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Cognition 100 (2006) 100–130
COGNITION
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Are we "experienced listeners"? A review of the musical capacities that do not depend on formal musical training ☆

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Available online 17 January 2006

Abstract

The present paper reviews a set of studies designed to investigate different aspects of the capacity for processing Western music. This includes perceiving the relationships between a theme and its variations, perceiving musical tensions and relaxations, generating musical expectancies, integrating local structures in large-scale structures, learning new compositional systems and responding to music in an emotional (affective) way. The main focus of these studies was to evaluate the influence of intensive musical training on these capacities. The overall set of data highlights that some musical capacities are acquired through exposure to music without the help of explicit training. These capacities reach such a degree of sophistication that they enable untrained listeners to respond to music as "musically experienced listeners" do.

Keywords: Music cognition; Musical priming; Implicit learning; Emotion; Musical expertise

☆ Thanks are due to Barbara Tillmann and Philippe Lalitte for helpful comments and suggestions on the manuscript. This research was supported by a grant from The International Foundation for Music Research.
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0010-0277/$ - see front matter
doi:10.1016/j.cognition.2005.11.007

1. Introduction

The origins of musical competence have been largely debated and even today it remains an open question (Deliège & Sloboda, 1997; Peretz & Zatorre, 2003; Wallin, Merker, & Brown, 1999). In this paper, we will argue that studying the influence of intensive musical training on the perception of music contributes to highlight the very nature of human capacity for processing and understanding music. If this capacity is rooted in innate predispositions (Trehub, 2003) that have been selected through evolution for adaptation (social bonding, for example, Cross, 2003), musical competence should be largely shared in the general population. Moreover, given the richness of musical stimulations in everyday life, and given the remarkable ability of human beings to internalize regularities of the auditory environment through implicit learning processes (Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999; Saffran, Newport, & Aslin, 1996), it is likely that this initial predisposition could become considerably sophisticated in adulthood. Along this line, listeners without musical training but with sufficient exposure to a given musical idiom may be viewed as "experienced listeners" who use the same principles as musically trained listeners when listening to music and structuring what they hear, "but in a more limited way" (Lerdahl & Jackendoff, 1983, p. 3). How this learning takes place in the general public remains an open issue, which we will return to in the last section of the paper.

A quite opposite approach to the implicit learning hypothesis stipulates that musical competence is mostly determined by an intensive musical training and remains rather rough in untrained listeners (see Levinson, 1997 for a debate; Wolpert, 1990, 2000). Some authors have argued that musical abilities develop naturally up to 10 years but do not longer evolve without explicit musical training (Francès, Zenatti, & Imberty, 1979). Verbal reports provided after the experiments by our participants (both musically trained or untrained) usually support this view. Explicit training is supposed to have a deep impact on both the cognitive and neural architectures, notably when training starts early in life (Pantev & Lütkenhöner, 2000). Recent studies showing that musicians' and nonmusicians' brains differ from both anatomical and functional ways argue along this line (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995; Gaser & Schlaug, 2003; Pantev et al., 2003; Schlaug, 2001). In a recent study, Seung, Kyong, Woo, Lee, and Lee (2005) provided evidence that comparable musical tasks performed with the same stimuli differently activated the brain on prior musical training of participants. For some authors, an important issue is thus to understand whether these brain differences result from training or correspond to genetic differences that predispose some individuals to become musicians (Schneider et al., 2002; Thompson et al., 2001). In cognitive psychology, the influence of intensive training on the processing capacities of experts has been well established in several fields, such as chess (Chase & Simon, 1973), mathematics (Schoenfeld & Herrmann, 1982), physics (Chi, Feltovich, & Glaser, 1981) or more recently wine expertise (Chollet & Valentin, 2000; Hughson & Boakes, 2002). Training lead experts to develop skills, processing strategies and declarative knowledge that are not found in novices. These skills influence the way experts attend to and encode stimuli from their field of expertise by comparison to novices. The effect of expertise stands similarly in music. Musical training is very demanding since it requires several hours of training per week and several hours of practice per day for a very long period (from 10 to 15 years in French conservatories). During this period musicians learn specific perceptual skills in ear training, and music analysis and acquire a lot of declarative knowledge about the structure of Western music. Moreover, they develop motor skills to be able to play music. All of these skills are likely to deeply influence the way they process musical stimuli. For example, the motor skills that are activated during music listening influences the processing of musical stimuli (Haueisen & Knösche, 2001; Janata & Grafton, 2003). In a related vein, the possibility to use the linguistic labels of musical events enable musically trained listeners to encode musical structures in a more relevant way than "musically illiterate persons" can (Francès, 1958). As a consequence, it is reasonable to expect important differences between musically trained and untrained listeners (see Levinson, 1997 for a debate; Wolpert, 1990, 2000).

Delineating the musical abilities that are specifically linked to an intensive and formal training from those that emerge through mere exposure to music is a key issue for music cognition. Nonmusicians do not learn a formal system with which they can describe and think about musical structures but they have a considerable amount of experience with music: they hear music every day of their lives, they all sung as children and sung in school, they have moved and danced to musical rhythms, and most of them have attended concerts. How sophisticated are the emergent abilities to process music that result from this exposure when compared to those caused by an intensive formal musical training? Given the huge difference in training, finding differences between musically trained and untrained listeners would not be really surprising. However, showing that some elaborated musical capacities do not strongly differ as a function of musical expertise, would be critical to further our understanding of the human aptitude for music. The aim of the present paper is to survey several findings collected in our laboratory on that issue. The initial goal of the research program was to identify the type of structures untrained listeners were unable to process by contrast to trained listeners.[1] This issue was addressed by considering several aspects of Western music perception, ranging from melodic and harmonic processing to emotional responses to music. Before explaining these studies in detail, two methodological considerations deserve attention.

2. Which methods can be used to compare musically trained and untrained participants?

Numerous examples indicate that the experimental task, which participants are required to complete, considerably matters when probing the competence of musically untrained listeners. The initial experiments of the categorical perception of musical

[1] We thank B. Tillmann, F. Madurell, P. Lalitte, D. D'Adamo, and M. Pineau, who contributed to this research program.

intervals indicated that nonmusicians were unable to categorize minor versus major intervals (Burns, 1982). A change in task demonstrated that they actually did categorize musical intervals in a similar way as musically trained listeners did (Smith, Nelson, Grohskopf, & Appleton, 1994). In a related vein, the primary finding about tonal hierarchies (Krumhansl & Shepard, 1979) suggested that only musically trained listeners were sensitive to the most sophisticated aspects of Western pitch hierarchy, with nonmusicians being at best sensitive to the difference between diatonic and nondiatonic tones. However, the probe-tone task used in this study created an ambiguity about what criterion should be adopted for the responses[2] and this might have encouraged nonmusicians to respond in a psychophysical rather than in a musical way. Once again, a slight change in the experimental task revealed that musically untrained listeners were actually highly responsive to Western tonal hierarchies (Cuddy & Badertscher, 1987; Cuddy & Thompson, 1992; Hébert, Peretz, & Gagnon, 1995). More recently, Wolpert (2000) presented musically trained and untrained participants with a single song sung in a different key from its accompaniment. Whereas 100% of the musicians heard the clash of keys, only 40% of the nonmusicians indicated that they heard the difference in keys between singer and accompaniment. One problem of these data however was that correct responses (“perfect matches”) corresponded to responses in which participants described any difference that included specific musical terms such as “off key”, “lower”, “higher”, “in tune”, “out of tune” or “different pitch”.

