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Music Cognition and the Cognitive Sciences

Marcus Pearce,[a] Martin Rohrmeier[b]

[a]*Music Cognition Lab, School of Electronic Engineering & Computer Science, Queen Mary, University of London*
[b]*Cluster Languages of Emotion, Freie Universität Berlin*

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Abstract

Why should music be of interest to cognitive scientists, and what role does it play in human cognition? We review three factors that make music an important topic for cognitive scientific research. First, music is a universal human trait fulfilling crucial roles in everyday life. Second, music has an important part to play in ontogenetic development and human evolution. Third, appreciating and producing music simultaneously engage many complex perceptual, cognitive, and emotional processes, rendering music an ideal object for studying the mind. We propose an integrated status for music cognition in the Cognitive Sciences and conclude by reviewing challenges and big questions in the field and the way in which these reflect recent developments.

Keywords: Music cognition; Music; Cognitive science; Evolution; Development; Perception

> Is music the most important thing we ever did?
>
> —Cross, 1999

> You are browsing, let us imagine, in a music shop, and come across a box of faded pianola rolls. One of them bears an illegible title, and you unroll the first foot or two to see if you can recognize the work from the pattern of holes in the paper. Are there four beats in the bar, or only three? [...]. Eventually, you decide that the only way of finding out is to buy the roll, take it home, and play it on the pianola. Within seconds, your ears have told you what your eyes were quite unable to make out […]. How does the brain solve the problem you were unable to solve in the music shop? Can we construct a precise and plausible theory of the cognitive processes that must be involved?
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> —Longuet-Higgins, 1979, pp. 307–308

Correspondence should be sent to Martin Rohrmeier, Cluster Languages of Emotion, Freie Universität Berlin, Habelschwerdter Allee 45, 14195 Berlin, Germany. E-mail: mrohrmeier@cantab.net
The authors contributed equally to this article.

1. Music and the cognitive sciences

These words, written by the man who coined the term *cognitive science* (Longuet-Higgins, 1973), were published in the same year that the Cognitive Science Society was founded and in the same month as its first annual conference. The paper from which they are taken reviews and synthesizes Longuet-Higgins's own work on computational modeling of the perception of tonal relations and that of Mark Steedman on the perception of rhythm and meter in music (e.g., Longuet-Higgins, 1976; Steedman, 1977). Given that music appears so early in the history of cognitive science, we might well ask: Why should music be of interest to cognitive scientists? What role does it play in human cognition and can it generate real insights into the functioning of the mind? Guided by the contributions to this issue, we consider three answers to these questions and provide historical and introductory background to them: the argument that music is a fundamental human trait, the role of music in human evolution and development, and the richness of general cognitive mechanisms involved in musical behaviors.

Longuet-Higgins's work introduced some of the first computational models of music cognition, which were reported in *Nature* (Longuet-Higgins, 1976).[1] 1979 saw publication in the journal *Cognitive Psychology* of a seminal article by Krumhansl (1979) based on her PhD dissertation, supervised by Roger Shepard. This was the beginning of a long line of studies that led ultimately to the publication, a decade later of Krumhansl's landmark book *The Cognitive Foundations of Musical Pitch* (Krumhansl, 1990). In 1981, Diana Deutsch and John Feroe published their work on the cognitive representation of pitch sequences in tonal music (Deutsch & Feroe, 1981), extending early research by Herb Simon (Simon & Sumner, 1968). In his Harvard lectures, Leonard Bernstein (1976) proposed ideas that linked music to linguistic ideas advanced by Chomsky. Soon after, music cognition came of age with the publication of *A Generative Theory of Tonal Music* (GTTM) by Fred Lerdahl and Ray Jackendoff (1983), an attempt to paint a comprehensive picture of the cognitive processing of the Western tonal music, drawing extensively on linguistic ideas and representing several years of interdisciplinary collaborative work between the two authors. The same year, the GTTM received a review by Longuet-Higgins (1983) in *Nature*. Looking back on these developments that focused mostly on cognitive processing of musical structure, we may view the years between 1979 and 1983 as a pivotal period in the establishment of *music cognition* as a field of its own, standing independent from the psychological and psychophysical research on music that had gone before (including the early work of Diana Deutsch, W. Jay Dowling, Robert Francès, and others dating back to Helmholtz, 1877/1985).

