the chord preceding the target and the target itself were identical. The strength of the priming effects varied as a function of the number of levels at which the target chord was expected: strongest facilitation was observed when the target chord was expected at both high and intermediate levels (highly expected condition). Facilitation was reduced when the target chord was expected at the higher level only (middle expected condition). The weakest priming effect was observed when the target chord was not strongly expected at either high or intermediate levels (unexpected condition). This finding provides some evidence that musical expectations derive from various levels of the hierarchical structure.

1. The chord sequences of the unexpected condition were matched to those of the expected condition: the melodic contour of the outer voices (i.e., soprano and bass voices) remained very similar, and the changes in pitch performed in the first six chords were minimal.

In the studies by Bigand and Pineau (1997) and Bigand et al. (in press), the global context was changed by keeping the chord(s) preceding the target constant. These studies were not designed to evaluate the combined influence of the local (i.e., chord) and global levels (i.e., sequence) on harmonic expectancy formation. The present experiment addresses this issue by performing crude changes in harmonic relationships at both global and local levels. As described in Table 1, the first six chords were considered as the global context and the penultimate chord as the local context. For example, in a C major sequence, the target chord was considered as globally and locally related (GRLR) when it was a tonic chord (C) and was preceded by a dominant chord (G). It was globally related, but locally unrelated (GRLU) when the preceding dominant chord was played 1 semitone higher (G♯ or A♭). In this case, the target and the preceding chord do not belong to the same key, but the target is still related to the global context.[2] The target was globally unrelated, but locally related (GULR) when the first six chords of the sequences were transposed 1 semitone higher (i.e., in the C♯ or D♭ major key). Finally, the target chord was said to be both globally and locally unrelated (GULU) when the first seven chords were transposed 1 semitone higher (in the C♯ major key). Following Bigand et al. (in press), it was predicted that the strength of the priming effects will vary as a function of the number of levels at which the target chord was expected: facilitation should be strongest in the GRLR condition, moderate in both GRLU and GULR conditions, and weakest in the GULU condition.

TABLE 1
Modifications of the Global and Local Contexts Illustrated with a Sequence in C Major

Condition	Global Context (chords 1 to 6)	Local Context (chord 7)	Target (chord 8)
GRLR	C major key	G chord	C chord
GRLU	C major key	G♯/A♭ chord	C chord
GULR	C♯/D♭ major key	G chord	C chord
GULU	C♯/D♭ major key	G♯/A♭ chord	C chord

GRLR = globally and locally related; GRLU = globally related, locally unrelated; GULR = globally unrelated, locally related; GULU = globally and locally unrelated.

2. The target chord is not strictly unrelated to the A♭ chord in the LU condition because the A♭ chord can be considered as a flat VI chord. However, the target chord is less related to an A♭ chord than to a G chord, which is the crucial point for the purposes of the present experiment.

A Spreading-Activation Account of Harmonic Priming

Bharucha's (1987) spreading-activation model provides an elegant account of harmonic priming of both single chords and long chord sequences. In the MUSACT model, the knowledge of Western harmonic hierarchy is conceived of as a network of interconnected units. The neural net units are organized in three layers corresponding to tones, chords, and keys. Each of the 12 tone units are connected to six chord units representing three major and three minor chords of which that tone is a component. Analogously, each chord unit is connected to three major key units representing keys of which it is a member. The structure of the Western musical system is expressed in the model by the strength of the connections that link tone units to chord units and chord units to key units. This pattern of connections constitutes a knowledge representation of Western harmony that generates automatic and schematic expectations in listeners (Bharucha, 1987, 1994).

When three triadic tones are played (say, c-e-g), the units representing these tones are activated, and phasic activation is sent toward the chord units via the connected links. The chord unit connected to all three tones receives the strongest activation (the C major chord in this example). During a second cycle, phasic activation from the active chord units spreads towards the key units (bottom-up activation) and starts to reverberate toward tone units (top-down activation). During the next cycle, activated key units send top-down activation to chord units that simultaneously receive bottom-up activation from the tone units. After several cycles, the model reaches equilibrium in such a way that the activation pattern reflects Western tonal hierarchy and takes into account the key memberships of a chord. Chord units related to the prime receive more activation than do unrelated chords. For example, the activation that reverberates after the C major chord is greater for the B♭ chord than for the F♯ chord (see Bharucha, 1987).

