

The Relative Importance of Local and Global Structures in Music Perception

Research in experimental psychology has shown two paradoxes in music perception. By mere exposure to musical pieces, Western listeners acquire sensitivity to the regularities underlying tonal music. This implicitly acquired knowledge allows listeners to perceive subtle relations between musical events and permits musically untrained listeners to behave as musically trained listeners, notably in experimental settings that tap into implicit levels of music processing. The second paradox concerns the apparent inability of the cognitive system to deal with large-scale musical structures. The musical brain, which appears to be very smart when dealing with fine musical structures in short temporal windows, turns out to be somewhat defective when short time structures have to be integrated in larger structures. The present paper provides an overview of both issues. We start with reviewing research on implicit learning in the music domain, and then present research investigating the perception of global musical organization.

One of the main reasons leading human beings of Western culture to develop musical activities is the expressive power of music. The content of this expressivity is probably extremely large, rendering the domain of music expression and emotion difficult to address with scientific methods.¹ By contrast, the perceptual processes involved in expressive reactions to music have been the object of substantial research in music cognition. For the most part, this research admits more or less explicitly that emotional reactions to music derive from the cognitive processing of musical sounds and structures. The foundation of a cognitive approach to

emotion in music is developed by L. B. Meyer.² According to Meyer, listeners are not passive, but rather constantly develop perceptual expectancies about the possible evolution of the music. Emotions arise from the way the composer (or the improvising performer) fulfills or frustrates these expectancies. To some extent, music perception may involve cognitive processes comparable to those occurring when reading a novel. Like the plot of a novel, musical structures instill suspense until the end of the piece.

For a cognitive approach, the crucial issue raised by Meyer concerns the nature of these anticipatory processes.³ It is well documented in cognitive psychology that a context generates automatic expectancies that prepare (or prime) the processing of probable events. Most of these expectancies remain at an implicit level, suggesting that the underlying processes are also implicit. We first present the contribution of implicit processes to music perception, and then turn to the time-span of the musical expectancies involved. Several music theories have underlined the crucial role played by hierarchical structure in Western tonal music,⁴ but only a few have argued for a more concatenationist understanding of musical structures.⁵ Cognitive psychology aims to understand the influence of hierarchical musical structures on cognitive processes involved in music perception. For example, one of the questions raised concerns the time-span of perceptual anticipations, notably whether they occur from moment to moment or whether they encompass larger temporal windows. In the latter case, expectations at a given moment in the musical piece may be linked to

what has occurred several minutes ago.⁶ As developed below, a surprising paradox of music perception is that implicit processes lead to very sophisticated perception in short temporal windows, but remain very approximate for large-scale structures.

I. IMPLICIT PROCESSING OF MUSICAL STRUCTURES WITHIN SHORT TIME WINDOWS

An increasing number of studies provide evidence that even musically untrained listeners have implicit knowledge about the Western tonal musical system.⁷ When tested with experimental paradigms that do not ask for explicit, verbalized comments on musical structures, nonmusicians show musically expert behavior. To some extent, they might be compared to children judging their mother tongue: they understand structures and can detect mistakes without being able to name them explicitly. The learning of musical structures by nonmusicians in everyday life can be considered as one example of implicit learning processes.

In experimental psychology, the cognitive capacity to become sensitive to regularities of the environment via implicit learning is studied in the laboratory with artificial material.⁸ One of the experimental protocols consists in presenting participants with event sequences (e.g., letters, light positions, sounds). The sequences are generated by an artificially defined grammar determining legal transitions between the events.⁹ In the first phase of a typical experiment, participants are asked to memorize event sequences that conform to the rules of the grammar. In the second phase, participants are informed that the sequences of the first phase have been produced by a rule system (which it is not explained), and they are asked to judge the grammaticality of new sequences, with half being ungrammatical and half being new grammatical exemplars. In general, participants differentiate above chance between the two types of sequences, even if most of them are unable to explain the grammatical rules in free verbal reports.¹⁰ The artificial materials are, of course, simpler than environmental event sequences (e.g., musical sequences). However, the opportunities to listen to materials obeying the musical system are so numerous that the implicit learning of tonal regularities

can be considered as an ecological example of the cognitive capacity to become sensitive to statistical regularities.¹¹

