Focus Article

The role of expectation in music: from the score to emotions and the brain

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Like discourse, music is a dynamic process that occurs over time. Listeners usually expect some events or structures of events to occur in the prolongation of a given context. Part of the musical emotional experience would depend upon how composers (improvisers) fulfill these expectancies. Musical expectations are a core phenomenon of music cognition, and the present article provides an overview of its foundation in the score as well as in listeners' behavior and brain, and how it can be simulated by artificial neural networks. We highlight parallels to language processing and include the attentional and emotional dimensions of musical expectations. Studying musical expectations is thus valuable not only for our understanding of music perception and production but also for more general brain functioning. Some open and challenging issues are summarized in this article.

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INTRODUCTION

As expectations are central in perception, cognitive sciences and neurosciences are investigating the predictive brain. In music perception, the central role of expectations is reflected in phenomenological experiences, such as 'waiting for the next tone', 'feeling of suspense', 'hearing the continuation in your head', or 'anticipating the next track of a CD'. Studying expectations in music provides insights in cognitive processing (e.g., learning, memory) and their neural correlates, as well as shared resources with the processing of other structured materials (language, movement). Beyond the information-processing aspect, musical expectations have been attributed a role for musical expressivity and emotion. This has been first postulated by musicologists, but more recently shown in empirical research. This article begins from musical expectations in musicology studying musical structures, and then presents an overview of behavioral and neurophysiological research on musical expectations, providing insights in brain functioning and our understanding of the power of music.

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MUSICAL EXPECTATIONS IN THE SCORE

Musical expectations are related to the concepts of musical tension and relaxation. According to Meyer,[1] Lerdahl and Jackendoff,[2] and more recently Huron,[3] experienced tension (conscious or not) can generate expectations. Western listeners implicitly expect that tensions should be followed by relaxation, induced by a musically more stable event. The critical point is to define the features that could instill 'tension' in music. The simplest explanation considers that some pitch intervals (e.g., minor seventh as for the tones C and B*b*) create a conflicting stimulation in the auditory filters of the basilar membrane. The resulting sensory dissonance is of considerable esthetic value when it is followed by a related consonant pitch interval (the tones F and A in this example), but may result in an unpleasant feeling otherwise. Western listeners usually prefer a musical 'happy-end' and do not expect sensory dissonances at the end of a piece.[2]

Reducing musical expectations solely to sensory consonance (dissonance) would however be an oversimplification. For instance, jazz pieces end sometimes with a dissonant chord (e.g., a minor chord with a major seventh, C–E*b*–G–B), but in that context, this dissonance is understood as a stylistic gesture without syntactic implication because all tension has already been resolved. A further counterexample is provided by early baroque music where soloists ornamented the upper voice to avoid consonant intervals (i.e., octave and perfect fourth), which recalled the medieval style. Musical expectations are thus partly sensory and partly cognitive, and are context- and style-dependent. The syntactic implications of sensory consonance and dissonance were fully explored by composers of the early Baroque music (i.e., in the 17th century, notably in Italy). The intense practice of polyphonic improvisations leads composers to discover how musical tension and relaxation could be elegantly patterned through time. Their practice, referred to as 'diminution', was rather similar to that of jazz musicians today. A melodic line (either in the upper or the bass voice), which was made of long note durations, was repeated. Over the repetitions, long notes were replaced by shorter ones. Valuable diminutions 'turn' around long tones by providing melodic lines with strong Gestalt-like qualities that fit well with the metrical frame, and that display an interesting balance between consonant and dissonant intervals. Expectations arising from these diminutions were of esthetic value. Given that the melodic pattern was constantly repeated, these expectancies were rather automatically generated. Some of the most famous pieces of Western music (e.g., Pachelbel' s canon, aria 'la folia') provide good examples of the art of diminution.

