

Revisão

Brain and the music: A window to the comprehension of the interactive brain functioning

Música e cérebro: Uma janela para o entendimento do funcionamento interativo do cérebro

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Abstract

Here we review the most important psychological aspects of music, its neural substrates, its universality and likely biological origins and, finally, how the study of neurocognition and emotions of music can provide one of the most important windows to the comprehension of the higher brain functioning and human mind. We begin with the main aspects of the theory of modularity, its behavioral and neuropsychological evidences. Then, we discuss basic psychology and neuropsychology of music and show how music and language are cognitively and neurofunctionally related. Subsequently we briefly present the evidences against the view of a high degree of specification and encapsulation of the putative language module, and how the ethnomusicological, pscychological and neurocognitive studies on music help to shed light on the issues of modularity and evolution, and appear to give further support for a cross-modal, interactive view of neurocognitive processes. Finally, we will argue that the notion of large modules do not adequately describe the organization of complex brain functions such as language, math or music, and propose a less radical view of modularity, in which the modular systems are specified not at the level of culturally determined cognitive domains but more at the level of perceptual and sensorimotor representations. © Cien. Cogn. 2011; Vol. 16 (1): 137-164.

Keywords: music; language; modularity; brain; evolution; cognition.

Resumo

Aqui revisamos os aspectos psicológicos mais importantes da música, seus substratos neurais, sua universalidade e prováveis origens biológicas e, finalmente, como o estudo da neurocognição e das emoções associadas à música pode fornecer uma das mais importantes janelas para a compreensão das funções cerebrais superiores e da mente humana. Iniciamos com os principais aspectos da teoria da modularidade, suas evidências comportamentais e neuropsicológicas. Então discutimos a psicologia e a neuropsicologia básicas da música e mostramos como a música e a linguagem estão cognitiva e neurofuncionalmente

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interrelacionadas. Em seguida, apresentamos brevemente as evidências contrárias à visão de um alto grau de especificação e encapsulamento do módulo putativo da linguagem e como os estudos etnomusicológicos, psicológicos e neurocognitivos sobre música auxiliam na elucidação dos temas modularidade e evolução e parecem fornecer subsídios adicionais para uma visão interativa e intermodal dos processos neurocognitivos. Finalmente iremos argumentar que a noção de amplos módulos não descreve adequadamente a organização de funções cerebrais complexas, como a linguagem, a matemática, ou a música. Propomos uma visão menos radical de modularidade, na qual os sistemas modulares são especificados não ao nível de domínios cognitivos culturalmente determinados, e sim mais ao nível de representações perceptuais e sensoriomotoras. © Cien. Cogn. 2011; Vol. 16 (1): 137-164.

Palavras-chave: música; linguagem; modularidade; cérebro; evolução; cognição.

1. Introduction

Nowadays, the principles of natural and sexual selection are being used to guide theoretical and empirical research in the behavioral and social sciences with increasing frequency, and nearly all of this research has focused on social behavior, cognitive mechanisms, and other phenomenon that are thought to be evolved as universal adaptations, such as features of human behavior that are evident in all cultures as, for instance, language (Geary, 2001). Here, the core idea is that some current behaviors are universally present in the human cultures because it would have been evolutionary efficacious. From the perspective of evolutionary psychology, natural selection shapes species to their environment not only in physical and physiological traits but also in behavioral traits, and any trait that has evolved with time is likely to be distributed universally, to be found in immature members of the species, and to be processed with some degree of automation.

Consider language as an example. All languages sum approximately 150 different phonemes, but each human languages contain about 25 to 40 phonetic units, varying from 11 in Polynesian to 141 in the language of the Bushmen (Pinker, 1994), and for any given language all speakers distinguish between grammatical and ungrammatical sentences without any formal instruction, suggesting universal linguistic principles defining sentence structure. This led Chomsky to conclude that children have implicit knowledge of both phonemes and abstract grammatical rules, the latter assumed to be a very general kind allowing them to learn whichever language they are exposed to, rather than just learning by imitating the language they hear (Chomsky, 1957). Thus, language was one of the primary examples of what Fodor (1983) called a mental module in his theory of modularity of mind, where a module is described as domain-specific (only activated by language-specific information), informational encapsulated (do not interfere with other modules), and innate.