During this period, music was used as an example in two of the twelve issues for *Cognitive Science* (namely emotion and performance) in an article published under that title in *Cognitive Science* (Norman, 1980). Nonetheless, it was to be another 15 years before the word *music* appeared in the title of an article published in the journal (Large, Palmer, & Pollack, 1995). The years since then, however, have witnessed an increasing interest in the study of music perception and cognition. Understanding music as a uniquely human trait like language, recent research trends in music cognition have encompassed practically all branches of cognitive science, including developmental psychology, linguistics, neuroscience, education, computer science, and experimental psychology. Monographs, special issues, and edited volumes have been published on music cognition, in general (e.g., Cross & Deliège, 1993; Honing, 2011a; here Howell, Cross, & West, 1985; Howell, West, & Cross, 1991; Huron, 2006; Koelsch, 2012; Peretz, 2006; Sloboda, 1985), language and music (Patel, 2008; Rebuschat, Rohrmeier, Hawkins, & Cross, 2011), computational and technological perspectives (Hardon & Purwins, 2009), and the neuroscience of music (Ashley et al., 2006; Avanzini, Faienza, Lopez, Majno, & Minciacchi, 2003; Avanzini, Lopez, & Koelsch, 2006; Dalla Bella et al., 2009; Peretz & Zatorre, 2003; Spiro, 2003). In addition, the comprehensive introduction to cognitive neuroscience by Baars and Gage (2010) contains an entire section on music perception.

However, although it appears very early in the history of cognitive science and has grown rapidly in recent years, music cognition is still sometimes regarded as a peripheral phenomenon compared with the study of language, vision, planning, reasoning, or problem solving. This may partly originate from a view that ''[as far as biological cause and effect are concerned] music is useless'' (as famously stated by Pinker, 1997, p. 528) and also perhaps because its complex structure (or at least the language used to describe it) is less accessible to those without training (compared with language and visual perception). However, there are many reasons to think that music is a fundamental feature of human cognition, a perspective which is emphasized and elaborated by the contributions appearing in this issue of *Topics in Cognitive Science*.

The links between music and the cognitive sciences are manifold, but three factors make music an important topic for cognitive scientific research. First, there is an increasing understanding that music is a universal human trait, which plays crucial roles in everyday life and at different stages of life. Second, music has an important part to play in ontogenetic development and is also thought to play a major role in human evolution (of language, in particular). Third, from the perspective of studying the human mind, the cognitive processing of music simultaneously engages most of the perceptual, cognitive, and emotional processes that we (as cognitive scientists and neuroscientists) are interested in (see also Zatorre, 2005, stressing this point), rendering it an ideal object for the study of domain-general temporal and emotional processing, as well as motor activity and interaction. In the sections below, we elaborate on these points in proposing an integrated status for music cognition in the *Cognitive Sciences* and finally reflect on changes with respect to big questions in the field.

1.1. Music as fundamental, universal, and ubiquitous human trait

Like language, music is a universal human trait existing in all cultures across the world. Despite huge diversity, ''every known human society has what trained musicologists would recognize as 'music''' (Blacking, 1995, p. 224; see also Bohlman, 1999; Wallin, 1991). Music has fulfilled many different functions at different points in time in Western and non-Western societies. As an important part of everyday life in many of these cultures and despite immense cross-cultural variety (Bohlman, 1999), it serves functions of social bonding, emotional (self-) regulation, mother–infant interaction, healing, and religious ritual, as well as aesthetic experience (cf. Cross & Woodruff, 2009; Cross, 2008; Cross, 2011a,b;