The practice of diminution shapes the Western musical idiom by encouraging developing tension and relaxation in a hierarchical way,[4] as described in Meyer,[5] Huron,[3] and formalized by Lerdahl and Jackendoff.[2] According to Meyer, each parameter of music contributes to create tension and has implications for the suite of the piece. A large pitch interval, for instance, implies the gap will be filled by returning to the initial tone. This implication could be suspended temporally if an additional large pitch interval occurs during the filling of the initial gap. This new event thus creates a new expectancy, which is embedded in the previous one. Narmour[6] provided a full account of expectations related to changes in pitch. Rhythm and harmony also induce tensions, which imply further relaxation. Meyer[5] demonstrated how the tension resulting from each musical component may be temporarily aligned or shifted, thus creating a full network of embedded expectations of perceptual and esthetic interest. Composers can easily play with these expectations by manipulating these parameters, as illustrated in Figure 1. The beginning of this musical excerpt creates the strong feeling that a loud intervention of the full orchestra is likely to occur soon. All musical parameters linked to Western tonal hierarchy (ostinato on the dominant chord), rhythm, (shortening of rhythmic cells), and thematic organization (repetition of thematic cells), lead one to anticipate this intervention at the specific time indicated by the arrow of Figure 1 (top). Tchaikovsky, however, has delayed this intervention by inserting at this specific time a long phrase played by the violin, and only then letting the full orchestra intervene, as illustrated by the arrow of Figure 1 (bottom). This example further suggests that an intensification of expectations can occur when expectancies for other parameters (melodic intervals, meter, or even loudness) are also violated, as described by Meyer,[5] or when expectancies are embedded at several levels of the structural tree as described by Lerdahl and Jackendoff.[2]

FIGURE 1 | A short excerpt of the last movement of Tchaikovsky 4th Symphony. Top: Melody, rhythm, and harmony are combined in such a way that listeners anticipate that an orchestral tutti should intervene at a specific moment in the piece (represented by the arrow). Bottom: Representation of what the composer actually created: at the specific moment where the orchestral tutti is likely to occur, a further melodic line is played by the violins for some seconds and then, the expected orchestral tutti actually occurs (represented by the arrow).

Musical expectations are not limited to short time spans. According to Lerdahl and Jackendoff,[2] tension and relaxation patterns are organized in a hierarchical way over the entire duration of a musical piece. The core concept of 'reduction' (i.e., that is the process of identifying the basic musical progression underlying the musical surface) is the counterpart of the 'diminution' that baroque musicians developed in the 17th century. Western musical pieces can be

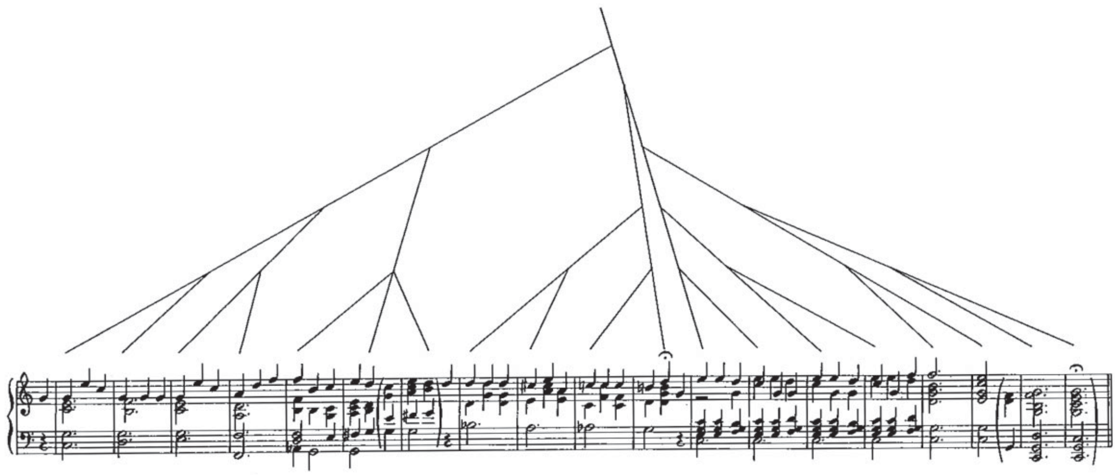

FIGURE 2 | Prolongational tree structure proposed by Lerdahl and Jackendoff[2] illustrating how musical tensions and relaxations are hierarchically embedded over the entire duration of a musical piece. (Reprinted with permission from Ref. 2 Copyright 1983 MIT Press). The event connected to the right branch instills a tension, which is resolved by the event connected to the left branch.