The following brief description highlights the most salient regularities in Western musical pieces, which can be found in all styles of Western music (from baroque music to rock n' roll and jazz). The Western tonal system can be described as a three-level hierarchical grammar based on a restricted set of twelve *tones* (C-C#/Db-D-D#/Eb-E-F-F#/Gb-G-G#/Ab-A-A#/Bb). These tones appear together in groups of three tones that define *chords* and create a second-order level of the musical system. Some chords are often used together, and these groups define *keys*, the third-order level of the musical system. Keys that have strong harmonic relations share several tones and chords with each other, and the more they share the closer they are related. Musical pieces change key over time, and related keys occur more often together than distant keys. As the tonal system is based on a restricted event set, the same tones and chords occur in different keys, but with different functions in each of them: the same chord (e.g., a C-major chord) is a stable tonic chord in the C-major key, but a less stable one, the subdominant (IV) in the G-major key. When Western composers decide to modulate from one key to another, they know that the functions of tones and chords change and that these changes result in expressive effects for Western listeners: the more distant the musical keys are, the stronger the effect of the modulation. Composers of the romantic period (e.g., Chopin) used to modulate more often toward distant keys than did composers of the baroque (e.g., Vivaldi, Bach) and classical (e.g., Haydn, Mozart) periods.

Despite the complexity of the tonal system, experimental studies in music cognition have shown that sensitivity to musical structure does not require explicit learning: nonmusician listeners tacitly understand the context dependency of events' musical functions and, more generally, the complex relations between tones, chords, and keys.¹² The perception of tonal relations on the three levels has been investigated by using different behavioral methods: for example, subjective judgments of melody completion,¹³ similarity judgments, and recognition memory performance for tones and chords.¹⁴ On the key

level, studies provided evidence that listeners are sensitive to the currently active key, to key changes, and to associated changes in musical functions of events.¹⁵

The implicit learning of tonal regularities and its influence on perception can be simulated by artificial neural networks. These networks (also called connectionist models) are rooted in the biological structure of the neural system: artificial neurons (units) are linked via synaptic connections of different strengths. The goal is not to describe neural anatomy and physiology, but to be inspired by neural principles so as to simulate perceptual and cognitive processing. A principal advantage of these models is their capacity to adapt in such a way that representations, categorizations, or associations between events can be learned. These models expand our understanding of the acquisition and representation of knowledge about our environment and the influence of this knowledge on perception. For music cognition, connectionist models simulate the implicit learning of regularities, the representation of this knowledge, and the influence of the knowledge on the perception of musical events.¹⁶ For example, a hierarchical network based on self-organizing maps learns basic regularities of the Western tonal system by mere exposure to musical sequences and simulates tonal acculturation as it might take place in nonmusicians. After learning, the model simulates a variety of experiments dealing with the processing of tone, chord, and key relationships.¹⁷ The learned representation is activated by a tonal context and the activation levels reflect relations and functions of musical events in this context. Levels of activation have been interpreted as different strengths of musical expectations that a listener might develop for future events. The outcome of the simulations has been confronted with listeners' performance in experimental situations investigating musical expectations and their influence on the processing of musical events (see below).

What kinds of musical structure can be perceived with the help of implicit tonal knowledge? We first consider the perception of musical structures in short time windows. Experimental studies investigate the perception of musical structures with short musical excerpts whose durations generally extend the psychological present (i.e., ten to fifteen seconds, including

about thirty to thirty six events). Some studies are directly linked to the hierarchical musical organizations described in Lerdahl and Jackendoff's *Generative Theory of Tonal Music*.¹⁸ One hierarchical concept is the time-span reduction. Time-span reduction analyses are based on the assumption that a particular musical event (i.e., the head) structurally dominates the other events within a time-span. The hierarchical importance of the head is defined by both its position in the metrical structure and its musical stability in the tonal hierarchy. To test the perception of hierarchical structures in short time-spans, participants listened to musical excerpts that were followed by either an original real time-span reduction (containing the musically important events) or a foil reduction (containing less important or unimportant events). Results provided some evidence for listeners' sensitivity to hierarchical structures underlying the musical surface.¹⁹ In a related vein, Bigand constructed a family of melodies that differed in their musical surface (melodic contour, rhythm) but were similar in their underlying hierarchical structures.²⁰ These melodies were presented together with melodies of another family that mimicked the surface of the previous one, but were based on different hierarchical structures. Participants were asked to group those melodies together that came from the same family. Performance was surprisingly good, even for musically untrained listeners. The outcome suggests that listeners do not stop at the musical surface but process structures underneath it.