Sloboda, O'Neill, & Ivaldi, 2001). All of these functions employ the ability of music to induce and alter psychological states (Juslin & Laukka, 2004; Laukka, 2007); to elicit strong emotions and regulate attention, emotion, and mood; and to enhance cognitive and physical performance and well-being (MacDonald, Kreutz, & Mitchell, 2012). The ubiquity of music and extent to which it is ingrained in our cultures and daily lives makes it a fundamental aspect of everyday cognition. In Western cultures, music is used in dozens of ways (DeNora, 2000; Sloboda et al., 2001). People spend a large proportion of their time listening to music (Ter Bogt, Mulder, Raaijmakers, & Gabhainn, 2011), and in Britain, adults were in the presence of music 39% of the times they were randomly probed via their mobile phones (North, Hargreaves, & Hargreaves, 2004). As noted by Huron (2001a, p. 51), ''music may not be more important than sex, but it is arguably more expensive, and it is certainly more time consuming.'' In spite of some proto-musical behaviors and abilities in nonhuman species (e.g., Bispham, 2006; Bregman, Patel, & Gentner, 2012; Fitch, 2006; Patel, Iversen, Bregman, & Schulz, 2009; Schachner, Brady, Pepperberg, & Hauser, 2009), genuine engagement in musical creation and appreciation appears to be a uniquely human trait. The fact that it is ubiquitous, powerful, and ancient, and specifically human suggests that music may have evolutionary foundations.

1.2. The evolutionary and developmental role of music

According to Cross (1999), one of the most important contributions of research on music to the *Cognitive Sciences* is the prospective role of music in human evolution, shaping human interaction, social structures, and human cognition. Apart from well-established research on processing, learning, and development, interest in music and evolution has triggered a growing body of theoretical and empirical research in recent years.

Various hypotheses have been proposed about the adaptive functions of music but, given the difficulty of subjecting these to empirical testing, we must be careful not to degenerate into post hoc telling of ''just-so'' stories (Fitch, 2006). Therefore, perhaps a conservative default position is that music is a spandrel exapted from a collection of abilities, that is, originally adapted for other reasons or else that it originated through other mechanisms of biological evolution, such as genetic drift, not entailing any adaptive function (cf. Gould & Lewontin, 1979). Pinker (1997) famously suggested that music is ''auditory cheesecake'': a by-product of cognitive and behavioral ''technology'' adapted for language in the same way that preference for cheesecake reflects an evolved preference for fats and oils that were advantageous in the moderate quantities naturally occurring in nuts and seeds (but are disadvantageous in the unlimited quantities available in Western cultures today). In this context, Honing (2011a, p. 11) argues for a different perspective:

> Pinker's idea may actually be a very fruitful hypothesis, whose significance has wrongfully gone unacknowledged because of all the criticism it elicited. After all, the purely evolutionary explanations for the origins of music largely overlook the experience of music we all share: the pleasure we derive from it, not only from the acrobatics of making it but also from the act of listening to it.

Even if musical behaviors were shaped directly by evolutionary forces, Huron (2001a; Huron, 2012) points out that evolutionary study of music is sometimes hampered by the fact that current uses of music may not correspond to the selection pressures that originally favored proto-musical behaviors.

These reservations notwithstanding, music has several characteristics that are indicative of it being an ''evolutionarily adaptive behaviour'' (Cross, 2011a,b) subject to direct selective pressures (Cross, 2011a,b; Cross & Morley, 2009). It is an ancient (the earliest archeological evidence being bone and mammoth-tusk ivory pipes dating to before 42.000 BP; Conard, Malina, & Münzel, 2009; Higham et al., 2012) and cross-culturally universal trait (see above; Blacking, 1995) which, across cultures, is viewed as emotionally expressive (Feld, 1984) and possesses a powerful ability to trigger emotions and alter psychological states (Juslin & Västfjäll, 2008; Juslin & Sloboda, 2010; Fritz et al., 2009).

What selection pressures might have conferred an evolutionary advantage on (proto-) musical behaviors? One venerable proposal is that musical virtuosity (being costly and rare—an ''honest'' signal) may have evolved, like bird song, through sexual selection to support mate choice (Darwin, 1871; Miller, 2000, 2001). Other scholars have argued that an adaptive function for music might be found in its effects on ontogenetic development, including emotional development; the acquisition of communication, bonding, social interaction, and play; learning of empathy and social competence (Cross, 2008; Rabinowitch, Cross, & Burnard, 2012); and cognitive development (cf. Schellenberg, 2005, 2012; see also Stalinski & Schellenberg, 2012). For example, it has been argued that music evolved due to selective pressure for mother–infant interaction (Dissanayake, 2000, 2008; Papousek, 1996a,b; Roederer, 1984), playing an important role in emotional bonding and the acquisition of speech perception. Another suggestion is that due to the sheer number of cognitive processes involved in music production, interaction, and perception (cf. Alluri et al., 2011), music might play an adaptive role in human cognitive development (Cross, 1999, 2007), facilitated by increasing altriciality in the hominin lineage (Cross, 1999, 2008). In a similar context, Honing and Ploeger (in press) discuss the (pitfalls and) prospects of studying music as an adaptation and argue that at least two seemingly trivial musical skills may be considered fundamental to the evolution of music: relative pitch and beat induction (see also the contributions by Marcus, Cross, Stevens, and Huron in this issue).