The activation levels are interpreted as the array of expectations for further incoming events. The extent to which a potential target chord is primed is a function of the activation of that target chord unit: The more a chord unit is activated, the more the chord is expected. Given that perceptual expectancies create a bias in favor of expected events—that is, harmonic expectancies generate greater consonance for related chords (Bharucha & Stoeckig, 1986, 1987)—it is possible to make predictions for consonant and dissonant targets on the basis of activation levels. The processing of a consonant target chord will be more accurate and faster when the target corresponds to a strongly activated chord unit. In contrast, the processing of dissonant targets will be more accurate and faster when the target corresponds to a less activated chord unit. This crossed interaction between context and target type (i.e., consonant versus dissonant) provides a reliable demonstration of the influence of musical context on the perceptual processing of incoming chords.

For long chord sequences, activations from several chords are accumulated during the sequence and together determine the level of expectation for further incoming events. When the model has reached equilibrium after an event, the pattern of activation decays over time. The activation of a new event is added to the residual activation from the previous event. The total activation pattern represents the influence of the whole sequence, with the activation of the most recent chord having decayed the least. When the chord sequence remains in the same key, the overall activation pattern represents the influence of the harmonic hierarchy of that key with, in addition, a strong activation for the most recent chord. In other words, the activation of a tonic chord will be stronger than that of the dominant chord and the subdominant chord, as long as the dominant or the subdominant chord does not correspond to the last event of the sequence. The degree of activation of the target chord in this overall activation pattern determines the degree of expectation for the target. The present spreading-activation model provides a possible account of the global context effects observed by Bigand and Pineau (1997) and Bigand et al. (in press). Figure 1 illustrates the activation of all the major chord units at the end of the chord sequences used by Bigand and Pineau (1997). The target chord unit received significantly stronger activation when the target acted as a stable tonic chord (I)

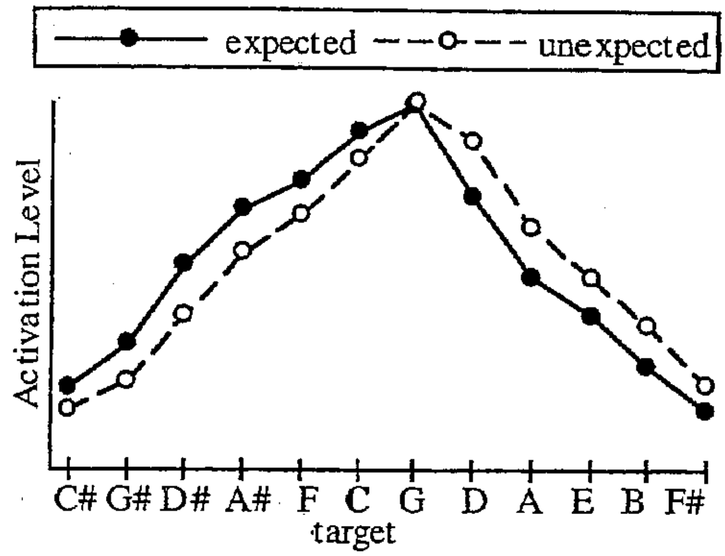

Fig. 1. Activations observed for all major chord units once the network has reached equilibrium on the penultimate chord in the expected and unexpected contexts. For convenience, the state of the network is represented with reference to the C major key. In this key, the C chord unit represents the target. (From Figure 3, Bigand et al., in press. ©American Psychological Association. Adapted with permission.)

in the expected context than when it was a less stable subdominant chord (IV) in the unexpected context.

The spreading-activation model is further tested in the present experiment, which analyzed the combined effects of global and local contexts. Neural net simulations were conducted with the first seven chords of each experimental condition (GRLR, GRLU, GULR, GULU) played at two tempi.[3] As shown in Figure 2, Bharucha's spreading-activation model predicts an effect of both contexts: the target chord receives stronger activation when it is globally or locally related to the context. This activation pattern suggests that the processing of consonant targets will be more accurate and faster in the globally and locally related conditions. In contrast, the processing of dissonant targets will be facilitated in the globally and locally unrelated conditions (see above). The model also anticipates that the tempo of the sequences influences the effect of global context. During the sequence, activations of both local and global contexts accumulate and decay exponentially over time, with the most recent events being more active. As the decay is weaker at fast than at slow tempo, the effect of global context should be more pronounced at fast tempo. This influence of decay strength due to tempo should be negligible for the local context. Neural net