understood as an elaborated 'diminution' of reduced basic structures. All musical tones and chords act as a direct or indirect elaboration of each pitch of these reduced basic structures. The prolongational trees of Lerdahl and Jackendoff (Figure 2),[2] formalize this elaborative network by linking each tone to the one it is an elaboration of, as visualized by the attachment in the tree. The sounding of a given tone can instill a tension that listeners expect to be solved by the occurrence of the tone to which it is related to in the tree. Prolongational trees have several levels of branching, and this expresses the intuition that musical expectations are hierarchically organized over the entire piece. Several empirical investigations provided some support of the cognitive reality of the prolongational structure.[7–10]

MUSICAL EXPECTATIONS: FROM THE SCORE TO PERCEPTION AND COGNITION

While listening to unfolding music, listeners develop expectations about the 'what' and 'when' of future musical events, as shown by music cognition research using various subjective judgments, production, memory, and attention tasks.

Produced Continuations and Feelings of Completion

Earlier studies have investigated musical expectations via production tasks: Participants listened to short melodic excerpts and were required to either sing the continuation[11,12] or produce continuations on the piano.[13] Analyses of the produced continuations (in particular, the first note) reflect the influence of the tonal function of the events and correlate with direct expectancy judgments. While production tasks restrict potential participants to musicians, subjective completion judgments allow studying also nonmusicians (albeit via explicit judgments, see below for an implicit investigation method). Participants listen to musical excerpts, and rate how well a proposed continuation fit their expectations or how strong the ending induces a feeling of completion. Participants' judgments are strongly influenced by the tonal structure of the musical fragments as well as by Gestalt principles of perceptual organization.[13–16] Events with more referential tonal functions receive higher degrees of completion judgments and are more strongly expected. In addition, these tonal expectations can also be modulated by temporal expectations: for example, musical sequences ending 'on-time' are judged more complete than those ending earlier or later than expected.[17,18]

Memory

Expected musical events are better memorized than unexpected musical events. In short-term memory tasks, melodies with endings that fit listeners' expectations are better recognized than melodies with unexpected endings.[19] In a dictation task, melodies respecting listeners' expectations lead to less transcription errors than melodies with violated expectations. This memory advantage of tonally expected events can be decreased by a temporal expectancy violation.[20] However, note that expectancy violations can also facilitate recognition in melody comparison tasks.[21,22]

Processing Speed

The priming paradigm, extensively used in psycholinguistics,[23] is an implicit investigation method, which allows for testing nonmusicians' expectations. In this paradigm, a prime context is followed by a target event, and the tonal relation between prime and target is manipulated. The hypothesis is that the prime context leads listeners to form expectations about future events, and that the more an event is expected, the more its processing is facilitated. Bharucha and Stoeckig[24,25] (see also Refs 26 and 27) demonstrate an influence of local harmonic relations: Target chord processing is faster and more accurate when prime and target chords are harmonically related than when they are unrelated. Bigand and Pineau[14] extend this finding to global harmonic relations by keeping constant the last two chords (local relation) and manipulating the previous harmonic context: The last chord is processed faster and more accurately when it is more closely related to the previous context rather than less closely related (see also Refs 28–30). The priming paradigm has also been used for studying temporal expectations, showing faster processing for chords occurring on-time.[19,31]

More recently, the priming paradigm has been adapted to melodies and the influence of tonal expectations on tone processing.[32] This allows further investigation of musical expectations, notably by testing even more subtle differences between prime contexts and pointing out cognitive influences in musical expectations.[33,34]