It is not surprising to find important differences between both groups of listeners when experimental instructions or responses include technical musical terms, which are not explicitly understood or known by nonmusicians, or use notions so ill-defined and so ambiguous that only musicians can correctly grasp the instructions and the experimental task of the study. Similarly, experimental tasks requiring to judge an aspect of musical structure are tasks for which musicians have been explicitly trained in conservatories (detecting a change in pitch or timbre, singing back melodies, identifying meter, tapping in time with the music, etc...) therefore their use results in important differences between both groups. However, these differences might not be relevant to understand the real nature of musical competence. Most of the empirical research in music cognition involves tasks requiring explicit judgments on specific aspects of the musical structure. This approach seems to imply that human musical capacity necessarily involves explicit processes. This postulate is questionable since a large part of human cognition occurs at an implicit level with a possible continuum between unconscious and declarative knowledge (Underwood, 1996). There is no reason to believe that things occur differently in the music domain. If musical competence relies, for a large part, on implicit (or weakly explicit) knowledge, the use of explicit tasks to probe musical competence is simply misleading. More specifically, this could lead to a considerable underestimation of the human capacity to perceive music. Using implicit tasks to probe musical competence is thus

[2] The probe-tone paradigm consists in evaluating on a seven-point scale how well a probe tone fits with a previous context. The main ambiguity was that the goodness of fit of the probe tone could be determined by pitch proximity between the probe tone and the context as well as by tonal hierarchy.

likely to highlight unexpected abilities for musical processing. For example, the use of an implicit task has recently revealed preserved musical abilities in a brain damaged patient (IR), whose explicit abilities for music processing are definitely lost (Tillmann, Peretz, & Bigand, 2003). At the very least, if explicit tasks have to be used, it seems absolutely necessary that they involve fundamental musical intuitions that are understandable by musically trained as well as untrained listeners. If this were not the case, there would simply be a confusion between cognitive experimental tasks and academic musical exams.

A further methodological question deals with the type of processing that can be reasonably considered as representative of the human capacity to perceive music. For a long period, the musical stimuli as well as the experimental tasks used in empirical research on music cognition were oversimplified and without ecological validity. Using protomusical stimuli instead of realistic stimuli tell us more about the auditory abilities of listeners than about their musical abilities. Accordingly, the differences found between musicians and nonmusicians with such stimuli are difficult to interpret. For example, the fact that musically trained participants process elementary qualities of musical sound (pitch, timbre, and duration) more efficiently than musically untrained listeners is not surprising and has few implications: music perception implies abstract cognitive processes that cannot be revealed by elementary tasks on perceptual features. Moreover, the ability to analyze surface patterns of pitch, attack, duration, timbre in a refined way is probably less important than the ability to integrate all of these features in a structured whole. Without an integrative stage of processing, this perceptual ability, as refined as it may be, would not have any strong implication for musical experience. In the following set of experiments, we attempted to investigate these integrative processes in both musically trained and untrained listeners with tasks and stimuli that were designed to be as musical as possible. The outcome gives a preliminary overview of the musical listening abilities of the general public taken in comparison with those of trained musicians.

3. Processing underlying musical structures

The goal of the first set of studies was to investigate the ability of listeners to process the musical progression that underlies the musical surface. The distinction between surface (i.e., the acoustical feature linked to pitch, loudness, timbre, and so forth) and underlying musical structures is crucial to account for music competence (Lerdahl & Jackendoff, 1983; Schenker, 1935; Sloboda, 1985). If musical pieces were no more than suites of charming sounding stimuli, there would be a considerable redundancy from one piece to another. The critical feature of music (whether tonal or not) is that musical events fulfill different structural functions beyond these immediate sounding qualities. The way these functions are patterned through time defines more abstract and complex dynamic organizations, which are usually experienced by listeners as having emotional qualities. Given that music can be considered as a generative grammar (see Lerdahl & Jackendoff, 1983) there are infinite ways to pattern events of different structural importance through time, and then to create an infinite number of possible musical pieces, each having a specific expressive character. Extracting the dynamic structures that underlies the musical surface patterns is thus certainly a crucial aspect of musical competence. As Schenker (1935) writes, "the secret of balance in music lies in the permanent awareness of levels of transformation and of the movement of the surface structure towards the initial generative structure, or of the reverse movement. This awareness is always on the composer's mind, without it, every surface structure would degenerate into chaos", (Schenker quoted by Deliège, 1984, p. 59).

From an empirical point of view, the most direct way to study the ability of listeners to perceive the underlying structure of a musical piece is to evaluate their capacity to perceive links between a theme and its variations. Variations have musical surfaces that are very different from that of the theme from which they derive, but they rest on the same underlying musical structure. All variations of a given theme follow an invariant underlying dynamic process that should be identified despite the changes in musical surface. For example, it is usually possible to identify the tune on which a jazz player is improvising, even if we miss the initial theme exposition.

Let us now imagine a situation where a variation (V1A) on a given theme (A) is matched with another musical piece with an identical surface (same rhythm, melodic contour, pitch range, and so on), but which derives from another theme B (V1B). These pieces would have the same surface structure but different underlying deep structures. If we reiterate this operation for several variations we obtain two sets of matched pieces (V1A, V2A, V3A, V4A; V1B, V2B, V3B, and V4B), some having strong surface similarities but different underlying structures (e.g., V1A and V1B), others having strong differences in surface features but the same underlying structures (e.g., V1A and V2A). That is to say, the variations derived from theme A have less surface features in common than they have with variations derived from theme B. These musical stimuli define an interesting situation to assess the nature of musical competence: if listeners are unable to extract the underlying structure of musical pieces, then they would certainly be unable to group together the variations that derive from the same theme.

In one of our studies, we placed musically trained (referred to as *musicians*)[3] and untrained participants (referred to as *nonmusicians*) in such an experimental situation (see Bigand, 1990 for more detail). The task was to sort the variations that were derived from the same underlying structure. Musically trained participants performed significantly better than untrained participants (72% of correct responses versus 58%), but the striking finding was that the performance of the later group remained above chance. Although moderate per se, this performance was surprising given the complexity of the processing involved by the experimental situation: to respond above chance level, participants have to group together melodies that share same underlying structures but that drastically differ from obvious features such as

[3] In this study, as in all the others reported in this paper, the term "musicians" refers to students at national music conservatories who have learned musical and instrumental techniques for 10 years on average and whose abilities have been confirmed each year by formal examinations. Nonmusicians are students of the same age who have not had any specific musical training.

melodic contour and rhythm. This finding suggests that even musically untrained listeners managed to represent musical information mentally in a rather abstract format.

Different studies have then been undertaken to specify how the different parameters of musical events contribute to the extraction of an underlying musical structure. In Western music, tonal hierarchy and rhythm are the dimensions that contribute the most to instill an event hierarchy. A tonal hierarchy is an atemporal schema of Western tonal pitch regularities that is stored in long-term memory, whereas an event hierarchy is the hierarchy of specific pitch-time events for a musical piece. As exhaustively described by Lerdahl and Jackendoff (1983), an event hierarchy creates in listeners a hierarchy of tensions and relaxations, which defines the underlying structure of the piece (referred to as the "prolongational structure"). Changing either the rhythm or the key of a musical piece should have a strong impact on the underlying dynamic process of a given piece, even though the musical surface remains almost unchanged. The goal of the following study was to evaluate whether the influence of factors that determine event hierarchy (notably rhythm and pitch structure) are modulated by the extent of musical training of listeners. Consider for example the melodies in Fig. 1a (Bigand, 1997). As can be seen, the melody T1R1 contains almost the same notes as the melody T2R1, and the two melodies have the same rhythm and the same contour. The tonal functions of the notes in these melodies are nevertheless strongly different. Melody T1R1 is in the key of A minor, while melody T2R1 is in the key of G major. This change in the induced key entirely modifies the event hierarchy of the melodies and thus the perceived musical stability of the tones. The notes numbered 2, 5, and 7 (tonic notes) function as perceptual anchor points in T1R1, but as subtonic notes, which are structurally less important, in T2R1. The situation is

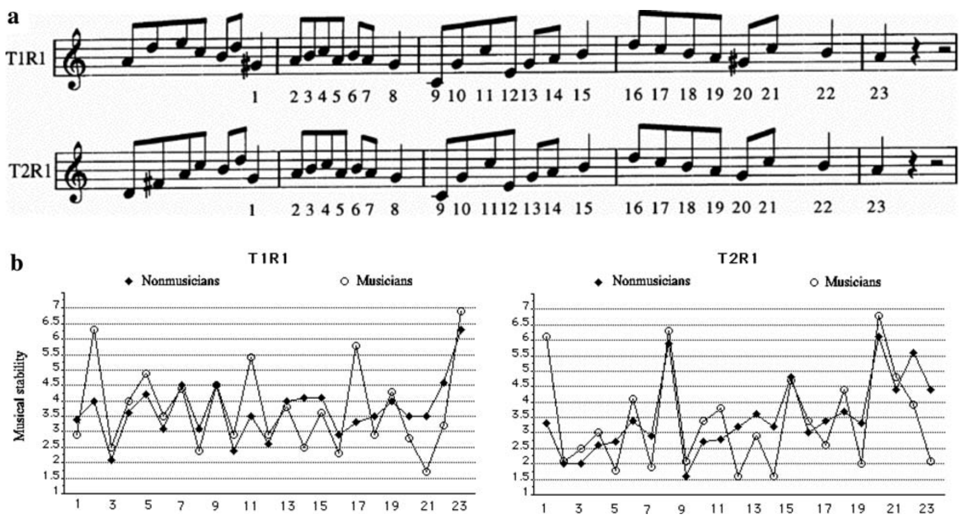

Fig. 1. Effect of key-context on the perception of musical stability in musically trained and untrained participants (modified from Bigand, 1997).