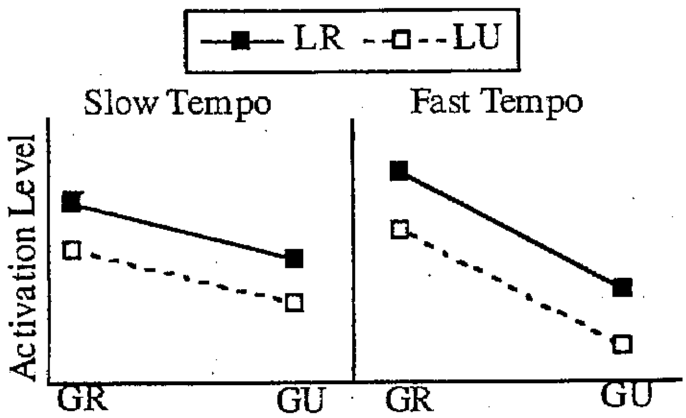

Fig. 2. Activations observed for target chord units once the network has reached equilibrium on the penultimate chord for the four experimental conditions in slow tempo and fast tempo.

3. All simulations were run with an implementation of Bharucha's model on Matlab (see Bigand et al., in press). The rate at which activation decays (d) was set to .04 as in Bharucha (1987). Given that all the chords were played without inter offset-onset silence and with the same duration, the time elapsed since the last offset (t) was identical for each chord. For the fast tempo condition, the t parameter was set to 1 and in the slow condition to 1.5. This change in t values (1 to 1.5) corresponds to the percentage of change in tempo performed between the slow and fast condition. Simulations were run separately for each sequence. At the beginning of each simulation, the state of the network was initialized to zero.

simulations thus indicate that the expectancy for the target chord depends on whether one or two sources of priming are present and, to some extent, on the tempo of the sequence. The target is most expected in the GRLR condition, as both contexts are related to the target chord. It is least expected in the GULU condition, where the target chord has no relation to the previous context. It is moderately expected in the GRLU and GULR conditions, as only one context (global or local) is related to the target. In these conditions, global and local contexts are expected to exert roughly similar effects at a slow tempo, but the global context should prevail over the local context at a fast tempo.

In summary, the first goal of the following experiment was to assess the simultaneous contribution of global and local contexts to chord processing. The second goal was to compare human performances with neural net simulations.

Method

PARTICIPANTS

Forty-eight students from the University of Dijon participated in the experiment: 24 students with no formal musical training or any practice with a musical instrument (referred to as "nonmusicians") and 24 graduate students from the music department (referred to as "musicians").

MATERIAL

Twenty chord sequences ending on an authentic cadence were used (see Bigand & Pineau, 1997; Pineau & Bigand, 1997). They were played in one of seven keys (C major, G major, D major, A major, E major, F major, or B♭ major). The original sequences were referred to as globally and locally related sequences (GRLR). For each sequence, three other versions were created by systematically varying the local and global relatedness to the target chord (see Table 1 and Appendix): a globally related, locally unrelated version (GRLU); a globally unrelated, locally related version (GULR); and a globally and locally unrelated version (GULU). The unrelated context, either on a global or local level, was constructed by transposing the chord(s) of the context 1 semitone higher. The target chords were rendered dissonant by adding an augmented octave to the root. This added tone was played more quietly than the other pitches in order to make this dissonance less salient.

APPARATUS

All the stimuli were played with sampled piano sounds produced by the EMT10 Yamaha Sound Expander. Velocity, a parameter related to the force with which a key is struck, was constant for all pitches except the added augmented octave for dissonant targets, which was played at half velocity. The sound stimuli were captured by SoundEditPro software 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 66 quarter tones per minute for the slow tempo (910 ms per chord) and 99 quarter notes per minute for the fast tempo (600 ms per chord). These tempi were chosen because they roughly match the range of spontaneous tempi (Fraisse, 1967) while still sounding natural: below 60 quarter notes per minute sounds too slow and above 90 quarter note per minute sounds too fast.

PROCEDURE

Participants were first trained with isolated chords, then with chord pairs. These chord pairs were extracted from the sequences and corresponded to the locally related (LR) and locally unrelated (LU) contexts. Participants had to make a consonant/dissonant judgment on the second chord of the pair as quickly as possible by pressing one of two keys on the PsyScope button box. In the experimental phase, the eight-chord sequences were presented and participants made the consonant/dissonant judgment for the last chord of the sequences. The participants were alerted by a feedback signal if they gave an incorrect response. The next trial began when the subject pressed a button on the button box.