In addition to the anthropological (universalities) and behavioral/psychological evidences, the modular approach of mind is further supported by neuropsychological cases. Brain lesions causing impairments in one domain while sparing others, and selective congenital deficits in one domain in the presence of otherwise completely normal cognitive functions have been taken as a strong support for domain-specific neural networks of some cognitive domains, particularly language, and more recently also number processing (Dehaene, Dehaene-Lambertz & Cohen, 1998) and music (Dalla Bella & Peretz, 1999; Peretz & Coltheart, 2003). Evolutionary psychologists have incorporated with much enthusiasm the hypothesis that some cognitive mechanisms and its respective neural substrates can be viewed as individual traits that have been subject to selection and perfected in recent human evolutionary history. In their view, some cognitive mechanisms involved in language, or mathematics, would be a highly complex and specific adaptation evolved with admirable

effectiveness, have a genetic component and, finally, have no parallel in nonhuman animals (Geary & Huffman, 2002). In this perspective, although homologous mechanisms may exist in other animals, the human versions have been modified by natural selection to the extent that they can be reasonably seen as constituting novel traits (*e.g.*, social intelligence, toolmaking) (Bickerton, 1990; Dunbar, 1996; Kimura, 1993; Lieberman, 1984).

However, a strong modular view, predominant in the evolutionary psychology, is not a consensus in the field of cognitive neuroscience. Both lesion (Dominey & Lelekov, 2000; Keurs, Brown, Hagoort & Stegeman, 1999), imaging (Bookheimer, 2002; Koelsch, *et al.*, 2002; Koelsch *et al.*, 2004), and developmental (Bishop, 1999) studies do not unequivocally support the idea that language is an autonomous function relying on its own encapsulated structural and functional architecture. In addition, to make the claim that a trait evolved uniquely in humans for the function of language processing, it must be demonstrated that no other animal has this particular trait, because any trait present in nonhuman animals did not evolve specifically for human language, although it may be part of the language faculty and play an intimate role in language processing. In this respect, recent studies have shown that the sensory-motor and conceptual intentional systems believed to be language-specific are also present in non-human animals (Gil-da-Costa *et al.*, 2004; Hauser, Chomsky & Fitch, 2002).

An alternative view is the interactive approach where cognitive outcomes arise from mutual, bidirectional interactions among neuronal populations representing different types of information, and many primary brain areas (e.g., primary visual or auditory cortices) appear to participate in the representation of the global structure of a stimulus or response situation, and these brain areas that are treated as modality specific can be modulated by influences from other modalities (McClelland, 2001). The discovery of various cross-modal interactions in recent years suggests that these interactions are the rule rather than exception in human perceptual processing (Macaluso & Driver, 2005), and even the visual modality, which has long been viewed as the dominant modality, has been shown to be affected by signals of other sensory modalities (Foxe & Schroeder, 2005; Murray et al., 2005; Saint-Amour, Saron, Schroeder & Foxe, 2005; Schroeder & Foxe, 2005; Shams, Iwaki, Chawla & Bhattacharya, 2005; Shimojo & Shams, 2001). Thus, in place of the notion that complex brain functions such as language, math or music, are organized in specific and encapsulated large modules, we present a less radical view of modularity, in which the modular systems are domainspecific not in terms of encapsulation, but in terms of functional specializations for their crucial relevance for a particular domain (Barret & Kurzban, 2006).

Since music is a stimulus involving complex auditory and motor patterns and representations, and also has an enormous power in generating complex emotions and abstract moods, we believe that its study offers a suitable window to understand the higher cognitive functioning of the human brain and to observe and to evaluate the extent up to which the brain has a modular organization.

2. Basic sensory-perceptive and cognitive aspects of music and language

Music, like verbal language, is based on the intentionally structured patterns of pitch, duration and intensity. Both domains are composed of sequences of basic auditory events, namely, phonemes (vowels and consonants) in language and pitches (melody and chords) and percussive sounds in music.