reversed for notes 1 and 8, which are tonic tones in T2R1 but subtonic tones in T1R1. A careful examination of the scores reveals that the tonal functions of the tones are systematically opposite in T1R1 and T2R1. As a consequence the tension–relaxation structures perceived in the two melodies should be inversely correlated. For example, on the note numbered 2, a relaxation should be experienced in T1R1, but a tension should be felt in T2R1. The reverse should be found on note 3, and so on. Once again, we assumed that experienced listeners should perceive these melodies as being very different. In addition to this change in key, changes in rhythm (not represented if Fig. 1) were also performed while keeping the pitch structure constant (see Palmer & Krumhansl, 1987 for a similar rhythmic manipulation). These changes in induced key and rhythm were crossed and the critical point of the study was to assess how both manipulations affected the perceived musical tensions and relaxations in musically trained and untrained participants.

The experimental task, used to address this issue, required participants to evaluate on a seven-point scale the degree of experienced "musical stability" on each tone of the melodies. A simple way to explain this concept to nonmusicians was to indicate that pieces ending on a musically stable event usually sound complete, while those ending on an unstable tone require a continuation. Although this task is based on an explicit judgment, it taps into a basic musical intuition (the feeling of completion), which is largely shared by both musicians and nonmusicians and for which the former group are not explicitly trained in music schools. The profiles of musical stability (with high value reflecting stability) obtained when the induced key was manipulated, are displayed in Fig. 1b. The change in profile from the left to the right panels indicated that listeners were sensitive to the contextual changes of tonal function between T1R1 and T2R1. That is to say, both melodies were perceived as rather different even if they shared highly similar surface features (i.e., the same sequencing of notes, the same rhythm and the same contour). In this study, as in a very similar one (Bigand, 1993), the results from musicians and nonmusicians were significantly correlated, with correlation ranging from $r(21) = .60$, $p < .01$ for the lowest to $r(18) = .89$, $p < .01$ for the highest correlation. On some notes of the melodies, differences were reported between musically trained and untrained listeners (as for example on the tonic notes in T1R1, left panel at the bottom), but on the whole, the pattern of data of both groups were very similar in all the tested experimental situations. Multiple regression analyses further revealed that pitch factors (tonal weights, melodic interval sizes) and rhythmic factors (durations and metrical weights) significantly contributed to perceived tensions in both groups, with the place of the notes in Western tonal hierarchy (tonal weights) as the most important contributor. This factor was also found to contribute a little bit more to perceived tensions in musicians.

A follow-up memory experiment, using the same melodies, resulted in a surprising illusory perception (Bigand & Pineau, 1996). After having been repeatedly exposed to one of the melodies (say, for example, T1R1), participants were presented with melodies that differed either by their induced harmony, by their rhythm, or by both (say, for example, T2R1). Participants were asked to evaluate how many notes had been changed between the learned and the comparison melodies. Musicians evaluated that 56.55% of notes changed when the induced key was manipulated (52.54% for nonmusicians). The percentage was 40.00% for musicians (37.56% for nonmusicians) when the rhythm was changed, and it went up to 83.87% for musicians (69.87% for nonmusicians) when both rhythm and induced key were changed.[4] Musically untrained participants performed as trained participants did, except they were less sensitive to the change in induced harmony.

This perceptual illusion of changes suggests that Western tonal melodies are mentally represented by an abstract structure, which typifies the principal dynamic trajectories developed during listening. For both trained and untrained listeners, these trajectories seem to be based on the relationships of musical tensions and relaxations that span different levels of musical time. Further studies provided evidence that the ability of Western listeners to perceive musical tensions and relaxations is not restricted to melodies, but can be observed for short and long chord sequences as well (Bigand, Parncutt, & Lerdahl, 1996; Bigand & Parncutt, 1999). In all of these experiments, strong correlations between perceived musical tension–relaxation patterns were found between the two groups of participants, ranging from $r(48) = .77$, $p < .01$ in Bigand et al. (1996) for the lowest to $r(28) = .94$, $p < .01$ in Bigand and Parncutt (1999) for the highest correlation. Moreover, perceived tensions were predicted by the same set of factors in both groups, with a tendency for Western pitch hierarchy to contribute more in musically trained participants.

4. Musical expectancies

The second set of studies addresses another aspect of music cognition, fundamentally related to the previous ones, but dealing more directly with musical expectancies. Studying the formation of musical expectancies offers an interesting opportunity to investigate the ability to process music at least for two reasons. First, perceptual anticipatory processes are of considerable importance in music since emotional responses are likely to be determined by how the composer fulfills or not the expectancies created by a previous musical context (Jackendoff, 1991; Meyer, 1956). Second, it is well established in several domains of cognition that the ability to anticipate events is a major characteristic of expertise. For example, fighter pilots are known to say that it is necessary to pilot the plane *in front of* the cockpit rather than *in* the cockpit. If musical competence was mostly a matter of an intensive explicit training, then the factors governing musical expectancies should considerably differ between musicians and nonmusicians.

Several studies were devoted to highlight this issue. Given the importance of harmonic hierarchy in Western tonal music, most of these studies have focused on musical expectations that are driven by the harmonic structure. A given musical context was assumed to activate the listeners' abstract knowledge of Western harmony. This activation would lead listeners to anticipate events that are most related to the pre-

[4] Of course none of these percentages correspond to the real number of tones changed.

vious context according to Western harmonic rules. Musical expectancies were tested with a priming paradigm. In this experimental setting, attention is drawn to an elementary perceptual task, which the listener performs on a *target* chord. The task may consist in deciding as quickly and accurately as possible if a target chord is in- or out-of-tune (Bharucha & Stoeckig, 1986, 1987), whether or not it contains an obviously dissonant note (Bigand & Pineau, 1997; Bigand, Poulin, Tillmann, Madurell, & D'Adamo, 2003; Bigand, Tillmann, Poulin-Charronnat, & Manderlier, 2005a), whether its constituent notes are played together exactly at the same time (Tillmann & Bharucha, 2002), or whether it is played with a given timbre A or B (Tillmann, Bigand, Escoffier, & Lalitte, in press). The critical point is to determine how the processing of the sensory qualities of the target chord could be influenced by the manipulations of the harmonic relatedness between target chord and prime context. As in semantic priming studies, the manipulation of harmonic relatedness is irrelevant for the performing of the perceptual task and participants are never informed of it. If this manipulation is shown to influence the performance, then it may be concluded that participants were able to process the harmonic relationship in an automatic and implicit way.

Pioneer musical priming experiments have been run with one chord as the prime context (Bharucha & Stoeckig, 1986, 1987). It was demonstrated that judging whether a target was in-tune or out-of-tune was facilitated when in-tune targets shared a parent (major) key with the prime chords. For example, after a C major prime chord, the processing of a D major chord (which shares the key of G major with the C major chord) is faster and more accurate than the processing of an E major chord (which shares no parent key with the C major chord). The prime context (one chord) activates the listener's knowledge of Western tonal hierarchies, leading him to anticipate events belonging to the same key, as does the target chord. Harmonic priming effects have been extended to longer musical contexts (Bigand & Pineau, 1997; Bigand et al., 2003; Tillmann, Bigand, & Pineau, 1998). In Fig. 2, the last two chords of the sequences are identical in all three contexts, the last chord being the target chord. The harmonic function of these last two chords changes from one context to the other. In the ‘‘expected’’ context, the final chord is the most referential event of Western music (the tonic chord, I). In the ‘‘weakly expected’’ context, the target acts as a structurally less important chord (the subdominant chord, IV) following a perfect cadence in the key of D major. In both conditions, the targets belong to the key context, but differ in their structural importance. In the ‘‘moderately expected’’ context, the harmonic function of the target is more ambiguous. Perceived in relation to the second part of the sequence (which is identical to that of the ‘‘weakly expected’’ condition), the target would act as a subdominant chord (IV). If perceived in relation to the first part of the sequence (which is identical to the ‘‘expected’’ condition), the target would act as a tonic (I) chord marking a return (albeit rapid) to the main key. In other words, the target chord is ‘‘primed’’ in the ‘‘moderately expected’’ condition by the first part of the sequence.