Guiding Auditory Attention

Another role of musical expectations is to guide attention, aiming for more attentional resources for expected musical events. In a stream-segregation situation, Dowling et al.[35] hypothesized that listeners' knowledge of a particular tune (i.e., expectations about which tone played when) would guide listeners' attention: Listeners would have 'expectancy windows' through which tonal and temporal structures are perceived and anticipated. In this study, notes of familiar melodies (e.g., *Frère Jacques*) are temporally interleaved with distractor notes in the same pitch range and of the same timbre. The temporal presentation is manipulated, with target notes of the familiar melodies being presented either 'on beat' (i.e., on the strong beats of the metrical structure) or 'off beat'. The familiar melodies are easier to identify when their tones are 'on beat' than 'off beat', suggesting that listeners use their knowledge of temporal organization to aim their expectations at times when target notes should occur. The results also show the influence of listeners' long-term knowledge about familiar melodies on musical expectations: it allows listeners to develop expectations about the pitch of the next tones, thus helping auditory stream segregation (see also[36]). Without this top-down influence (in the case of unfamiliar melodies) listeners do not succeed in this task.[37]

COMPUTATIONAL MODELS OF MUSICAL EXPECTATIONS

In music cognition research, computational models have been used to provide insights in musical expectations and the underlying processes in listeners' brains (see Ref 38 for a review). For example, they have been used to simulate the mental representation of listeners' knowledge about musical structures, the acquisition thereof as well as the influence of this knowledge on expectations and perception. Interestingly, the simulations have led to alternative hypotheses based on learning (instead of innate universals), distributed representations (instead of symbolic or rule-based ones), and sensory influences (instead of cognitive influences).

Principles related to melodic expectations, as defined by Narmour,[6] have been originally interpreted as reflecting general, bottom-up information processing, which can be observed cross-culturally and have been suggested to be innate (e.g., Ref 39), and some top-down influences linked to the knowledge about a particular musical system. Pearce and Wiggins[40] proposed a computational model that learns statistical regularities of various features between melodic events in a corpus of folk melodies. Even though one may raise the criticism that the coding of the input information is abstract (e.g., onset, duration, inter-onset intervals, pitch interval, contour, or scale degree), the model with its learned sequential dependencies allows one to simulate listeners' melodic expectations, thus providing a more parsimonious account without postulating innate principles. Based on the probabilistic nature of music, Temperley[41] suggests that the expectedness of a note could be seen as an estimate of its probability to occur in a given context. He proposes a Bayesian pitch model that simulates participants' completion judgments, exceeding other non-Bayesian models. Temperley[41] also proposed a Bayesian rhythmic model that can capture the phenomena of rhythmic expectations and that, along with the pitch model, could simulate the combination of both tonal and temporal expectations.

Another contribution of computational models is the proposition of parsimonious knowledge representations[42] that can be learned by mere exposure.[43] A hierarchical self-organizing map can learn relations between tones, chords, and keys via repeated exposure to musical sequences, thus imitating the implicit learning of musical knowledge in nonmusician listeners. Then, together with activation reverberating between the layers of the model, musical expectations have been simulated for chord sequences and melodies. Levels of activation are interpreted as strengths of expectations, and series of simulations have shown that the model can account for empirical data about musical expectations (see, however, Refs 29 and 44 for exceptions). A similar computational approach has also been used to simulate the perception of culturally familiar and unfamiliar music.[45,46] Models are exposed to either Western or Indian music and then tested with the experimental material. The findings of behavioral and computational approaches show that listeners' knowledge of the musical system of their culture influences musical expectations when listening to music from an unfamiliar system.

However, neither of these models is starting from the audio signal itself, but they are all using abstract input coding. Leman[47] proposes a short-term memory model taking the audio signal as input. An auditory peripheral system and a pitch module transform the audio signal into a 'pitch image' based on periodicity pitch. The pitch image is further processed into a 'local' image (the immediate pitch percept) and a 'global' image that covers a longer time window, and both local and global images are correlated. A stronger correlation suggests that the local event is strongly expected on a sensory level, while a lower correlation suggests its unexpectedness based on sensory similarity. This sensory short-term memory model, and in particular, the sensory similarity (or dissimilarity) of a to-be judged or to-be processed musical event with its preceding context aims to explain previously observed data without considering tonal structures and listeners' knowledge thereof. Indeed, in tonally composed music (from the repertoire or designed for the experiment), tonally important (and thus supposed to be expected) musical events occur more frequently in the tonal context than less-expected or unexpected events, thus leading to a confound between tonal expectations and sensory memory effects. Simulations of Leman's short-term memory model have challenged the claim that Western listeners have internalized tonal hierarchies in long-term memory and provide an alternative account for studies investigating musical expectations (e.g., Ref 48), challenging their cognitive interpretation. More recently, this auditory model has been used to evaluate how acoustically related a target was to the preceding context.[34,49]