It has also been argued that music facilitates social cohesion within groups using its immediate but vague aboutness, which Cross (2005) termed ''floating intentionality,'' to communicate emotional meaning and potential associations immediately and to many people at once (Kopiez, 2002; Roederer, 1984). For instance, in a brief TV commercial, an electric rock guitar sound immediately conveys a sense of freedom to individuals sharing a cultural understanding of this music. It is immediately recognizable yet at the same time anything but specific. The use of a regular cyclical pulse in many musics (cf. London, 2004) is a powerful way of influencing social interactive behavior and providing social ''glue'' by enabling performers and audiences to focus their attention on specific temporal locations (Jones & Boltz, 1989) and affording coordination and entrainment of behaviors such as dance (Clayton, Sager, & Will, 2005). Entrainment further constitutes a key element in social interaction and social cognition (Konvalinka, Vuust, Roepstorff, & Frith, 2010;

Macrae, Duffy, Miles, & Lawrence, 2008; Miles, Nind, & Macrae, 2009; Valdesolo & DeSteno, 2011). Lastly, music contributes to the establishment and maintenance of social structures and relations (see, e.g., Marett, 2005) and may act as a mnemonic device to maintain community knowledge (Dissanayake, 2008; Sloboda, 1985).

Finally, there is an ongoing debate about the evolutionary relationships between music and language, reflected in their cognitive relationships (e.g., Cross, 2011a,b; McMullen & Saffran, 2004; Patel, 2008; Rebuschat et al., 2011). Although it has been argued that language precedes music (Spencer, 1858) or that music precedes language (Darwin, 1871; Mithen, 2005), recent theories suggest a common *musilanguage* precursor (Brown, 2000) or their coevolution as ''components of a generalised human communicative toolkit'' (Cross, 2011a,b). In the same spirit, it has been argued that forms of meaning conveyed by language *other than propositional semantics* are largely shared with music (Cross & Woodruff, 2009; Patel, 2008; Reich, 2011; Hanslick, 1854). Although music and language differ in several respects (e.g., the role of dialog, communication, and specificity of meaning), the communication of features such as emotions, attitudes, social status, and relations appear to share similar means of expression (e.g., prosody). These overlaps suggest dependent evolutionary and developmental origins.

1.3. Music as complex cognitive system

Western and non-Western cultures have developed musical forms of stunning variety and complexity, which engage a multitude of cognitive processes in perception, production, and interaction. This remarkable cross-cultural, historical, and social variety (Bohlman, 1999) may even exceed variability in language. Beyond its role in evolution, social interaction, and development, this richness makes music an excellent case for studying human cognition, as well as the interaction of processes at different levels in a multitude of different domains (cf. Koelsch, 2012; Zatorre, 2005). Music perception involves the cognition of complex and parallel temporal processes that combine local and hierarchical structures at multiple levels of organization (cf. Koelsch, 2010; Levitin & Tirovolas, 2009) according to the syntax of a style. In many ways, music is as complex as language (see below), yet the absence of an explicit, referential semantics makes it an ideal object for studying complex cognitive processing in a self-contained way without considering the complexities of propositional meaning. Musical listening, performance, and interaction involve a wide range of cognitive functions and processes, including auditory scene analysis, streaming, attention, learning and memory, formation of expectations, multimodal integration, recognition, syntactic processing, processing of forms of meaning, emotion, and social cognition. As a result, Koelsch (2012, p. x) further remarks that

> Music psychology inherently covers, and connects, the different disciplines of psychology (such as perception, attention, memory, language, action, and emotion) and is special in that it can combine these different disciplines in coherent, integrative frameworks of both theory and research.

To substantiate these arguments, we briefly outline some exemplary cognitive functions and processes involved in music processing.