For the purpose of the experimental task, target chords were perfect triads in half of the trials, and were voluntary rendered dissonant (i.e., by adding a nontriadic tone a semitone above one of the chord component tones) in the other half of the trials.

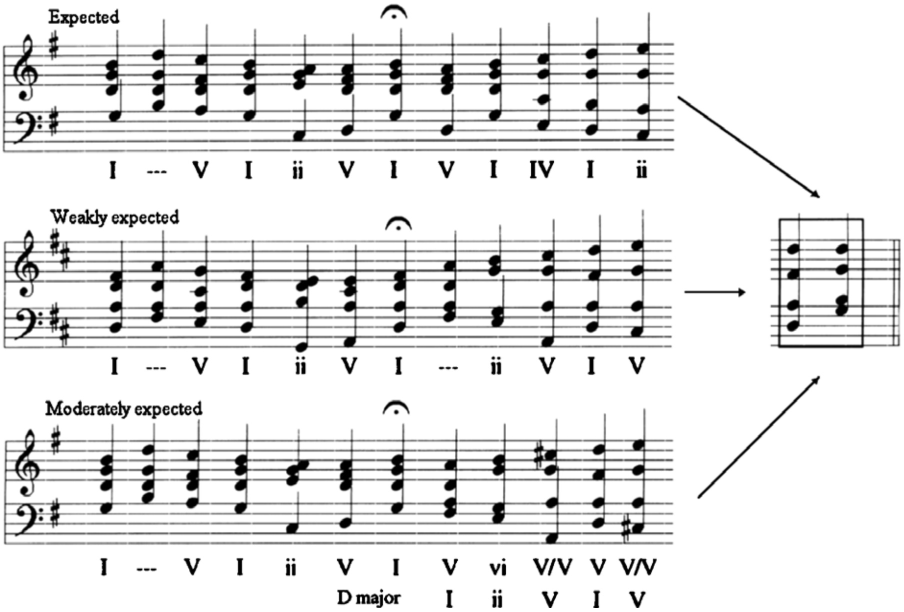

Fig. 2. Effect of harmonic context on chord processing (modified from Bigand et al., 1999).

Participants were only required to indicate as fast and accurately as possible, whether the last chord (the target) was consonant or dissonant. It is worth noting that accurately performing this task does not require paying attention to the previous context played before the target.[5] Listening to these sequences would convince the reader that the differences between consonant and dissonant targets was rather easy to perceived while the differences of structural ending performed in the three relatedness conditions remain extremely small. This difference was even difficult to notice explicitly by musically untrained listeners.[6] For that reason, we initially expected a strong effect of musical expertise. It turned out that musically trained and untrained participants (selected as explained in footnote 3) performed the consonant/dissonant task faster and more accurately in the ‘‘expected’’ context than in the two other conditions. The critical finding concerns these two other conditions: the responses were faster and more accurate in the ‘‘moderately expected’’ condition than in the ‘‘weakly expected’’ condition and this was found for both groups of participants. This finding demonstrates that expectancies for a given event integrate several levels of the hierarchical structure: expectancies do not only occur from chord to chord, but also depend on both local and global contexts preceding the target. In this experiment, as in other priming studies requiring participants to perform fast conso-

[5] Since all chord sequences were of the same number of chords (14), participants might have simply counted up to 14 and paid attention to the sensory consonance or dissonance of the last chord.

[6] An example of these sequences is available on http://www.u-bourgogne.fr/LEAD/people/bigand.html.

nant/dissonant judgments, although musically trained participants usually performed better and faster than untrained listeners (which is not surprising per se since the former group has been highly trained on this type of task), the critical point is that the size of the priming effect[7] was never found to be significantly larger in musically trained compared to untrained participants. This finding suggests that both groups of participants are similarly sensitive to the harmonic function of chords, even if the musicians performed better in the perceptual task.

The strong convergence between the data of musically trained participants and the data of untrained ones has been systematically replicated in all priming experiments run by our group, and other teams have never reported an influence of musical expertise in such an experimental setting (Bharucha & Stoeckig, 1986, 1987). Although a survey of all these studies is beyond the scope of this paper, two of these studies deserve further attention since they point out astonishing aspects of the nonmusicians' abilities to process musical structures. In one of them (Bigand et al., 2003), we were interested in disentangling priming effects that might occur from sensory or cognitive relationships between prime and target. Sensory priming in music is potentially very important since Western rules of harmony are partly correlated with the psychoacoustic structures of sounds (Bigand et al., 1996; Huron & Parncutt, 1993; Leman, 1995, 2000; Parncutt, 1989; Parncutt & Bregman, 2000). As a consequence, target chords related to a previous context, according to Western harmonic rules, generally also have more component tones in common with the context than target chords musically less related to the context. In other words, sensory and cognitive priming may often be confounded in Western music. This confound could potentially have explained why musically untrained listeners exhibit similar performances as trained listeners in the experimental situation: while musical expectancies of the former group may be based on sensory priming, and those of the later group on cognitive priming, they may lead to similar performances. To assess whether nonmusicians were actually sensitive to cognitive (and not sensory) priming effects, we ran an experiment designed to contrast both forms of priming.

As shown in Fig. 3, the target chord ended eight-chord sequences. In the related condition the target chord acted as a tonic (I), in the less related condition it acted as a subdominant chord (IV). Following previous findings (reported above), we expected facilitated processing of the tonic over the subdominant. The critical new point of the study was to contrast sensory and cognitive priming by manipulating the occurrence of the target chord in the previous context. In the "no-target-in-context" condition (Fig. 3a), neither the tonic nor the subdominant target occurred in the context. Larger facilitation for the tonic target would thus support cognitive priming. In the "subdominant-in-context" condition (Fig. 3b), the subdominant targets occurred once or twice in the context. As a consequence, the subdominant targets shared more sensory features with the previous context than the tonic targets did. Sensory prim-

[7] The size of the priming effect is revealed by an increase of correct responses and a decrease of correct response times for related (primed) compared to unrelated (unprimed) targets.

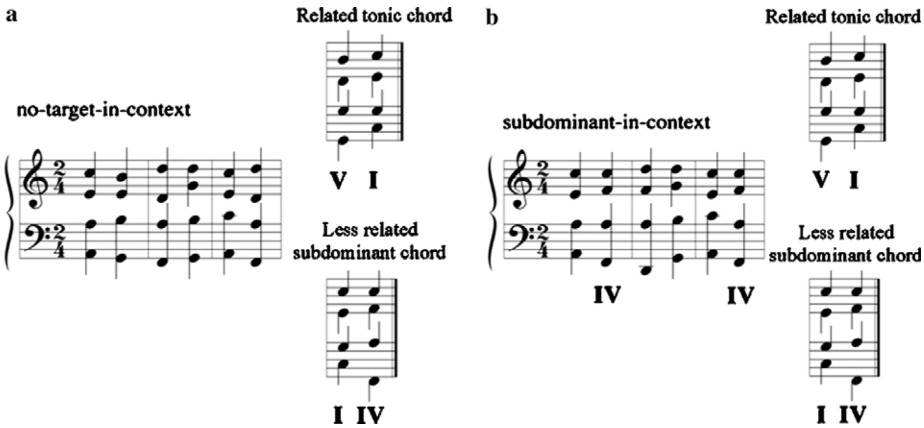

Fig. 3. Harmonic versus sensory priming influence on chord processing (modified from Bigand et al., 2003).

ing was thus expected to be stronger than cognitive priming in this condition. At the very least, the strength of cognitive priming was expected to decrease from the no-target-in-context condition to the subdominant-in-context condition. Finally, if musically untrained listeners were more responsive to sensory than cognitive priming, the decrease in cognitive priming effects should have been more pronounced in this group than in the musically trained group. The experimental data clearly showed that both groups were mostly influenced by cognitive priming. That is to say, the processing of target chords was always faster and more accurate for the tonic targets, and this effect was not at all affected by the occurrence of the subdominant target in the prime context. Once again the size of the priming effect was not found to be more pronounced in musicians: by comparison to the subdominant chord, with tonic target chords nonmusicians responded 190 ms faster (i.e., 23% faster than their average response times) and musicians 90 ms faster (i.e., 16% faster than their average response times). This predominance of cognitive over sensory priming was consistent with other results obtained with a different experimental setting (Bigand et al., 2005a), and it was recently replicated with 6-year-old children (Schellenberg, Bigand, Poulin-Charronnat, Garnier, & Stevens, 2005).