Further experiments show that listeners process subtle changes in the musical function of melodic tones. Sets of pairs of melodies were created in the following way: two melodies were matched to share the same melodic contour (that is the up and down of pitches) and the same rhythm, and in addition the tones used were almost identical in the two melodies. By changing only the five first tones of a long melody, the perception of the remainder of the melody is entirely changed.²¹ When directly comparing the two melodies of a pair, musician and nonmusician listeners judge more than 40 percent of the pitches as being changed from one melody to the other.²² The main reason for this strong difference in perception seems to be that the musical functions of the tones differ

drastically between the two melodies. For example, one melody is perceived in reference to the key of A minor while the other melody is perceived in reference to the key of G major. Given that the musical importance of pitches changes with the current key, the musical functions of the same tones differ systematically in the two melodies: the tone A acts as a tonic tone in the first melody but as an unstable tone in the second melody, while the tone B acts as a relatively stable mediant tone in the second melody but as an unstable tone in the first melody. This finding documents sophisticated perception in short time windows.²³

Further evidence for fine perceptual processes comes from empirical studies investigating the influence of the current context on the formation of expectations for possible future events. The expectations are influenced by the listener's knowledge about typical combinations of musical events (on the basis of the regularities in Western tonal music), and—depending on their nature—the expectations facilitate or delay the processing of incoming events.

In experimental psychology, the development of expectations in a musical context and their influence on event processing has been investigated with a musical priming paradigm.²⁴ A musical context (e.g., the first seven chords of a sequence) is followed by a target event (the eighth chord of the same sequence). The musical relations between the prime context and the final target chord are manipulated so that the target is either strongly related (a tonic chord), less related (a subdominant chord), or unrelated (an out-of-key chord). The processing of the target is investigated by requiring participants to make a simple perceptual judgment on the target (without explicitly judging the harmonic relations). For this purpose, half of the targets in the experimental session are rendered acoustically dissonant and the other half remain consonant (in other experiments, the target is either played by instrument A or B, or sung on the phonemes /i/ or /u/). Participants have to judge as quickly and accurately as possible the consonance/dissonance of the target. The underlying rationale is based on the concept of mental chronometry: the longer it takes to make the judgment, the longer the underlying processes must take and the more difficult the event processing must be. The hypotheses for predicted

processing times are based on musical relations: the context activates the listener's tonal knowledge that allows him or her to develop expectations for future events that then influence processing. When an expected event (i.e., generally a musically related event) occurs, processing is facilitated and participants answer faster and more accurately. In other words, the context primes the processing of expected events.

The influence of a prime context on chord processing has been shown for strong violations of musical expectations (with slower processing for out-of-key targets),²⁵ but also for subtler differences: the processing of a target that functions as a tonic chord is facilitated in comparison to a target that functions as a subdominant chord, even if the subdominant also belongs to the current key and is placed relatively high in the intra-key hierarchy. The experimental manipulation of musical relations between prime and target makes it possible to further investigate how far the influence is due to listeners' knowledge (cognitive priming) or to acoustical information inside the context (sensory priming).²⁶ The result patterns of these experiments provided clear evidence for the influence of listeners' knowledge on musical expectations. For both musicians and nonmusicians, musical priming is governed by a cognitive component—irrespective of the psychoacoustic structures of the context (e.g., the occurrence of musical events).

All musical priming studies reported high consistency in the data of musically trained and untrained listeners.²⁷ Listeners' sensitivity to violations of musical expectancies has also been reflected in neurophysiological measurements for melodies²⁸ and for chord sequences.²⁹ Based on the priming material of Bigand and Pineau,³⁰ Regnault et al. measured event-related potentials related to the target chord.³¹ They reported for musician and nonmusician listeners that less-related, weakly expected target chords evoke a P3 component (i.e., a positive evoked potential with a 200–300ms latency range from target onset) with larger amplitude than do strongly related targets. Neurophysiological correlates of musical context effects have been further reported with magneto-encephalography (MEG)³² and functional magnetic resonance imaging (fMRI).³³ In Maess et al. a deviant musical event evoked an increased bilateral

mERAN (early right-anterior negativity with a maximum around 150ms after target onset) with a slight asymmetry to the right for some of the participants. The generators of this MEG signal were localized in Broca's area and its right hemisphere homologue. The authors suggested that the observed mERAN is related to the processing of syntactic-like musical structures, and compared this component with the left early frontal negativity ELAN observed in auditory language studies for syntactic incongruities.³⁴ A recent fMRI study investigated neural correlates of target chord processing with the musical priming paradigm³⁵ and provided corroborative evidence to the MEG source localization: the activation of bilateral inferior frontal regions was increased for unrelated targets in comparison to related targets. The present studies thus reported neurophysiological evidence for the sensitivity of musically untrained listeners to fine manipulations of musical structure.