DESIGN

Global Context (related/unrelated), Local Context (related/unrelated), and Target Type (consonant/dissonant) were defined as within-subject factors. Musical Expertise (nonmusicians/musicians) and Tempo of the sequences (fast/slow) were defined as between-subject factors. Half of the participants listened to sequences played in the fast tempo, the other half to sequences presented in the slow tempo. Crossing Global Context, Local Context, and Target Type produced 8 possible versions for each sequence. The 20 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/dissonant) for each group of sequences was reversed for the other half of the participants. Each participant heard 80 sequences presented in a random order.

Results[4]

RESPONSE ACCURACY

Percentages of correct responses (Figure 3 top) were analyzed by a 2 x 2 x 2 x 2 x 2 (Musical Expertise x Tempo x Global Context x Local Context x Target Type) analysis of variance (ANOVA).[5] As shown in Figure 3, there was a main effect of Global Context, with higher percentage of correct responses for globally related contexts, $F\,(1,44) = 28.32$, $MSE = 1.24$, and a main effect of Local Context, with a higher percentage of correct responses for locally related contexts, $F\,(1,44) = 17.48$, $MSE = 1.80$. As also reported by Bharucha and Stoeckig (1986, 1987), these effects of global and local context varied as a function of the target type ($F\,(1,44) = 66.20$, $MSE = 1.57$, for Global Context, and $F\,(1, 44) = 58.54$, $MSE = 2.11$, for Local Context). For consonant targets, responses were more accurate in

4. An alpha level of .05 was used for all statistical tests, unless indicated otherwise.
5. As suggested by a reviewer, a supplementary ANOVA was performed on arcsine-transformed data. It provided the same results as the ANOVA with the original data.

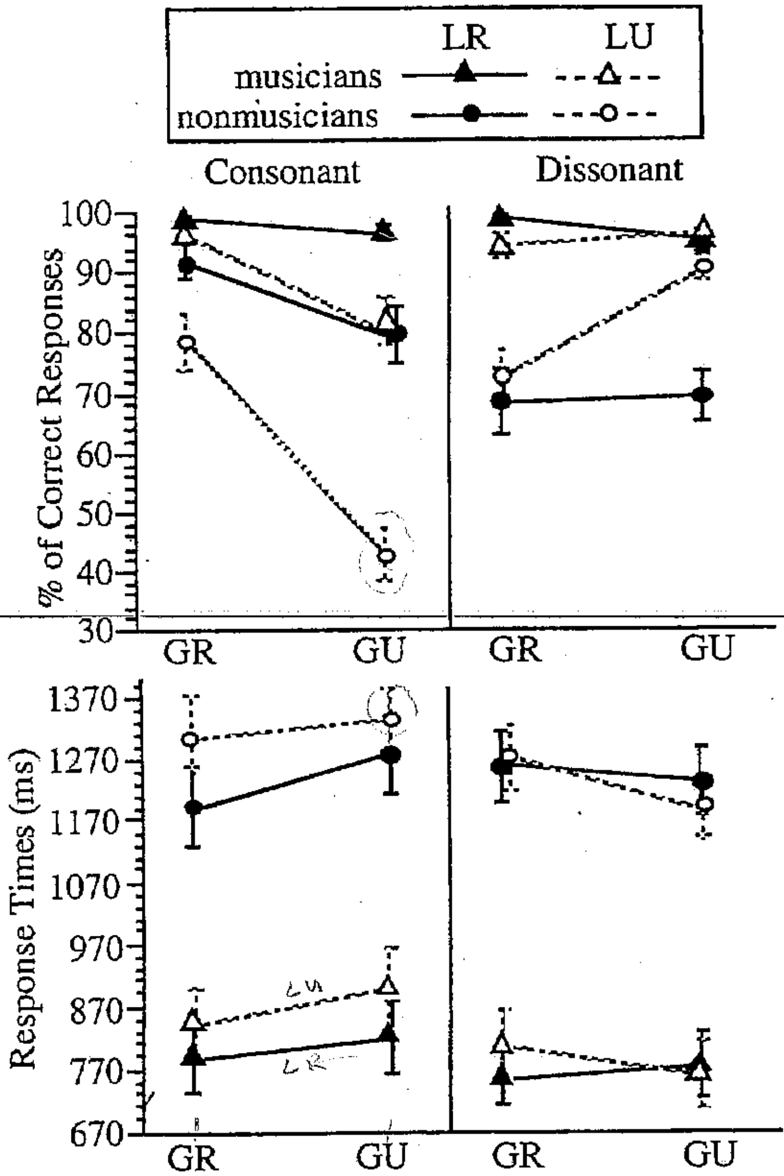

Fig. 3. Percentage of correct responses (top) and correct response times (bottom) averaged across the chord sequence set and tempo as a function of global context, local context, target type, and the level of musical expertise (GR = globally related; GU = globally unrelated; LR = locally related; and LU = locally unrelated). The bars represent the standard errors for each mean.