A further point of interest in this study was to compare the time-course of sensory and cognitive priming as a function of the extent of musical expertise. In Experiment 2, we manipulated, in addition to the factors mentioned above, the tempo of the musical sequence: using 300, 150, and 75 ms per chord. Following Tekman and Bharucha's finding (1998), we expected cognitive priming to overrule sensory priming at a moderate tempo (300 ms per chord) and a reverse effect at extremely fast tempo (75 ms). Our results revealed an effect of musical expertise only at the fastest tempo (75 ms). At this tempo, nonmusicians' performance was more influenced by sensory priming (i.e., greater processing facilitation for the subdominant targets), suggesting that one possible difference between both groups would relate to the velocity at which musical processing occurs, with musically untrained listeners being "less cognitive" at fast tempi. However, it is worth noting that 75 ms per event represents an extremely fast tempo that is never used in music (Fraisse, 1967).

Another finding of musical priming studies deserves attention. In the studies presented above, participants were involved in a perceptual task that encouraged them to focus on a specific musical feature of the target chord (e.g., its sensory consonance–dissonance). In two other studies, we investigated harmonic priming effects in sung-like music (Bigand, Tillmann, Poulin, D'Adamo, & Madurell, 2001; Poulin-Charronnat, Bigand, Madurell, & Peereman, 2005). Using sung-like music allows us to ask participants to perform a linguistic task on the sung target chords and to assess whether this linguistic processing may be affected by a musical priming effect. That is to say, the main goal was to put musical and linguistic computations in competition, in a design that explicitly required participants to focus on a linguistic task. In Bigand et al. (2001), musical chord sequences (illustrated in Fig. 3) were played with sung phonemes that did not form meaningful words. The target chords were sung either with the syllable /di/ or /du/. This sung target chord acted either as a tonic or as a subdominant chord in the context. Musically trained and untrained participants were asked to indicate as fast as possible whether the last chord was sung on the one or the other phoneme (/i/ versus /u/).

It appears that this phoneme monitoring was faster and more accurate when the sung target acted as a tonic in the context (79 ms faster for musicians and 64 ms faster for untrained participants). Both groups of participants exhibited similar performances and there was not any statistically significant effect of expertise. In Poulin-Charronnat et al. (2005), we investigated with the same chord sequences whether harmonic relatedness might also influence semantic processing in sung vocal music. Semantic priming and musical priming were simultaneously crossed so that there were four possibilities for the target event: the target could be semantically and musically related, semantically related and musically unrelated, semantically unrelated and musically related, or semantically and musically unrelated.[8] Musically trained and untrained listeners performed a lexical decision task on the target event. They were not required to pay attention to the musical dimension of the experimental stimuli. For both groups, the musical function of the target was shown to modulate semantic priming effects: stronger semantic priming effects were observed when the target word was sung on a tonic rather than on a subdominant chord. No interaction was observed between harmonic function and musical expertise: related target words were processed 33.82 ms faster by musicians and 30.76 ms faster by nonmusicians, when sung on the tonic rather than on the subdominant. The only significant effect of musical training was revealed in this study by a significant interaction with semantic relationship: semantic priming effects were stronger in musically untrained participants.

The critical point of both experiments was that participants were not required to process the musical dimension of the stimuli. Moreover this processing could not help to perform the experimental tasks. The fact that the musical structure of the

[8] An example of these sequences is available on http://www.u-bourgogne.fr/LEAD/people/bigand.html.

sequences modulates fast-acting linguistic computations (phoneme monitoring and semantic processing), which are considered as automatic processing, points to an interesting aspect of the human musical capacity: musical structures are processed in an irrepressible way, by automatic processes that occur as fast as those found in linguistic domain. The fact that this data pattern was obtained for both musically trained and untrained listeners further suggests that this musical ability does not derive from an intensive music training.

5. Processing large-scale structures

The preceding studies investigated the ability of listeners to process structures of Western music on short time spans, usually no longer than 30 s. To what extent can the reduced nature of these musical stimuli explain the weak effect of musical training? Several other studies have been conducted with longer pieces stemming from the existing musical repertoire (Tillmann & Bigand, 1998; Tillmann, Bigand, & Madurell, 1998). In these studies, which involved explicit tasks, musicians performed better than nonmusicians but showed the same pattern of data. For example, both groups encountered the same sorts of difficulty in solving musical jigsaw puzzles derived from short minuets by Bach, Haydn and Mozart. Both groups failed to integrate local harmonic structures into the global structures (Tillmann et al., 1998).

In a recent study, we further investigated the ability to integrate local structure in large-scale forms in memory experiments (Poulin-Charronnat, Dowling, & Bigand, in revision). This study was designed to assess whether well-established effects of expertise on the memorization of structured versus random materials could be replicated in the music domain (Chase & Simon, 1973; Chi et al., 1981; Larkin, McDermott, Simon, & Simon, 1980; Schoenfeld & Herrmann, 1982). In these studies on the effects of expertise, experts and novices in a given domain were required to memorize material with either a real or a random organization (for example, a real configuration of a chess game or a random organization of chess pieces). The main result was that the experts took advantage of the real configuration of the material to memorize, resulting in better performances in recalling the real configuration for experts than novices, while no differences were observed between both groups for the random configuration.

Following the same rationale, we required musicians and nonmusicians to memorize 20 excerpts taken from the exposition sections of four Haydn piano sonatas. These excerpts were presented in either a coherent or an incoherent condition. In the coherent condition, the five excerpts taken from the exposition of one of the four sonatas were presented in the normal sequential order (the original order of the composed pieces). The excerpts were separated by short breaks. Five excerpts from another sonata were then presented and so forth. In the incoherent condition, the 20 excerpts of the four sonatas were presented in a random order. Following this memorization phase, participants heard 44 musical excerpts (the 20 excerpts heard during the memorization phase, plus 24 new excerpts taken from the same or different Haydn piano sonatas). The participants had to indicate on a six-point confidence scale whether the heard excerpt was new or old. Both groups performed well in this experiment, whit musicians memorizing a little better than nonmusicians. To our view, the most striking point was to see that musicians did not outperform nonmusicians in the coherent condition. In other words, they did not benefit from the coherent presentation of the material more than nonmusicians did. This finding, which differs from what has been systematically reported in studies on expertise in other domains, suggests that musically trained listeners may not have a better comprehension of large-scale musical structures than nonmusicians. This result, which is in agreement with many others (Cook, 1987; Karno & Konecni, 1992; West-Marvin & Brinkman, 1999), does not represent a surprise to teachers of music analysis who observe the extent to which expert musicians, though good instrumentalists, encounter great difficulties in perceiving musical structures and forms (Levinson, 1997).

6. Learning new musical idioms

A further important aspect of the musical capacity of the human brain rests on the ability of listeners to assimilate new musical idioms. To what extent may an intensive musical training help to learn new musical idioms? Musically experienced listeners should not only be able to process subtle musical structures of their familiar musical idiom, they are also expected to better internalize and comprehend new musical idioms coming either from other human cultures, or from new compositional languages. At the current stage of research, we would probably find more evidence against this assumption than in support of it. For example, Francès (1958) reported that musically trained listeners did not perform better than untrained ones when asked to detect grammatical errors in contemporary music. Moreover, the considerable and persistent confusion reported by listeners about Western contemporary music does not seem greater in the musically untrained than in the trained audience. Investigating the ability to learn new musical idioms of great complexity (such as Western contemporary music) in both musically trained and untrained listeners should contribute to illuminate the very nature of the human capacity to process music: if both groups have the same ability to acquire knowledge about these new idioms, this observation would reinforce the claim that a sophisticated musical competence exists in human beings, and that it is rather independent of intensive explicit training.