In sum, the experimental data provide evidence for the influence of hierarchical structures in short time windows on perception. The sensitivity to musical context is observed to be similar for musician and nonmusician listeners. This outcome points to the implicit nature of the involved knowledge of musical relations. The role of tonal knowledge for musical expectancy formation and its influence on musical processing may be understood in light of the connectionist models presented above,³⁶ which represent tonal knowledge as a network of interconnected units. When a chord sequence is played, the chords are presented one by one to the input layer (coding the occurring notes) and activation propagates through the system until an equilibrium is reached. After each chord, activation is weighted by a temporal delay (simulating temporal decay in memory) and the activation state of the network at the end of the prime context is interpreted as the state of expectation for further incoming events (e.g., chords). When the experimental material is given as input stimuli to the models, the emerging and accumulated activation patterns simulate participants' performance in the experiments. The chord units representing the related targets showed stronger activations than units representing unrelated or less-related targets. This outcome thus predicted processing facilitation for the related chords, as it has been observed with human listeners. It is worth

underlining that musical relations emerge from reverberation and accumulation of activation patterns over time, without explicit concepts of hierarchy or functions being programmed into the models.

Overall, empirical studies at short time scales provide evidence for listeners' sophisticated processing of local musical functions and structures, for instance, distinguishing tonic and subdominant. Even nonmusician listeners do not stop at the musical surface, but extract some levels of the underlying structure and develop expectations about future events.

II. PERCEPTION OF MUSICAL STRUCTURES IN LONG SEQUENCES

The implicit knowledge of the tonal system allows Western listeners to understand the context dependency of musical functions and relations. In light of this outcome, the question arises as to how far this tonal knowledge and the apprehension of local structures allow listeners to integrate musical events and groups of events into an overall global structure. Music theory describes hierarchical structures inside a musical phrase, between musical phrases, and between movements of an extended musical piece.³⁷ Schenker describes how different levels of harmonic structure lead from a simple harmonic organization (I-V-I) to the richness of the elaborated surface of a musical piece.³⁸ Hierarchical structures in musical pieces can be linked to the underlying harmony and the organization and development of musical themes (e.g., in the sonata form). The hierarchical structures in musical pieces "are of signal importance because they enable the composer to invent and the listener to comprehend complex interactive musical relationships."³⁹ The *Generative Theory of Tonal Music* proposes a theoretical framework describing the listener's perceptual work in deriving the hierarchical structure from the heard musical surface.⁴⁰ Based on several processing steps that analyze the incoming signal with the help of the listener's knowledge of the tonal system, "pitch-events are heard in a strict hierarchy, ... structurally less important events are not heard simply as insertions, but in a specified relationship to surrounding more important events."⁴¹ The

importance of structural organization for musical expressivity is summarized in the following musicological observation: "A musical phrase, no matter how beautiful it is, reaches its expressive summit only when it is in perfect harmony with preceding and following phrases. What would a musical piece be whose parts, far from working as a whole, could be suppressed, replaced, transplanted?"⁴²