1.3.1. Auditory scene analysis, stream segregation and integration, and grouping

Sound events are processed in cognition with respect to sources, streams, and locations, that is, with respect to components of the auditory scene (Bregman, 1990). For example, simultaneously sounding elements may either fuse into a single percept or segregate into distinct perceptual streams (Huron, 2001b) processed in parallel over time. In addition, as with the components of visual scenes, sequential musical elements are grouped into larger objects in a variety of ways (Deliège, 1987; Deutsch, 1999; Bregman, 1990). Boundaries are identified through the perception of points of segmentation between adjacent groups (Pearce, Müllensiefen, & Wiggins, 2010; Temperley, 2001).

1.3.2. Signal processing, perception of pitch, and time

The perception of complex musical structure as well as meaning and emotion requires the cognitive system to extract from the acoustic signal features such as pitch, timbre, timing (rhythm, meter, and tempo), stress and accent, loudness, and spatial location. Each of these features themselves involves complex higher order organization at different levels: Pitch structure is perceived and represented in a multidimensional space (Cross, 1997, 1998), allowing for several types of similarity relations between pitches (Shepard, 1982) including chroma, height, pitch interval, contour, and tonal relations. Music processing is further grounded on beat induction and entrainment affording for temporal attention and rhythmic coordination, as well as social cognition (Clayton et al., 2005; Honing, 2012; London, 2004; see above). There is an ongoing debate on the extent to which pitch and temporal structure are processed independently (Boltz, 1999; Jones, Moynihan, MacKenzie, & Puente, 2002; London, 2004; Palmer & Krumhansl, 1987). However, temporal predictions related to musical meter are known to engage neural regions involved in motor planning and execution, which suggest a interactive process of perception and action (Grahn & Brett, 2007; Grahn, 2012).

1.3.3. Pitch distributions and transitions

Musical pitch exhibits nonuniform frequency distributions termed ''tone profiles'' (Krumhansl, 1990) that are characteristic of Western tonal music and other musics, such as North Indian music (e.g., Castellano, Bharucha, & Krumhansl, 1984). Short pitch sequences in turn exhibit characteristics that trigger specific patterns of implication and realization (Narmour, 1990, 1992; Schellenberg, 1996; also involving closure). Regularities in patterns of pitch sequences are acquired through implicit learning (Rohrmeier, Rebuschat, & Cross, 2011; Rohrmeier & Rebuschat, 2012; Huron, 2012) and afford the generation of expectancies (Pearce & Wiggins, 2006, 2012; Pearce, 2011; Rohrmeier & Koelsch, 2012).

1.3.4. Tonal centers, keys, chords, and harmonic syntax

In contrast to other musics, Western tonal music additionally exhibits systematic organization of pitches by keys (i.e., stable pitches established as tonal center of reference with respect to other pitches; ''tonal music'' refers to music having a tonal center) and chords (simultaneous sets of pitches). At another level of organization, keys may change dynamically (''modulation'') and in specific key sequences according to various kinds of musical form (e.g., Caplin, 1998). Chords may in turn act as entire building blocks (from a specific repertoire or alphabet) in Western tonal music. On a local level, chords prime specific chord continuations (Bharucha & Stoeckig, 1986; see Tillmann, 2006; for a review). At a level beyond local structure, pitch, and harmony in Western music they embody a complex recursive hierarchical structure, which resembles the structure of language syntax (cf. Johnson-Laird, 1991; Lerdahl & Jackendoff, 1983; Rohrmeier, 2007, 2011; Steedman, 1984, 1996) and shares neural processes with language (Koelsch, 2012; Patel, 2003, 2008).

1.3.5. Recursive processing

Several aspects of music have been argued to require recursive processing, making a major contribution to the debate concerning recursion as a core human faculty of language or cognition (cf. Hauser, Chomsky, & Fitch, 2002; Jackendoff, 2011). These include grouping structure (by analogy to words, phrases, and sentences in spoken language), metrical structure, pitch (or voice-leading), and harmony (Lerdahl & Jackendoff, 1983; Rohrmeier, 2011; Schenker, 1935), although some of these are debated (e.g., London, 2004; Tymoczko, 2011).