In a first attempt to address this issue, we compared the capacity of both groups to learn a new artificial grammar of musical timbres implicitly (Bigand, Perruchet, & Boyer, 1998). Musically trained listeners did not perform better than untrained ones in this experiment. More recently, we focused on the implicit learning of the rules of the serial system of composition developed by Schoenberg, Berg and Webern (Bigand, D'Adamo, Poulin-Charronnat, in revision). Serial works of music obey compositional rules that drastically differ from those governing Western tonal music that listeners are familiarized to. The considerable complexity of this compositional system has been largely criticized and several authors even argued that this system was too complex to be internalized (Dienes & Longuet-Higgins, 2004; Francès, 1958). A serial musical piece is based on a specific temporal ordering of the 12 tones of the chromatic scale, (i.e., the tones C, C#, D, D#, E, F, F#, G, G#, A, A#, and B), irrespectively of their pitch height (i.e., their octave placement). The specific ordering of these tones defines the "tone row" of a musical piece. Each tone of the tone row has to be played before a given tone occurs for the second time. The serial musical system defines four types of transformation that can be applied to the tone row: (1) the tone row can be transposed to each of the 12 tones it contains. It can be played in (2) retrograde way or (3) inverted way. And finally, (4) a tone row can be inverted and played in retrograde way, resulting in a retrograde-inversion of the original row. Each serial composition results from a complex combination of these transformations that are applied on a specific tone row. Schoenberg argued that these manipulations would produce an interesting balance between perceptual variety and unity.

To test the ability of musically trained and untrained listeners to extract the underlying tone row and recognize it despite the various transformations, we asked a contemporary composer to create 40 canons, all being based on the same dodecaphonic tone row (Fig. 4). In the learning phase, half of these canons were presented

Fig. 4. Implicit learning of serial musical grammar. The three canons derive from the same tone row. In the test phase, the foil and the canon have similar surface features but the foil derives from another tone row.

twice to the participants, who simply had to indicate whether a given piece was heard for the first or for the second time. In a test phase, 20 pairs of canons were played to the participants. In Experiment 1, each pair contained a new canon composed with the same dodecaphonic tone row and a matched foil (Fig. 4). Matched foils had the same musical surface (i.e., same pitch range, melodic contour and rhythm), but were derived from another dodecaphonic tone row. As a consequence, foils sounded very much like the canon with which they were matched. The task of the participants was to indicate which canon of the pair was composed in the same fashion as those they heard during the learning phase of the study. Even if they felt the task was extremely difficult, musicians (62.10%) and nonmusicians (60.71%) performed above chance, with no significant difference between the two groups. In a second experiment (run with musically untrained listeners only), the canons illustrated the retrograde inversion form of the same dodecaphonic series. The interesting finding was that musically untrained listeners continued to discriminate canons from foils above chance level (59.74% of correct responses), suggesting that they were able to internalize through passive exposure complex regularities derived from the serial compositional rules.

7. Emotional responses to music

Finally, the most critical aspect of the human capacity for music resides in the ability to emotionally (or affectively) respond to musical stimuli. Musical activities would probably have disappeared from all human societies if listeners were unable to confer (or perceive) an affective value to musical stimuli. Being able to apprehend the emotional quality of musical stimuli is so important that it might be at the heart of all musical abilities. How does musical training influence emotional or affective responses to musical stimuli? It seems unlikely that musical training is positively correlated with the *strength* of emotional responses to music. Even nonmusicians experience intense musical emotions, and it would be difficult to assume that the more intensive the musical training, the more intense the emotional experience. We may however, reasonably consider that musically trained listeners experience a larger variety of affective responses to music and better discriminate subtle differences in musical expressiveness.

Addressing this issue via explicit tasks would be misleading: differences found between musicians and nonmusicians could simply reflect their different abilities to use linguistic terms to describe their intimate emotional experience with music. As nicely coined by the composer F. Mendelssohn, "emotional experience with music is so rich and complex than even language cannot account for it". Experimental methods that avoid a linguistic translation exist and can be used in the music domain (Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005b). The rationale was to use multidimensional scaling techniques (MDS) to characterize the content of emotional responses to music (see McAdams, Winsberg, Donnadieu, De Soete, & Krimphoff, 1995 for application in MDS in the auditory domain; see also Plomp, 1976; Wessel, 1979). The most direct method to obtain a dissimilarity matrix of emotional responses to music was to ask the listeners to classify a set of excerpts in a free number of classes, by grouping together excerpts that induced the same type of emotional (affective) feeling. That is to say, participants were encouraged to focus on their subjective response to excerpts, without being required to verbalize these feelings. A simple rule transformed the obtained groupings into a dissimilarity matrix.

In Bigand et al. (2005a, 2005b) musically trained and untrained participants were faced with 27 musical excerpts of serious nonvocal music.[9] According to several constraints, music theorists and psychologists selected these excerpts for their great emotional impact. The most important constraints were that these excerpts had to illustrate a great variety of emotions, which had to be representative of the key musical periods of Western classical music (baroque, classic, romantic, and modern) as well as of the most important instrumental groups (solo, chamber music, and orchestra). In Experiment 1, excerpts were 30 s long on average and participants performed the entire experiment twice, the two sessions being two weeks apart. On average, participants distinguished eight groups of excerpts (7.68 for session 1, and 7.74 for session 2). Musicians did not produce more groups than did nonmusicians, suggesting that they did not categorize the emotions induced by the 27 excerpts in a finer way than untrained listeners. The groupings of the participants were then converted into a 27×27 matrix of co-occurrence. The matrices obtained for sessions 1 and 2 were compared. There was a high correlation for musicians $r(349) = .87$, $p < .001$, and for nonmusicians, $r(349) = .78$, $p < .001$, indicating that emotional experiences were strongly consistent with these excerpts from one session to the other for both groups of listeners. Moreover, the matrices of both groups (averaged over the sessions) were also strongly correlated, $r(349) = .83$, $p < .001$. The obtained matrices were then analyzed with MDS and cluster analysis methods. MDS analyses revealed that two main dimensions (i.e., arousal and valence) govern emotional responses to music. The locations of the 27 excerpts in this geometrical representation were highly similar in musically trained and untrained listeners, suggesting that both groups experienced similar emotions with these excerpts. This finding is rather remarkable given the richness and the variety of the experimental stimuli.

A second experiment was run with new groups of musicians and nonmusicians who were presented only with the first second of each of these 27 excerpts (session 1) and then with the entire excerpts (session 2). The findings of session 2 replicated the representations obtained in Experiment 1. The most intriguing outcome was that decreasing considerably the length of the musical excerpts (i.e., from 30 s to 1 s) only had a weak effect on emotional response. It affected neither the number of groups produced by participants (eight on average) nor the content of these groups, which remained almost unchanged (18.12% of changes, on average). Moreover the emotional dissimilarity matrices were highly correlated between session 1 (1 s excerpts) and 2 (entire excerpts), in both musicians $r(349) = .76$, $p < .001$, and nonmusicians $r(349) = .70$, $p < .001$. The matrices of both groups were correlated in session 1, $r(349) = .80$, $p < .001$ and session 2, $r(349) = .87$, $p < .001$. MDS analyses further

[9] These excerpts are available on http://www.u-bourgogne.fr/LEAD/people/bigand.html.

revealed that emotional spaces for the 1 s and 30 s conditions resulted in geometrical representations that were highly similar in musicians and nonmusicians. This finding thus suggests that a short amount of music is sufficient to induce, in both groups of listeners, a large variety of emotional responses to music (see Peretz, Gagnon, & Bouchard, 1998 for consistent findings). This study provides preliminary data challenging the claim that an intensive training would result in different emotional experiences with music.

8. Conclusion

This set of studies highlights several cognitive characteristics of the human capacity to perceive and process music: this capacity rests on fast-acting and irrepressible processes that enable us to extract subtle musical structures from short musical pieces, but that are less efficient when integrating local patterns into large-scale structures (see Levinson, 1997 for a discussion). It seems that these processes can be adjusted relatively fast to new musical idioms, even highly complex ones. Finally, the musical capacity of the human brain is also expressed by the fact that emotional responses are consistent between and within participants, and that they seem to be immediately triggered by short musical excerpts. This finding is not incoherent with the fact that musical emotions probably become richer as one listens to a musical piece for a longer time. It only shows the importance of the irrepressible emotional responses to music, which nicely mirror the automaticity and rapidity of cognitive processes in music perception (see musical priming studies reviewed above). Further consistent evidence for the irrepressible aspect of musical processing comes from neurophysiological studies, which demonstrates that several features of musical sounds and structures are processed very early in a pre-attentional way (see below).