In cognitive psychology, the encoding of musical information as a hierarchy of events has been one of the principal research hypotheses.⁴³ The hierarchical conception is attractive for cognitive psychology because hierarchical structures are economic representation forms with numerous advantages for processing and storage in memory (as has been shown for letters, numbers, etc.). These advantages for memory-related processes seem to be particularly important in music perception as the listener discovers the musical events successively within short temporal windows.⁴⁴ The listener's experience is thus successive and irreversible. The perceptual task consists in discovering the structure that underlies the incoming information and evolves over time. The temporal discovery is based on small temporal segments or units: incoming events are perceived as if through a short temporal window that is sliding in a discontinuous way along the stream of events.⁴⁵ The size of a segment is influenced by several factors, such as the complexity of the stimulus or the underlying structure. Its maximal duration corresponds to the limits of the perceptual present⁴⁶ with estimations varying from five seconds,⁴⁷ over eight seconds,⁴⁸ to ten seconds.⁴⁹ To ensure that the temporal sequence does not remain a simple succession of relatively short segments, the information of several segments has to be linked together at another organizational level. The perceptual process thus concerns two levels of organization: creating relations between events in short time-spans (inside segments) and linking this information at higher levels of structure (between segments). The activation of musical knowledge is supposed to allow processing of relations between events and their representation in an event hierarchy. Based on local organizations, relations of higher levels should be established that allow the integration of different local groups in an overall hierarchical structure. Per-

ceiving relations *inside* the segments (on a local level) should contribute to the fact that a musical sequence is more than just a superposition of tones. Perceiving relations *between* segments (on a more global level) should contribute to the fact that musical pieces are more than a simple chaining of units with coherent note groups.

Based on this description, the question comes up about a listener's capacity to temporally integrate musical events (on global and local levels), and about the role of tonal knowledge in this integration. Does a listener perceive the different levels of hierarchical organization? Or is the perception of structural relations restricted to local connections? In the following, we present experimental studies of music cognition aiming to answer these questions.

Two aspects that are particularly underlined in musicology have been studied: tonal unity and the global organization of a musical piece. The importance of tonal unity (or closure) is reflected in the following quotation: "A feeling of harmonic completeness arises when the music returns to the harmonic base from which it began."⁵⁰ However, the perceptual reality of tonal unity seems to be rather restricted for the listener, even musically experienced ones. Cook manipulated musical excerpts of different duration (between thirty seconds and six minutes) so that the tonality at the end of the excerpt is different from the main tonality (thus undermining tonal closure).⁵¹ Beginning music students judged the excerpts on subjective scales for coherence, completion, pleasure, and expressiveness. Results showed an influence of tonal closure only for excerpts as short as thirty seconds and only for the scales of coherence and completion. Converging data have been reported for musician listeners by West-Marvin and Brinkman with explicit judgments.⁵² Participants had to indicate whether an excerpt (shorter than two minutes) ends in the same or a different tonality than it had started in. The outcome showed that participants succeeded in detecting the tonality change with 64 percent of correct responses, though differences were reported depending on the musical specialization of the participants (71 percent for music academics [theory and musicology], 61 percent for performers, 48 percent for composers). In a second experiment, musical excerpts (~ one minute) were segmented in four groups (ABCD) that were reorganized in

order to violate tonal closure (CDAB, DCAB, DCBA). As in the first experiment, participants indicated whether the resulting musical piece showed tonal closure or not. In this situation, subjects performed roughly at chance (55 percent) and seemed “completely unaware that the large-scale musical structure of these works had been violated by the rearrangement.”⁵³ The authors suggested, however, that the manipulated versions might be missing stylistic features that were naturally associated with a modulation.

Other studies have investigated the perception of global form by systematically manipulating the global organization of musical pieces. In a series of studies, Konecni and collaborators investigated different levels of organizational structures: starting from the relations between movements inside a sonata up to the relations between different sections inside a single sonata movement. Participants rated the musical pieces with the help of subjective scales (e.g., on levels of interest, preferences, expressivity, pleasingness, desire to own a recording). Somewhat surprisingly, overall judgments did not differ between original and modified versions. Manipulations of the order of movements inside a sonata by Beethoven⁵⁴ and of the order of the Goldberg Variations by Bach⁵⁵ did not result in clear changes of listeners’ subjective judgments (judgments indicating either levels of interest, preferences, or expressivity). In the study using Bach variations, two of the random orders used did not lead to different subjective judgments on several scales (interesting/not, orderly/not, pleasant/not, weak/strong, beautiful/ugly, wish to own/don’t wish), except for warm/cold. These studies have led to a strong criticism by the musicologist Batt.⁵⁶ He argued that the modifications used temporal units that were too large and that musician listeners should have been tested. He further suggested manipulating different sections inside a sonata movement, since the “full range of tonal parameters is operative” in a sonata. He illustrated his argument with possible manipulations for Mozart’s symphony in G minor (K550). Karno and Konecni accepted the criticism and effected the proposed modifications in an experimental study.⁵⁷ However, once again, subjective judgments on different scales (level of interest, pleasingness, desire to own a recording, best overall structure) did not

differ between original and modified versions for either nonmusicians or music students. As the authors observe, these results clearly question the perceptual impact of musical structures for the listener. However, it is important to note that the averages of all judgments tended to favor the original versions, which—even if not statistically significant—renders the demonstration somewhat less conclusive.