1.3.6. Attention, learning, and memory

Processing all of these levels of structure requires learning of relevant relations between musical elements and the ability to maintain in memory features of specific musical pieces, musical cues, and schemata, as well as generalized properties of musical styles (Deliège, 1996, 2001; Deliège, Mélen, Stammers, & Cross, 1996; Halpern & Bartlett, 2010; Koelsch, 2012; Snyder, 2000). In addition, musical structure generates patterns of salience that guide attention toward significant events in time (e.g., Jones & Boltz, 1989; Large & Jones, 1999). Furthermore, attentive listening to music has been found to recruit brain regions involved in general processes of working memory and attention rather than relying on regions that are specific to musical processing (e.g., Janata, Tillmann, & Bharucha, 2002).

1.3.7. Emotion and meaning

The broad range of emotional effects of music arises from cognitive processing at all the levels of complexity mentioned above (cf. Huron, 2006; Juslin & Sloboda, 2010; Koelsch, 2012). Meaning in music appears at various levels of structural organization and complexity, carrying a variety of forms of expression (Cross, 2005; Juslin & Västfjäll, 2008; Koelsch, 2011a). Although musical structures may refer to external entities (objects, relations, actions, psychological states, etc.), it is different from language in that it does not possess an explicit referential semantics (see for discussion, e.g., Koelsch, 2011a,b; Slevc & Patel, 2011; Reich, 2011; Hanslick, 1854).

1.3.8. Cross-modal cognition

From a broader perspective, music is frequently combined with performative, visual, interactive ritual, or dance elements (in many cultures the concepts ''music'' and ''dance'' are inseparable) and therefore goes well beyond the auditory domain. Examples of such activities include sight reading from a score, singing along to a song, transcribing a performance, and dancing to music. Musical behaviors such as these often involve perception–

action loops and interactions with processing of information in other modalities, including color vision (Ward, Huckstep, & Tsakanikos, 2006; Ward, Tsakanikos, & Bray, 2006), and even taste and olfaction (Crisinel & Spence, 2010a,b, 2011).

Together, the factors outlined above underpin the fundamental role of music in human cognition and the cognitive sciences. The contributions in this issue of *topiCS* flesh out many of the current issues in evolution, development, learning, processing, modeling, music and language, and cross-cultural music cognition, and raise themes that are closely interconnected. Honing and Ploeger provide a perspective on the role of music in human evolution. They argue that ''musicality'' (distinguished from music) constitutes a natural, spontaneously developing trait upon which music is based and consider accumulative evidence to understand musicality as an adaptation. In a similar context, Marcus discusses the extent to which musical behavior is acquired or instinctive. Stalinski and Schellenberg review musical development with a nuanced perspective on general cognitive abilities and cross-cultural differences.

The link between learning and processing on simple and more complex levels of structure is the focus of three contributions: Rohrmeier and Rebuschat review the picture presented by current experimental and computational evidence about implicit learning of musical structure. In an experimental study that relates to a series of previous experiments, Loui explores statistical learning of a new musical system. Pearce and Wiggins present a comprehensive review of their modeling of auditory expectation with a computational model of probabilistic learning and discuss integrative and higher order models of music cognition. In contrast, to many modeling approaches that are focused on structural processing, Eerola provides a perspective on computational models of musical emotion and discusses his own research in this exciting new area. Tillmann reviews research on priming, expectancy, and potential shared resources between music and language processing. Finally, Grahn provides an overview of neural mechanisms of rhythm perception and the benefits of neuroscientific research methods in this area.

Music varies enormously within and between cultures and, from this perspective, Stevens surveys music cognition from a cross-cultural perspective and discusses shared cognitive processes, emotion, and links between music and language. In a similar context, Cross provides a detailed discussion of the pervasive influence of Westernized views of music on music cognition research and identifies the issues that need to be addressed by general, cross-cultural research on music. Finally, Huron provides a critical discussion of key challenges in theories of statistical learning and musical evolution.

2. Challenges in music cognition

The contributions in this volume of *topiCS* reflect the state of the art and many of the present challenges in the field of music cognition. Therefore, we will close this introduction by taking the opportunity to reflect on how the challenges in the field have changed. In 2006, the 100th volume of *Cognition* featured a set of special articles about music cognition. Inspired by Hauser et al. (2002) and Pinker and Jackendoff (2005), a contribution by Jackendoff and Lerdahl (2006) posed five central questions about the human capacity for music drawing on a close analogy with the human faculty of language.