The present paper points out a set of characteristics that do not depend on the extent of the listeners' musical training. The studies summarized above indicated that musically untrained listeners perceive musical tensions and relaxations in both melodies and harmonic sequences similarly as musicians did (as attested by the high correlations between both groups systematically reported in these studies). They also manage to anticipate musical events on the basis of subtle syntactic-like features of the prime sequence. It is remarkable that the size of priming effects was never smaller in musically untrained listeners despite the subtle changes manipulated. Both groups encountered the same type of difficulty to integrate local structures in large-scale structures, even though musicians performed usually better with explicit tasks. Performances of both groups have never been found to be better in musically trained listeners when participants were required to learn new compositional systems. Finally, both groups respond very consistently to music in an emotional (affective) way, and the content of the emotional experience, as revealed by MDS, does not seem to differ between musically trained and untrained listeners. On the whole, both groups were shown to perform similarly in cognitive and emotional tasks, suggesting that an intensive musical training is not required to respond to music in a sophisticated way. This is not to say that no differences exist between both groups, but that these differences remain tiny in light of the considerable difference in explicit training that exists between both groups.

This finding is consistent with those reported by other studies. For example, Schellenberg (1996) found no difference due to the extent of musical training in rating how well additional single tones continued melodic fragments, suggesting that melodic expectancies are based on general psychological principles that are not limited to listeners with extensive training in music. Other studies reported even more provocative findings by showing that to a certain extent musically untrained listeners may possess absolute pitch (AP, ability to recognize the frequency of tones (and most of the time name the tones) without any reference tone), an ability generally attributed only to musicians. These studies suggest that tunes may be stored with much exact information and that even musically untrained listeners may possess long-term memory for pitch and remember the pitch level of familiar instrumental recordings (Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003). Similar results have been observed for tempo showing that the long-term memory of nonmusicians for tempo was very accurate (Levitin & Cook, 1996).

All these findings support the view that there is an initial predisposition of the human brain for music processing that is triggered by the extensive exposition to musical stimuli in everyday life. Thanks to both factors (predisposition and intensive exposure), nonmusicians become "experienced listeners" that do not strongly differ from musically trained listeners in numerous experimental tasks. A key issue for future research would be to further investigate how the learning processes that occur in natural environment through exposure may be accelerated or slowed down according to the extent of musical training. For example, Morrongiello and Roes (1990) showed that musical training might enhance the acquisition of diatonic scale structure. Musically trained and untrained 9-year-olds were required to listen carefully to the (less or more complex) up-and-down pattern (contour) of a tonal or atonal melody and then select the picture that went with the melody. Musically trained 9-year-old children showed better encoding of contour information for tonal than atonal melodies compared to musically untrained children. Moreover, their performance levels of tonal melodies were not affected by contour complexity, whereas the performance of the untrained children declined with increasing contour complexity. Musical training, in addition to enhancing the acquisition of specific knowledge about diatonic scale structure, may also more generally facilitate the encoding of and memory for musical material (see Morrongiello, 1992 for a review; Morrongiello, Roes, & Donnelly, 1989).

The claim that several musical capacities reach a remarkable degree of elaboration without the help of explicit training requires several additional comments to avoid any misinterpretation. First of all, we are not arguing that musical training does not have any beneficial impact on the development of a musical competence. Musical training mostly consists in learning perceptual, cognitive and motor skills, which are necessary to encode musical stimuli through conventional symbolic codes, or to play a musical instrument. It is difficult to deny that this learning may give an advantage to musicians. Learning to expressively perform music certainly contributes to boost the processes involved in music cognition and emotion. Notably, good performers are likely to be more sensitive than nonmusicians to the small changes in musical surfaces that have deep emotional impacts on listeners. In a related vein, an explicit knowledge of musical structures also confers some processing advantage to musically trained listeners (Francès, 1958). Our findings, however, indicated that these advantages remain small in light of the huge difference in training exhibited by the two groups of listeners. The fact that an intensive 15-year long training only causes small differences between musicians and nonmusicians suggests that a sophisticated musical ability can develop just by living in a rich musical environment. As for the linguistic competence, the development of the brain's musical competence may require a musically rich environment, but not necessarily an intensive training.

In a related vein, it may sound paradoxical to notice that musical training may have side effects on noncognitive abilities (Brandler & Rammsayer, 2003; Chan, Ho, & Cheung, 1998; Cheek & Smith, 1999; Schellenberg, 2003, 2004), with musicians performing better in numerous nonmusical tasks (verbal or spatial tasks), while musical training would only have a weak effect on several musical tasks. One way to conciliate this apparent paradox is to consider than any intensive training in a given domain may have side effects on several other general cognitive abilities. Given that the training in music is probably one of the most demanding training that children encountered outside school, it is likely that side effects of musical training may result from the considerable cognitive effort required, but not from the fact that musical stimuli per se are involved in the training. We may also consider that children (and then adults) who are engaged in such a demanding training could have more general cognitive abilities, on average, than others.

In addition, it could be argued that the musical ability we focused on in the present article relates to the perception and comprehension of musical structure, which is only one part of musical competence. Musicians definitely differ from nonmusicians by the fact that the former are able to produce music, but not the latter. This difference, however, is far from compelling. Being able to accurately transform a musical score into sounds does not necessarily imply that musically trained people have more creative musical skills than untrained ones. In Western cultures, most of the musicians have been trained to perform musical scores, but many of them complain that they are unable to improvise or to compose music. At the same time, there are several examples of musically untrained people that have expressed a remarkable competence to play and improvise music (as illustrated by famous musicians such as Django Reinhart, John Coltrane, and many other popular self-taught musicians). It is also very impressive that the composer who had the greatest influence on Western music during the last century (A. Schoenberg) was musically self-taught. To our view, this suggests that an intensive explicit training in music is neither a necessary nor a sufficient condition to acquire a competence to produce music. Of course, learning motor skills to play a musical instrument contributes to externalize the creative aspect of the human competence for music, but it is unlikely to be its cause. Moreover, several authors have suggested that the ability to dance with music could also be considered as a form of musical production (Barthes, 1985; Eitan & Granot, 2004; Krumhansl & Schenck, 1997; Lidov, 1987): dance would be a musical creation performed without any instrument. Along this line, the importance played by dance in all human cultures throughout history, for both musically trained and untrained listeners, would emphasize the fact that human beings are not only able to passively respond to music, but they are also able to produce musical related gestures.

Claiming that all of us are experienced listeners, of course, does not imply that every human being has the same musical ability to perceive and produce music. Individual differences exist in music domain as well as in numerous others domains. The individual differences can be found inside each group of listeners and we doubt that the extent of musical expertise is the most important factor that would account for them. For example, in all of our experiments, there were some musically untrained participants who responded more accurately than musically trained participants. This suggests that other personality factors may better explained the difference in performances than musical expertise. We may even wonder whether both groups would continue to exhibit some differences if these factors (as for example IQ) were measured and held constant. Unfortunately, the differential approach of music cognition and emotion has not been developed enough to further elaborate on this issue. This approach would probably considerably improve the understanding of the human capacity to perceive music.

Another frequent criticism to our conclusion is that the musically trained participants used in our experiments are not real experts in the domain. They are music students finishing their studies in the conservatory but they have not yet acquired a well-established expertise in music comparable to those of composers, famous conductors or performers. Larger effects of expertise should be obtained if we tested a very small sample of very famous musical experts. Although some of our data contradict this claim (Poulin-Charronnat, Bigand, & Madurell, in revision), we acknowledge that clear-cut effects of musical training are more likely to occur with great experts than with highly trained musical students. Let us note however, that the comparison with very high experts would be interesting only if their performances were compared with those of great music lovers such as radio presenters, music critics, or sound engineers. For now, we simply emphasize the part of the answer that we obtained to the question on musical expertise: a 15-year-training does not result in considerable differences between the two groups and is thus not enough to obtain a clear effect of intensive training.

The last potential concern raised by our conclusion is its contradiction with another large set of neuroscientific data, which points out anatomical and functional differences between the brain of musicians and nonmusicians. If the capacity to perceive and process music is rooted in innate predispositions that develop through mere exposure to musical stimulations, the neural pathways involved in music cognition and emotion should not drastically differ in musicians and nonmusicians. There is an increasing amount of evidence against this claim. For example, Ohnishi et al. (2001) reported with a passive music listening task that musicians showed a left hemispheric dominance in the processing of music, whereas nonmusicians demonstrated a right hemispheric dominance (see also Bever & Chiarello, 1974). A significant difference in the degree of activation between musicians and nonmusicians was noted in the bilateral planum temporale and the left posterior dorsolateral prefrontal cortex. The degree of activation of the left planum temporale correlated well with the age at which the person had begun musical training. Schmithorst and Holland (2003) also reported similarities and differences between musicians and nonmusicians in the processing of melody and harmony. Melodic processing activated the most anterior part of the superior temporal gyrus for both musicians and nonmusicians. However, harmonic processing activated different visual association areas for musicians relative to nonmusicians, and the inferior parietal lobules were recruited only by musicians for both melodic and harmonic conditions.