the globally and locally related conditions. For dissonant targets, correct responses were more numerous in the unrelated conditions. The effects of global and local contexts were not found to be independent: the effect of local context was more important when the target was unrelated to the global context. A significant three-way interaction among Global Context x Local Context x Target Type indicates that the interactive effects of global and local contexts changed as a function of the target type, F (1,44) = 29.46, MSE = 1.88 (see Table 2). For consonant targets, the number of correct responses decreased for locally unrelated contexts, and this decrease was stronger when the target chord was also globally unrelated. In the case of dissonant targets, the number of correct responses increased for locally unrelated contexts only if the global context was also unrelated. This effect was mostly observed in nonmusicians. In addition, percentages of corrected responses were significantly higher for musicians than for nonmusicians, F (1, 44) = 48.81, MSE = 8.19. Musicians generally exhibited a high level of performance that decreased strongly for consonant targets that were both globally and locally unrelated (GULU condition). It is worth noting that nonmusicians did not perform above chance level in this GULU condition. The influence of musical expertise also found expression in a three-way interaction of Musical Expertise x Global Context x Target Type, F (1, 44) = 23.83, MSE = 1.57, and a three-way interaction of Musical Expertise x Local Context x Target Type, F (1, 44) = 24.83, MSE = 2.11. The interactions between contexts (local and global) and Target Type were both more pronounced for nonmusicians. Finally, there was no main effect of Tempo on response accuracy but a significant two-way interaction between Tempo and Target Type, F (1, 44) = 7.15, MSE = 3.22. Percentages of correct responses tended to be higher for consonant targets (86.36%) than for dissonant targets (83.96%) at a fast tempo, whereas the opposite was observed for the slow tempo (79.90% for consonant targets, 87.30% for dissonant targets).[6]

TABLE 2

Percentages of Correct Responses for the Interaction of Local Context x Global Context x Target Type, Averaged Across Musical Expertise, Tempo, and Chord Sequences

	Consonant Target		Dissonant Target	
	GR	GU	GR	GU
LR	95.21	88.13	83.54	82.08
	(11.1)	(18.86)	(24.45)	(20.93)
LU	87.50	61.66	83.33	93.54
	(19.51)	(28.0)	(20.25)	(8.87)

Numbers in parentheses are standard deviations. GR = globally related; GU = globally unrelated; LR = locally related; LU = locally unrelated.

6. Following a reviewer's suggestion, a 2 x 2 x 2 x 2 (Musical Expertise x Tempo x Global Context x Local Context) ANOVA was performed on the sensitivity parameter d'. Results confirmed the main effects observed for percentages of correct responses. The main effect of musical expertise was significant, F (1, 44) = 50.9, MSE = 6.9: d' was higher for musicians than for nonmusicians. The main effects of Global context and Local context were significant, F (1, 44) = 23.9, MSE = 1.17 and F (1, 44) = 1.5, MSE = 19.77, respectively. The sensitivity parameter d' was higher for globally related and locally related contexts than for globally unrelated and locally unrelated contexts.