> Q1 (Musical structure): When a listener hears a piece of music in an idiom (or style) with which he/she is familiar, what cognitive structures (or mental representations) does he/she construct in response to the music?
>
> Q2 (Musical grammar): For any particular musical idiom MI, what are the unconscious principles by which experienced listeners construct their understanding of pieces of music in MI (i.e., what is the musical grammar of MI)?
>
> Q3 (Acquisition of musical grammar): How does a listener acquire the musical grammar of MI on the basis of whatever sort of exposure it takes to do so?
>
> Q4 (Innate resources for music acquisition): What preexisting resources in the human mind/brain make it possible for the acquisition of musical grammar to take place?
>
> Q5 (Broad vs. narrow musical capacity): What aspects of the musical capacity are consequences of general cognitive capacities, and what aspects are specific to music?
>
> (Jackendoff & Lerdahl, 2006, pp. 34–36)

It is notable that most of these questions refer to the perception of music by an individual, focus exclusively on cognitive processing (to the exclusion of emotional processing), and reflect Western perspectives on music. In recent years, music cognition research has established a number of directions that broaden such a perspective and forge new research agendas. This change of perspective parallels, in some respects, changing views on (computational) modeling: Although Marr's (1982) influential three levels of modeling (computational, algorithmic, and physical) center around the individual, recent views on cognitive modeling extend beyond the individual. Sun, Coward, and Zenzen (2005), for example, propose levels of modeling that explicitly include a social-level and an agent-level analysis (as well as levels within an individual agent: modules and architecture of modules). Other trends in music cognition research include a focus on affective processes in musical appreciation and production, increasing interest in evolutionary accounts of musical behavior and efforts to generalize existing theoretical and empirical findings to the musics of non-Western cultures. In Table 1, we attempt to summarize some of the key questions and themes we see reflected in these new developments in the field.

Many of these current challenges are specifically addressed by the contributions to this special issue of *Topics in Cognitive Science*, which we believe reflects the current research trends driving forward our understanding of music as a cognitive capacity. Music has fascinated cognitive scientists since the birth of the discipline because of the rich and multifaceted ways in which music is interwoven with virtually every aspect of human cognition. Some 40 years on, music cognition has become firmly established as a discipline within the cognitive sciences.

Table 1
Current challenges and research themes in music cognition with links to related articles in this issue

Structural/theoretical	Cognition	Emotion	Interactive	Evolution
What are the principles of structure building according to which music is organized? (*) Are there shared features, principles, or cognitive mechanisms in music across cultures? (3, 10, 11) Which features and principles of structure building does music share with language? (8) To what extent and how are principles of structure building mentally represented? (4, 6, 8) Which forms of meaning does music employ? (*) How can we explore music and music cognition in meaningful and unbiased ways? (10, 11, 12)	Which domain-specific and domain-general cognitive modules are involved and interact in music cognition? (1–12) Which features of music cognition are innate or acquired? (1, 2, 3, 4, 5, 6, 8, 10, 12) To which extent do implicit statistical learning theories account for music perception? (3, 4, 5, 6, 8, 10, 12) How does the brain process and integrate the different levels of structure (as in auditory, temporal, rhythm, tonality, syntax, emotion, multiple simultaneous streams)? (6, 7,8, 9) Can we build an overarching model incorporating learning, perception, cognition, emotion, and action? (4, 6, 7)	How (and why) do musical features trigger emotions? (6, 7) How do processes involved in musical emotions develop? (3) Which processes and brain mechanisms are involved in musical emotions? (*)	How do humans synchronize with each other and the music in perception, production, and dance? (*) (How) does music enhance social cognition and social bonding? (*)	Why do humans have music? (1, 2, 10, 11, 12) What is the role of music in human evolution? How did music evolve? z(1, 2, 11, 12) How do the evolution of music and language interact? (1, 2)

1—Honing amd Ploeger	4—Rohrmeier and Rebuschat	10—Stevens
2—Marcus	5—Loui	11—Cross
3—Stalinski and Schellenberg	6—Pearce and Wiggins	12—Huron
	7—Eerola	*—Questions that are not addressed in detail in this issue of *topiCS*
	8—Tillmann	
	9—Grahn	

Note

1. *See also http://musiccognition.blogspot.de/2011/10/history-of-music-cognition.html and Honing (2011b)*

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