The 'pitch' in language (determined mainly by the trajectory of fundamental frequency (f_0) of the vowels) originates the intonation of speech that contributes to mark the boundaries of structural units, distinguishes pragmatic categories of utterance and conveying

intentional and affective cue (Patel, Peretz, Tramo & Labreque, 1998). However, perception of the rapid acoustic transitions, i.e. noise bursts or formant transitions between consonants and vowels and vice-versa, within the range of tens of milliseconds have been empirically shown to be the crucial aspect for the discrimination of phonemes in language. For instance, when the spectral information is greatly reduced in artificially degraded speech, but with temporal variations preserved, adult listeners and 10 to 12 years old children are still able to recognize speech, although younger children of 5 to 7 years old required significantly more spectral resolution. Thus, spectrally degraded speech with as few as two spectral channels still allows relatively good speech comprehension, indicating that the perception of temporal changes is more relevant for speech than the spectral cues (Eisenberg, Shannon, Martinez, Wygonski & Boothroyd, 2000; Shannon, Zeng, Kamath, Wygonski & Ekelid, 1995).

Conversely, the primary acoustic cue in music is the trajectory of fundamental frequency (f_0) of pitches of the musical notes. Despite the importance of rapid temporal succession of tones to musical phrasing and expression, the gist of musical content relies on the succession of pitches, and the time intervals between them in music are normally greater than in language. However, it is difficult to precisely determine the time intervals common to music, as it greatly varies between musical styles and cultures. Zatorre, Belin e Penhune (2002) have noted that musical notes are typically much longer in duration than the range characteristic of consonant phonemes, what is definitely true, and that melodies with note durations shorter than about 160 ms are very difficult to identify. In sum, the gist is that the interval times between the notes in the musical rhythms as well the suprasegmental rhythm in language (Phillips & Farmer, 1990).

Cross-culturally, music involves not only patterned sound, but also overt and/or covert action, and even 'passive' listening to music can involve activation of brain regions concerned with movement (Janata & Grafton, 2003): it is not a coincidence that semantically speaking music is, unlike language, both embodied (involving not only sound but also action) and polysemic (mutable in its specific significances or meanings) (Cross, 2001; Cross, 2003b). Developmental precursors of music in infancy, and through early childhood, occur in the form of universal proto-musical behaviors (Trevarthen, 2000) which are exploratory and kinesthetically embedded and closely bound to vocal play and to whole body movement, and are universal. This leads some cultures to employ terms to define music that are far more inclusive than the western notion of music, like the word nkwa that for the Igbo people of Nigeria denotes "singing, playing instruments and dancing" (Cross, 2001). Music functions in many different ways across cultures, from a medium for communication (the Kaluli of Papua New Guinea used music to communicate with dead members), for restructuring social relations (the Venda tribes use music for the domba initiation), to constitute a path to healing and establishing sexual relationships (Tribes in northwest China play the 'flower songs', hua'er) (Cross, 2003b). Thus, music is a property not only of individual cognitions and behaviors but also of inter-individual interactions. Developmental studies give further support for the notion that music is embodied.

Based on these arguments, we consider a re-definition of music in terms of both sound and of movement and their relationships between them (Cross, 2001, 2003a, 2003b). Here, music is defined as a sound-based, embodied, non-referential and polysemic form of communication whose content is essentially emotional, built on the organization of sounds in two main dimensions, pitch and time.



3. Music, evolutionary psychology, and modularity

Some theorists (Pinker, 1994; Pinker, 1999) see no adaptive role for human musicality in evolution because it has no evident and immediate efficacy or fixed consensual reference (but see (Cross, 2001)). Unlike language, music is not referential: musical sounds do not refer to another object external to it, be it concrete or abstract, what led to the precipitous conclusion that music does not have an obvious adaptive value. However, this notion contrasts with the fact that neuropsychological, developmental and anthropological evidences are as strong for modularity of music as that for modularity of language, including the isolation of dedicated neural circuits in lesions and congenital musical deficits (Andrade & Bhattacharya, 2003; Peretz & Hebert, 2000; Trehub, 2003). Briefly, it includes double dissociation between music and language as well as selective impairments of musical subfunctions, congenital deficits specific to musical ability called congenital amusia (in which the most basic musical abilities are lacking, such as recognition of pitch changes and discrimination of one melody from another, despite intact intellect and language skills), universality of common features across different music styles and cultures, in the principles underlying melody, consonant/dissonant intervals, pitch in musical scales and metre and, finally, infants' musical abilities are similar to that of adults in the processing of melody, consonance and rhythms.