The fact that an intensive training in music modifies the anatomical and/or the functional structure of the human brain has considerable implications for the understanding of the human brain plasticity. However, to what extent does this finding contribute to explain the human capacity for music? Answering this question would require to build a bridge between the observed anatomical and functional differences and the performances of the listeners in music cognition and emotion experiments. Without such a direct link, the implications of these differences for the musical competence per se remain unclear. Let us consider the main differences reported between the brain of musicians and nonmusicians.

Some of these differences are obviously associated to the learning of motor skills involved in the playing of a musical instrument. Elbert et al. (1995) showed that the cerebral cortices of string players are different from the cortices of controls. This difference was greater in musicians who had begun to play their instrument earlier (see also Pantev, Engelien, Candia, & Elbert, 2001). Other differences revealed the importance of listeners' familiarity with musical sounds. Highly skilled musicians exhibit enhanced auditory cortical representations for musical timbres associated with their principal instruments (Pantev, Roberts, Schulz, Engelien, & Ross, 2001). That is to say, violinists have larger auditory cortical representations for violin sounds than trumpeters, who have larger auditory cortical representations for trumpet sounds than violinists. Furthermore, Pantev et al. (1998), by using functional magnetic source imaging, observed that dipole moments for piano tones were enlarged by about 25% in musicians compared with control participants who had never played an instrument. They also showed that the younger the musicians started playing their instrument, the larger their cortical reorganization in recognition of piano tones.

Several other studies report differences between the brain of listeners with or without AP. Musicians with AP revealed a stronger leftward planum temporale asymmetry than nonmusicians or musicians without AP (Keenan, Thangaraj, Halpern, & Schlaug, 2001; Schlaug, Jäncke, Huang, Staiger, & Steinmetz, 1995). This finding suggests that early training in music, often associated with the AP ability, results in anatomical changes in left and right planum temporale (but see Halpern, 1989). In addition, a series of anatomical studies by Schlaug and collaborators has demonstrated that the anterior half of the corpus callosum was significantly larger in musicians than in controls. This difference was mainly due to the subgroup of musicians who had begun musical training before the age of 7. Furthermore, male musicians had a significantly higher mean relative cerebellar volume (5%) compared to male nonmusicians, and there was a positive trend between intensity of musical training (practice time per day and across life) and relative cerebellar volume (Schlaug, 2001; Schlaug et al., 1995; Schlaug, Jäncke, Huang, & Steinmetz, 1995).

Other anatomical and functional differences, which are not linked to AP ability, were observed between musicians and nonmusicians. Schneider et al. (2002) found neurophysiological and anatomical differences between professional musicians, amateurs and nonmusicians when passively listening to sinusoidal tones. They observed that the primary source activity of the auditory cortex was larger in musicians than in nonmusicians. In addition, they found an increase in the gray matter volume in musicians compared to nonmusicians. The main interest of the study was to observe that both the primary source activity of the auditory cortex and the gray matter volume were highly correlated with musical aptitude measured by a pitch discrimination test. Gaser and Schlaug (2003) corroborated these results and speculated whether these differences could represent structural adaptations in response to a long-term skill acquisition and the repetitive rehearsal of those skills rather than innate predisposition. It is obvious that the capacity to differentiate subtle changes in pitches is one element of musical competence. It is understandable that listeners who have been trained to do that in conservatories, and who practice music daily should perform better at this test. That this ability can be linked to anatomical differences is important for the understanding of brain plasticity, but it only shows that a tiny portion of musical competence that is acquired by a very specific training could result in anatomical and functional differences.

The last important set of data about differences between the brain of musicians and nonmusicians is reported in electrophysiological studies. Koelsch, Schröger, and Tervaniemi (1999) showed a pre-attentively superior auditory processing in musicians: slightly impure chords (a major chord with the third marginally diminished in frequency) elicited a distinct mismatch negativity (MMN)[10] in professional violinists, but not in nonmusicians. Pantev et al. (2003) observed a clear MMNm in both hemispheres for contour and interval changes for musicians, but not for nonmusicians, who showed unclear responses in both conditions. By contrast, they observed that both musicians and nonmusicians had clear MMNm responses to a frequency change in a single tone condition (see also Fujioka, Trainor, Ross, Kakigi, & Pantev, 2004). However, the results of Trainor, Desjardin, and Rockel (1999) moderated these findings. They found that altered contour and intervals elicited robust P3a and P3b. These components did not differ across groups for contour changes, but they were smaller and delayed in nonmusicians compared to musicians for interval changes. The amplitude of the P3b in musicians was negatively correlated with the age at which musicians have begun their musical training. These findings are corroborated and extended by Trainor, McDonald, and Alain (2002) who showed that changes in both contour and interval were processed automatically in the auditory cortices of nonmusicians. Tervaniemi, Ilvonen, Karma, Alho, and Näätänen (1997) showed that both the occasional reversed order of two consecutives tones and the occasional change in pitch elicited MMN in musicians and nonmusicians, suggesting that the pitch content of the

[10] The MMN is assumed to reflect the cortical pre-attentive detection of change in a repetitive pattern.

sounds, as well as their order in the continuous stimulus stream were pre-attentively encoded by both groups of participants. The MMN was significantly larger in amplitude in the Order-change condition in musicians than in nonmusicians, whereas no difference was observed between both groups for the Pitch-change condition. The authors concluded that musicians have more accurate neural representations for temporal information than nonmusicians, whereas no such differences could be observed when the change included a new pitch (see also Brattico, Näätänen, & Tervaniemi, 2002 for similar results). Finally, Koelsch, Schmidt, and Kansok (2002) found that occasionally physically deviant timbre chords elicited an MMN that did not differentiate musicians from nonmusicians. In sum, this set of studies reveales that both groups of participants process several musical features (timbre change, pitch change…) at a pre-attentive level and that the effect of musical expertise found expression only in the fact that sometimes the ERP components were larger and/or earlier in musicians than in nonmusicians.

Electrophysiological studies have also investigated higher levels of musical processing. The Late Positive Components (LPCs) elicited by harmonic and melodic incongruities were larger in amplitude and had shorter onset latencies for musicians than for nonmusicians (Besson & Faïta, 1995; Besson, Faïta, & Requin, 1994). For example, by using experimental stimuli similar to those reported in Fig. 3, Regnault, Bigand, and Besson (2001) found a LPC that was larger to dissonant than to consonant chords in both musicians and nonmusicians, although it was larger for musicians. They also observed a P3 component in both musicians and nonmusicians, which was larger for the less expected subdominant chords than for the most expected tonic chords. In Koelsch, Gunter, Friederici, and Schröger (2000) nonmusicians listeners were found to be "musical" by eliciting a Early Right-Anterior Negativity (ERAN) followed by a larger N5 for irregular chords (Neapolitan) compared to regular chords (tonic). Nevertheless, a further study revealed that the amplitude of the ERAN was clearly larger for musicians than for nonmusicians (Koelsch et al., 2002).

Taken together, the neuroimaging studies reveal that an intensive musical training (especially for musicians having begun music before the age of 7, according to Pantev & Lütkenhöner (2000)) results in some anatomical and functional differences in the brain of musicians and nonmusicians. These differences seem to be linked to the learning of motor skills specific to the playing of an instrument, to a greater familiarity to specific musical timbre in musicians, or to the development of very specific analytic perceptual processes (AP perception, discrimination of fine pitch frequencies). Electrophysiological studies further indicate that similar ERP components may be elicited in both groups of listeners in response to very fine changes in musical structures, although ERPs were in general larger and earlier in musicians. Given the current stage of research, the differences found between the brains of musicians and nonmusicians remain rather weak in light of the considerable difference in musical training that exists between the two groups. These differences matter for the understanding of cortical plasticity but they are not large enough to support the claim that musical aptitude depends on an intensive training that should ideally start early in life. To our view, these differences are negligible in front of the large overlap in brain activities found in musically trained and untrained listeners. This large overlap suggests that the human brain is already intensively trained to music through everyday life experience: adding supplementary training in music schools makes it possible to acquire specific skills indispensable to be professional musicians, but it is not what determines the musical ability of human beings.

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