In the same line of investigation, Tillmann and Bigand made even stronger modifications of musical structures.⁵⁸ Three musical pieces (with a duration of about three minutes) were segmented into little chunks (of six seconds on average) that were chained together in either the original order of the composer or the inverted, retrograde order. The retrograde modification destroyed the global organization of the piece, but preserved the local structures inside the chunks. Nonmusician participants judged either the original or the retrograde versions on twenty-nine subjective scales. The judgments of expressivity and coherence were not influenced by the destruction of global organization, but they clearly distinguished among the three musical pieces (by Bach, Mozart, and Schoenberg). Listeners seemed to be sensitive to the information inside the local chunks, but not to the different temporal markers (e.g., cadences, modulations) that created the global organization of the musical piece.

Further experiments investigated the perception of these temporal markers and focused notably on one of them: the cadence. Cadences are local structures indicating musical endings that can be temporary or final, but their functions can depend on the overall global context of the piece. Previous research has shown that listeners perceive the functions of different forms of cadences when presented in isolation or in very short contexts.⁵⁹ But to what extent do listeners take into consideration the overall structure of a musical piece in understanding cadential functions? Tillmann, Bigand, and Madurell addressed this question with short musical minuets (of twenty seconds) based on cadences.⁶⁰ The experimental setup consisted in a musical jigsaw puzzle and allowed participants to be active: they had to reconstruct a coherent musical piece based on sections ending on different cadences. If the participants did not understand the temporal markers, they would

have difficulty in reconstructing the musical piece. The results of the musical puzzle and subjective judgments of completion revealed that listeners, both musicians and nonmusicians, understand the local functions of cadences, but are not able to integrate these local structures into an overall global structure of the musical piece. For example, when it was necessary to interpret the cadences by considering the global structure of the piece, more errors were committed in chaining the parts together.

In light of these data sets pointing to the weak perceptual importance of global organization, the question arises as to how far global structures might play a role in memory, as for example, weaker memory performance has been observed for incoherent versions of verbal texts.⁶¹ Following this line, Bigand, Poulin, Dowling et al. presented either a coherent chaining of excerpts of a musical piece (one and a half minute on average), or an incoherent chaining of the same excerpts. In a second phase of the experiment, participants had to indicate among a new list of excerpts those target excerpts that they had listened to in the first phase. Musician and non-musician participants rejected more easily the foils that were completely new excerpts than the foils that were from the same composers as the excerpts of the first phase. But the global coherence of the presentation did not influence memory performance. In a different study, Tillmann, and Bigand⁶² adapted target detection and recognition tasks that have provided evidence for global structures in visual perception⁶³ and in speech perception.⁶⁴ The global organization of minuets was destroyed at different levels (up to the level of one bar). Participants had to detect a musical excerpt while listening to the piece, or to indicate afterward if a short excerpt had been present in the piece. The results revealed that the global coherence of the context affected only weakly the identification of the excerpts and this only for extremely modified structures (at the level of one bar).

Overall, the behavioral data suggest that local structures prevail over global structures for the listener—at least in musical pieces between twenty seconds and three minutes. Global structures seem to have only weak influences on perception, and local structures seem to be much more important. Independently of level of musical expertise, listeners have difficulties consid-

ering relations between events that are far apart in time. And yet, understanding such distant relations would be necessary to integrate events into an overall structural organization. When referring to the hierarchical conception of the sliding temporal window presented above, the data suggest that listeners do not connect, to any appreciable degree, the different windows at a higher hierarchical level. Consequently, perception seems to take place through a succession of local structures. This conclusion comes close to a conclusion about the perception of music in ten-year-old children:⁶⁵ the children's perception does not imply the coordination of relations defining the role of each element in the overall structure. The understanding of temporal structures seems to be limited to relations that are close in time. On the basis of current empirical evidence, this conclusion seems to be valid also for the adult listener, whether trained or not.