RESPONSE TIMES

Analyses of correct response times[7] were performed separately for nonmusicians and musicians. Because of the low percentage of correct responses for nonmusicians in the GULU condition, correct response times cannot be considered to reflect the underlying processing of the target chord. Nonmusicians' correct response times were analyzed without this condition. For musicians' correct response times, a 2 x 2 x 2 x 2 (Tempo x Global Context x Local Context x Target Type) ANOVA was run (Figure 3 bottom). The outcome is globally consistent with the previous analysis of response accuracy. There was no main effect of Global Context but a significant two-way interaction between Global Context and Target Type, F (1, 22) = 22.35, MSE = 1765.7. For consonant targets, correct responses times were shorter in the GR than in the GU conditions. This effect tended to be inverted for dissonant targets. There was a main effect of Local Context, F (1, 22) = 16.49, MSE = 5242.7, and a significant two-way interaction between Local Context and Target Type, F (1, 22) = 8.63, MSE = 3289.8. For consonant targets, correct responses times were shorter in the LR than in the LU condition. This effect of local context vanished for dissonant targets. The analysis of response times provided further evidence that the effects of global and local contexts were not independent. The marginally significant three-way interaction among Global Context x Local Context x Target Type indicated that the effect of Local Context was more important when the target was unrelated to the global context, the form of this interaction depending on the target type, F (1, 22) = 3.75, MSE = 6054.59, $p < .065$. For consonant targets, the increase in response time caused by a change in local context (i.e., LR versus LU) was greater in the GU than in the GR condition. The opposite tendency was observed for dissonant targets (see Figure 3, bottom). There were no other significant effects except a main effect of Target Type (response times were shorter for dissonant targets, F (1, 22) = 9.6, MSE = 21029.0), and a marginally significant two-way interaction Tempo x Global Context, F (1, 22) = 4.13, MSE = 2772, p = .054. As anticipated by the spreading activation model, the difference in response times between globally related and globally unrelated targets was more pronounced at the fast tempo, especially for consonant targets (i.e., a difference of 60 ms between GR and GU at fast tempo versus 26 ms at slow tempo).

Nonmusicians' correct response times (Figure 3 bottom) were analyzed without the GULU condition. The three contexts (GRLR, GRLU, GULR) were considered as three conditions of one within-subject factor (Context).

7. Correct response is the judgment "consonant" for a consonant target and the judgment "dissonant" for a dissonant target (only the response times for these correct responses were taken into account in the analyses).

A 2 x 3 x 2 (Tempo x Context x Target Type) ANOVA was performed, and the effects of local and global contexts were examined through planned comparisons. Correct response times varied as a function of Context, F (2, 44) = 11.37, MSE = 3356.6, and this context effect was stronger for consonant targets, F (2, 44) = 12.81, MSE = 4154.2. Planned comparisons confirmed an interaction between local context and Target Type, F (1, 22) = 18.67, MSE = 4829.84, and between global context and Target Type, F (1, 22) = 14.04 MSE = 4839.64. In both contexts, correct response times for consonant targets were shorter for related targets than for unrelated targets. These effects of context tended to be inverted for dissonant targets. There were no other significant effects except a significant two-way interaction between Context and Tempo, F (2,44) = 4.49, MSE = 3356.6. As also reported for musicians, the difference in response times between globally related and globally unrelated targets was more pronounced for the fast tempo; F (1, 22) = 7.64, MSE = 3696.0. This difference was stronger for consonant targets (i.e., 115.5 ms between GR and GU at fast tempo versus 48.9 ms at slow tempo).

Discussion

The first aim of this experiment was to examine local and global level contributions to harmonic priming. The results confirmed that both local and global contexts influence the formation of harmonic expectancy. The processing of a consonant target chord was faster and more accurate when the target was harmonically related to the immediately preceding chord, regardless of the global context. This finding concurs with initial single-chord priming studies: one chord is sufficient to generate the expectancy that related chords will follow (Bharucha & Stoeckig, 1986, 1987). Results also confirmed an effect of global context as reported by Bigand and Pineau (1997) and Bigand et al. (in press). The present results went one step further in showing that global context effects persist even after the intervention of a chord that was strongly unrelated to the target. This provides further evidence that harmonic priming not only occurs sequentially from chord to chord, but also depends on the harmonic function of the chord in an extended temporal context. This finding concurs with the conclusion of Bigand et al. (in press) that musical expectations derive from different levels of the hierarchical structure. The strongest facilitation was observed for consonant targets that were harmonically related at two structural levels. When the target was related to one structural level only, this facilitation was reduced. The processing of target chords was least accurate and took the longest when the chords were unrelated to both levels of context.

The present experiment also provides some evidence that the effects of local and global contexts in music are unlikely to be independent. The effect of local context depends on the harmonic relationship of the target with the global context. The consonant/dissonant judgments were less accurate and took longer for consonant targets in the locally unrelated condition, but this effect of local context was more pronounced when the target was also unrelated to the global context of the sequence. This finding suggests that the strength of the priming effects does not result only from a simple additive combination of the priming effects generated at various levels of the hierarchic structure.