MUSICAL EXPECTATIONS: FROM BEHAVIOR TO THE BRAIN

Neural correlates of musical expectations have been mostly investigated with the introduction of expectancy violations. This experimental approach has been adapted from other domains investigating structure processing and expectations, in particular in language (e.g., Refs 50 and 51). The observed similarities for musical structure processing further confirms the hypothesis that while listening, listeners are indeed developing musical structure-related expectations, which have an influence on processing efficiency and also emotion (see next section).

Several studies using electroencephalography (EEG) have reported different Event-Related Potentials (ERPs) elicited by expectancy violations. Janata[52] as well as Regnault et al.[53] observe a larger P300 (a positive component peaking at around 300 milliseconds after the onset of the target chord) for unexpected or less-expected musical chords compared with expected chords (see also Refs 54–56 for a similar late positive component). When no task was requested, Koelsch et al.[57] report that harmonic expectation violations can elicit an early ERP, the ERAN (Early Right Anterior Negativity) maximal around 150 milliseconds that may or may not be followed by a later negativity (N5, maximal around 500 milliseconds).

The source localization of the magnetic equivalent of the ERAN studied with MEG[58] together with functional Magnetic Resonance Imagining (fMRI) data[59,60] point out the role of the inferior frontal cortex (in particular, bilateral frontal operculum, that is Broca's area and its homologue in the right hemisphere) for musical structure processing. This activation together with other activated areas (notably in anterior and posterior temporal regions and in inferior parietal regions) suggest a parallel to the neural correlates of structure processing and expectations in language (e.g., Ref 61). These data are part of the hypothesis proposed by Patel[62] for shared neural resources in syntax processing for both music and language.

However, as for the behavioral studies discussed above, these first neurophysiological studies have used strong musical expectancy violations and are thus submitted to a confound of sensory violations in their material (see Ref 63 for the investigation of sensory influences on ERPs). Indeed, activation differences could thus be solely due to either the detection of a new, acoustic deviant for the musically unexpected condition or repetition priming benefitting the musically expected condition. These alternative explanations have been tested in an fMRI study using controlled experimental material[64]: When neither the expected nor the unexpected musical event occur in the context, the unexpected event still activates the inferior frontal cortex more strongly than the expected event. Even though the overall activation pattern is less pronounced (also leading to significant activation of inferior frontal cortex only in the right hemisphere), the present study confirms the reported neural correlates of musical expectations. Similar controlled approaches have been subsequently used for EEG experiments (e.g., Refs 49, 65, and 66), suggesting that some observed effects might rely on more than purely sensory factors.

Finally, the central role of expectations in music is also reflected in mental imagery: The music stops, but it continues in our mind. Neurophysiological studies have provided evidence that imagined musical sounds can evoke early electrophysiological responses (N100[67]) and auditory cortex activation[68] (see Ref 69 for a review).

MUSICAL EXPECTATIONS: FROM COGNITIVE PROCESSES TO EMOTIONAL RESPONSES

Musical emotion and expressivity can be based on both sensory properties of sounds (e.g., the dynamics and richness of spectral features), and cognitive processes linked to musical structures. While sensory features raising emotion might be considered as more universal and be interpreted in parallel to acoustic properties of emotion expressed by voice (e.g., Ref 70), some of the structural features require knowledge about the musical system. As exposed in *Musical Expectations in the Score* section, listeners' musical expectations have been attributed a role for expressiveness and emotion evoked by music (e.g., Ref 1). In particular, listeners' expectations are not always immediately satisfied, but might be temporarily delayed. These violations, disruptions, and resolutions of expectations might then lead to meaningful and expressive moments in music (e.g., Ref 3).