III. CONCLUSION

Current research in psychology of music leads to two paradoxes. In short time windows (inferior to thirty seconds), the musical brain manages to process subtle musical structures, even for listeners who have never received formal musical training. We argue that implicit learning permits listeners to internalize the knowledge required to differentiate subtle changes in musical structures. Accordingly, nonmusicians behave roughly in the same way as do musicians, the former being as musical as the latter. This conclusion clearly contradicts the current belief that rich experiences of music require several years of explicit training. In our view, this social belief results from a profound misunderstanding of the cognitive abilities involved in musical perceptual activities, as well as from a complete ignorance of the real content of musical training programs developed in music schools. At least in French academic systems, musical training mostly consists in learning motor schemas necessary to play an instrument and to convert visual musical notation into sounds. Musical training programs are not designed to develop and improve the perception of musical structures, which is underlined by its complete absence in music analysis classes. It may be that an intense motor training has some influence on the way

musicians perceive music, but we did not find any evidence indicating that music is perceived in a more subtle way by musically trained listeners. Musically untrained but experienced people are generally musical, but often without realizing it.

The second paradox lies in the observation that the musical brain of trained and untrained listeners encounters huge difficulties in processing large-scale structures. Research on the perception of musical structures was initially based on the hypothesis that listeners integrate events in an overall hierarchical structure: with the help of their tonal knowledge, listeners were supposed to integrate events in small hierarchical structures inside short temporal windows and to integrate these substructures into larger hierarchical organizations covering the overall musical piece.⁶⁶ To the best of our knowledge there are no available data supporting this assertion. On the contrary, numerous experiments highlight the strength of local structure for music perception. In short temporal windows, listeners understand the local function of cadences, perceive changes in tonality, and go somewhat beyond the musical surface. However, their perception fails to integrate these structural markers into more global structures.⁶⁷ For short time-spans, simulations with the connectionist models suggest that the influence of local structures on musical processing can emerge from the simple accumulation of activation patterns over time (weighted by temporal decay), without necessarily extracting a hierarchical organization.

One way to understand this second paradox is to consider that local, small-scale musical units are so rich for aesthetic experience that processing larger musical units may fulfill no crucial need. This conclusion is supported by Tillmann and Bigand's findings showing that musical expressivity is entirely maintained even when musical pieces by Mozart and Bach are scrambled.⁶⁸ The empirical findings fit nicely with a concatenationist view of music perception as described by Gurney⁶⁹ and developed in Levinson.⁷⁰ "Music's form is continuational and successional, not spatial and architectonic."⁷¹ A listener perceives music moment by moment, with information inside these moments being perceived as a unity. Levinson underlines the perceptual importance of local coherence within these moments and of coherent transitions between

these momentary units: "A piece typically 'makes no sense' to a listener when he is unable to find it coherent on a small scale, when he is unable to perceive local connections . . . when he cannot become absorbed in the music's developing present."⁷² Levinson insists that even if global organization has some influence, perception of music essentially consists in the experience of locally coherent musical moments.

Experimental data contribute to reformulate the concatenationist issue in the following way: What is the real benefit for the musical brain in processing large-scale structure? Why should the brain consume attentional capacity for global processing if local musical structures are rich enough for emotional responses to music? To some extent, this question extends beyond the musical domain. Indeed, when listening to a speaker, it sometimes occurs that weakness in or the complete absence of large-scale structures of a discourse can be entirely compensated for by fascinating eloquence in short time windows. With a brilliant speaker, a listener may easily accept or fail to mark the lack of overall structure. Given that there are no empirical data addressing this issue with language, it remains difficult to evaluate whether the processing of large-scale structures results in comparable difficulties for different domains. However, on the basis of several dramatic historical examples that have demonstrated how global incoherence in discourse can be overcome by convincing local coherence, it may be that concatenationist theories have theoretical implications that go beyond the musical domain. More generally, time may tend to be processed moment by moment when such moments lead to an extremely rich aesthetic, intellectual, spiritual, or emotional experience.

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4. See F. Lerdahl and R. Jackendoff, *A Generative Theory of Tonal Music* (MIT Press, 1983); H. Schenker, *Der Freie Satz: Neue Musikalische Theorien und Phantasien*, trans. N. Meeùs (Liège: Margada, 1935).
5. See E. Gurney, *The Power of Sound* ([1880] New York: Basic Books, 1966); J. Levinson, *Music in the Moment* (Cornell University Press, 1997).
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