The second aim of this experiment was to test further a spreading-activation account of harmonic context effects. Neural net simulations indicate that the expectancy for the target chord depends on whether one or two sources of priming are present and to some extent on the tempo of the sequence. The present findings support these predictions. The priming effect was the strongest when both global and local contexts were related to the target chord. Moderate priming effects were observed in the GRLU and GULR conditions, in which only one context was related to the target. The priming effects were weakest in the GULU condition, in which the target chord had no relation to the previous context. Although the two-way interaction between global context and tempo was not observed for response accuracy, some evidence for this interaction was observed with response times. The manipulation of the global context tended to have a stronger effect when the sequences were played at a fast tempo. In the present experiment, the change in tempo between the slow and the fast conditions remains moderate (60 vs 90 beats per minute). Therefore, it seems likely that stronger evidence for this two-way interaction will be obtained by increasing the difference between these tempi.

Let us consider in more detail how MUSACT manages to simulate these effects. In this connectionist model, the activation consecutive to a single chord reflects the harmonic hierarchy of the key for which it is a tonic chord (Bharucha, 1987). During a sequence, the activation patterns consecutive to each chord are added up. When all the chords are in the same key, the overall pattern globally reflects the sequence's underlying key with, in addition, a strong activation of the most recent event. Figure 4a represents the state of the network on the penultimate chord in the GRLR condition. When a harmonically locally unrelated chord is interpolated (GRLU), the activation pattern resulting from this interfering event mirrors the tonal hierarchy of a key (G♯ or A♭ for a sequence in C major) that is negatively correlated to the tonal hierarchy induced by the previous context (Krumhansl, 1990). Because the activations are added up in the network, the overall pattern is flattened, and all the chord units tend to be nearly equally activated after this interfering event. Comparison of Figure 4a with