Steinbeis, Koelsch, and Sloboda[71] implemented musical expectancy violations and measured not only EEG responses, but also subjective responses and physiological markers of emotional processing (electrodermal activity, heart rate). They reported for both musician and nonmusician participants that unexpected events increase subjective responses for tension and emotionality as well as the electrodermal activity (see Ref 72 for similar results on electrodermal activity). Even though they did not observe changes in heart rate, this data set is in agreement with Meyer's hypothesis that musical emotions might arise through fulfillment and violation of musical expectations. This hypothesis finds further support in the fMRI studies reported above: In addition to the neural correlates summarized above, the unexpected chord also evokes increased activation in the orbitofrontal cortex,[64] a cortical area densely connected to limbic areas and previously reported for emotional stimuli,[73] as well as in the amygdala.[74]

In light of the role of expectancy violations for musical emotion and expressivity, what about repeated listening (and enjoying) of a same musical piece? How can a well-known familiar piece be pleasant and expressive when knowing exactly what will come next? Together with Jackendoff[75] and Meyer,[1] Dowling and Harwood[76] proposed to attribute these expectations, which are relevant for expressivity, to a subconscious level. This would allow violating schematic expectations (i.e., expectations linked to the musical structures of a cultural system), while no violation or surprise occurs at a conscious level related to the veridical expectations about a specific musical continuation. Behavioral studies have provided evidence for the automaticity of schematic expectations and their resistance to 'knowing what's to come'. In comparison to expected chords, response times to unexpected chords remain slowed down even when listeners have a preview condition directly presenting the violation[77] or when the experimental condition contains other exemplars of the violating structures or repetitions of the same sequences.[78]

It is worth noting that musical emotion and musical expressivity have been studied more extensively thanks to the rise of neuroimaging techniques over the last 10 years. These studies have provided evidence for the involvement of more general reward/motivation circuitry (previously observed for food, drugs, and sex) in musical emotion (e.g., Ref 73). Further investigating the link between emotions and expectations in music, Salimpoor et al.[79] provided evidence for distinct neural correlates (and more specifically, anatomically distinct dopamine release) during peak emotional experiences and the anticipation thereof. This work thus contributes to our understanding of musical emotion, expectations, and the impact of music in general.

MUSICAL EXPECTATIONS: SOME UNANSWERED QUESTIONS AND PERSPECTIVES

Musical expectations are a core phenomenon of Western music cognition. The Western musical idiom is indeed well designed to instill tensions, relaxations, and expectations. Beyond the relative contributions of sensory and cognitive components to musical expectations (as discussed above), there are other open questions. Most research has been conducted on musical material from the Western tonal system, thus questioning its relevance for the processing of other musical systems. While some data have overcome this ethnocentric bias and have provided some data for the perception of music from other cultures (e.g., Ref 80), there are still too few data on musical expectations *per se* and no data yet on musical expectations in contemporary musical pieces. A further issue that needs to be investigated is the formalization of how specifically each musical parameter contributes to expectations. Meyer[5] proposed an additive model of expectations, while Lerdahl and Jackendoff[2] proposed a unified model. The independent versus interactive processing of sounding parameters (in particular, pitch and time) has been a debate in music cognition (e.g.,[81,82]), and further studies are needed to address this issue for expectancy formation. Neural modeling approaches, as well as brain imagery studies, are likely to contribute to this issue, in particular by investigating the role of temporal attention in expectancy formation. Recent neuroscience research has been studying the 'predictive brain' on both 'what' and 'when' dimensions, for example, by referring to the role of neural oscillations in this process (e.g., Ref 83). It could be fruitful to bring these separated research domains together, also by using musical material with its strongly established pitch and time structures and the related expectations. This would allow us not only to further our understanding of music processing, but more generally our understanding of cognitive and neural correlates underlying 'predictive coding' (what) and 'predictive timing' (when) in the brain.

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