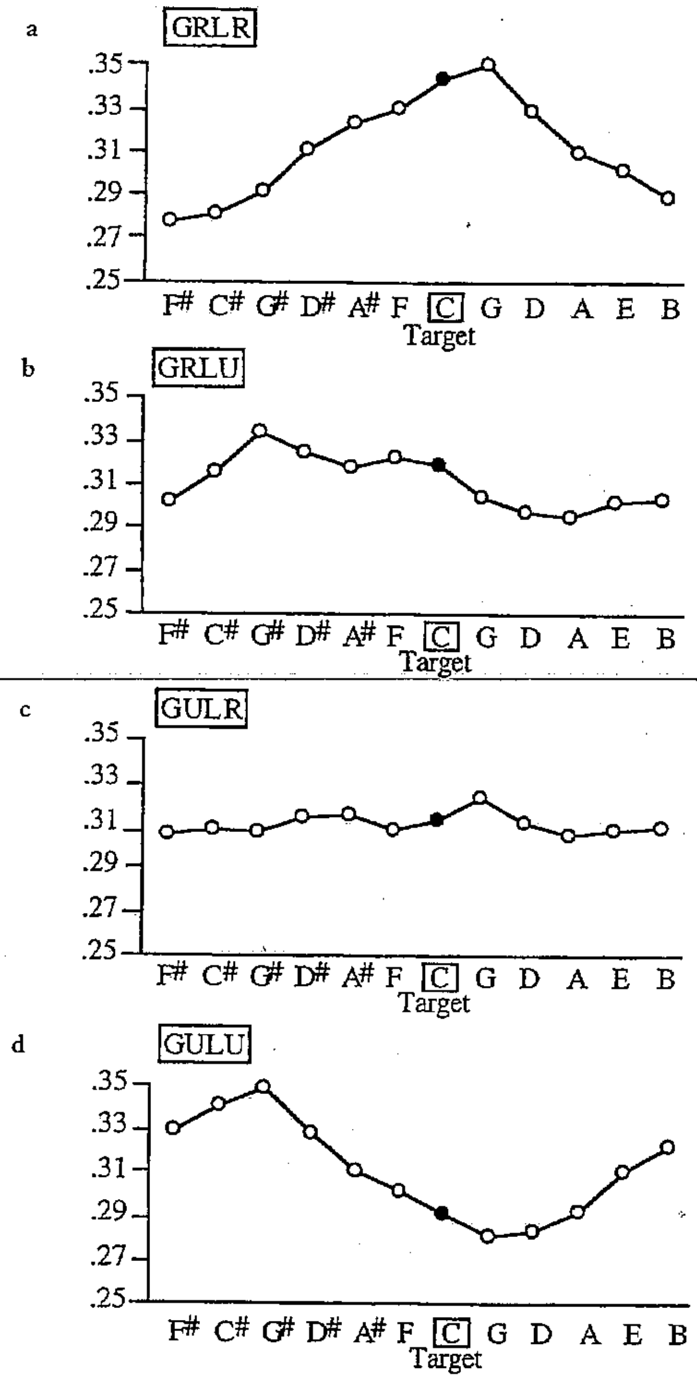

Fig. 4. Absolute activations observed for major chord units once the network has reached equilibrium on the penultimate chord for the four experimental conditions in a slow tempo. For convenience, the state of the network is represented with reference to the C major key. In this key, the C chord unit represents the target.

Figure 4b shows that this effect of local context is expressed in the model by a smaller activation for the target and by an increase in activation for several other major chord units. A similar process occurs when the target chord is harmonically unrelated to the global context, while being related to the immediately preceding chord (GULR) (Figure 4c). When the target chord is not harmonically related to either the global or local contexts (GULU), the state of the model approaches another tonal hierarchy in which the target chord is an unstable, weakly activated, nondiatonic chord. Overall, the simple accumulation of tonal hierarchy patterns takes into account the priming effects observed for local and global contexts. The influence of tempo on response times also suggests that tonal hierarchy patterns are accumulated and weighted by extent of decay, as if they were simply stored in a buffer.

In addition, a spreading-activation model also provides a possible explanatory framework to account for the critical finding that harmonic context effects were found to be almost independent of the extent of musical expertise. Of course, musicians were more accurate and faster in making the consonant/dissonant judgment, but nonmusicians reacted in the same way as musicians on changes in harmonic structure. These results are congruent with several other experiments that show that harmonic priming is not limited to subjects with formal musical expertise (Bharucha & Stoeckig, 1986, 1987; Bigand & Pineau, 1997; Bigand et al., in press). Harmonic priming seems to reflect a robust underlying system that can be acquired without formal instruction, through passive exposure to Western musical pieces (Bharucha, 1994; Tillmann & Bharucha, 1998).

One aspect of the present findings remains difficult to account for under this model. The effect of the local context changes as a function of the global context in which it is embedded. The lack of a local relationship seemed to be more disruptive when the target chord was unrelated to the global context. This interaction of global and local contexts on the processing of incoming chords was not predicted either by neural net simulations or on the basis of previous experimental results. To our knowledge, such an interaction between local and global contexts has also never been reported in psycholinguistic priming studies. The aim of further research would be to determine whether this interactive effect is limited to the performed manipulations or if it can be generalized to other manipulations of global and local musical structures.

Conclusion

In this study, we investigated the cognitive processes underlying harmonic expectancy formation at global and local levels. The fact that both global and local contexts simultaneously influence the processing of a target chord is consistent with single chord priming studies (Bharucha & Stoeckig, 1986, 1987; Tekman & Bharucha, 1992, 1998) and confirms the effect of global context on chord processing (Bigand & Pineau, 1997; Bigand et al., in press). Effects of global and local harmonic contexts on chord processing may be compared to the effects of global and local semantic context on word processing (see, for example, Sharkey & Sharkey, 1992; Patel, 1998). The effect of semantic context on word processing may be understood in light of two theoretical frameworks. For a spreading-activation model, priming is based on a fast-acting and automatic activation that spreads within the mental lexicon via the long-term connections between semantically related items. According to Duffy et al. (1989), several items in the sentence or discourse context may be the source of priming. Activations spread automatically in the mental lexicon and are accumulated in a buffer as sentences progress. In this way, a target word may be primed differently depending on the number of words semantically related to the target in the previous context. For a discourse-based model, "the locus of context effects is primarily outside of the lexicon, in processes that determine semantic relationships among incoming words" (Hess et al., 1995, p. 63). Facilitation thus occurs for target words that are easily integrated into the ongoing discourse representation.

Future research in the field of music has to determine whether a spreading activation model can satisfactorily account for the context effects on chord processing or if other theoretical frameworks are required. The present findings suggest that Bharucha's connectionist model (1987) provides a possible explanatory framework. During chord sequences, activations consecutive to both global and local context are accumulated in a buffer, and this added activation determines the processing of the target. In other words, harmonic priming effects seem to be the result of activation spreading via a stable cognitive structure that links related chords.

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Appendix
Example of One Sequence Used in the Four Experimental Conditions

GRLR

GRLU

GULR

GULU