4. Music cognition and modularity

Cognitively speaking, the pitch and temporal dimensions in music can be separated. The pitch dimension itself can be viewed under three distinct, although related, aspects: (i) the pitch direction that contribute to global pitch contour of the melody, (ii) the exact pitch distance between the notes that define the local musical intervals, and, (iii) the simultaneous combination of pitches that forms the chords. We can recognize melodies just by the global perception of its pitch contour, being the local interval analysis dispensable in this global task. The local interval analysis, in turn, is crucial to discriminate short melodies (motifs) with same contours, differing only by one note, in the construction and discrimination of scales (a particular subset of unidirectional sequences of pitches- equal contours), and, finally, in the appreciation and analysis of chords, once they are "vertical" structures that do not have a contour, and differentiate from each other in its interval structure.

On the pitch dimension we focus specifically on melody, defined as successive combination of tones varying in pitch and duration, because it is a universal human phenomenon that features prominently in most kinds of music around the world and can be traced back to prehistoric times (Eerola, 2004).

An early source of evidence for the modular view of language and music has been provided by the clinical cases of auditory agnosia. Amusias consist in an intriguing subtype of auditory agnosia selective for music, preserving perception and recognition of verbal and environmental sounds. Amusias can be divided in apperceptive (recognition is impaired by deficits in perception) and associative (recognition is impaired despite of intact perception) musical agnosia (or amusia), according to the terminology offered by Lissauer (1889). In short, we can say that music perception and recognition systems, in contrast to language, which is predominantly processed in left perisylvian cortex (frontotemporoparietal areas around Sylvian fissure), but almost mirroring it, rely mainly in right frontotemporal regions whose lesions are associated with selective impairments in music perception and/or recognition sparing language (Dalla Bella & Peretz, 1999; Peretz & Coltheart, 2003).

Gigneias Oognição

In the temporal organization, researchers have agreed on a conceptual division between the global meter and the local rhythm in music (Drake, 1998). Meter is the global perception of a temporal invariance of recurrent pulses, providing durational units by which we recognize a march (major accent on the first of two beats) or a waltz (major accent in the firs of three beats), and functioning as a "cognitive clock" that allow us to evaluate the exact duration of auditory events (Wilson, Pressing & Wales, 2002). Rhythm is the local perception of the temporal proximity, or clustering of adjacent auditory events that form larger units. This temporal grouping that leads to rhythm perception can occur solely on the basis of the estimation of note duration and, hence, does not require the exact evaluation of the note duration through the meter (Penhune, Zatorre & Feindel, 1999; Wilson *et al.*, 2002).

The existence of distinct local and global cognitive strategies in music perception, either in pitch and temporal dimensions, are supported by behavioral (Gordon, 1978; Peretz & Babai, 1992; Tasaki, 1982), neuropsychological (Liegeois-Chauvel, Peretz, Babai, Laguitton & Chauvel, 1998; Peretz, 1990; Schuppert, Munte, Wieringa & Altenmuller, 2000) and functional neuroimaging (Mazziotta, Phelps, Carson & Kuhl, 1982; Platel *et al.*, 1997) studies. According to the lesion studies, right hemisphere structures, mainly in the right superior temporal lobe (STG), are crucially involved in the fine perception of pitch variations in melody, while contralateral structures in the left hemispheres are crucially involved in the perception of rapid acoustic transitions like that occurring in the perception of consonant/vowel combinations (Zatorre *et al.*, 2002).

4.1. Evidences against modularity I: Language and music meet in pitch processing

The infant's incredible ability to virtually discriminate every phonetic contrast of all languages, initially taken as evidence for "innate phonetic feature detectors specifically evolved for speech", was also found when the stimuli are non-speech sounds that mimicked speech features, a categorical perception of phonemes also exhibited by several animal species, and monkeys, including perception of the prosodic cues of speech as well (Ramus, Hauser, Miller, Morris & Mehler, 2000). This discriminative capacity could be accounted by domain-general cognitive mechanisms rather than one that evolved specifically for language (Kuhl, Tsao, Liu, Zhang & De Boer, 2001). In addition, contrary to the modularity view which argues that linguistic experience produces either maintenance or loss of phonetic detectors, new evidences show that infants exhibit genuine developmental change, not merely maintenance of an initial ability. At 7 months, american, japanese and taiwanese infants performed equally well in discriminating between native and non-native language sounds, whereas at 11 months of age they showed a significant increase in native-language phonetic perception and a decrease in the perception of foreign-language phonemes (Kuhl et al., 2001). An emerging view suggests that infants engage in a new kind of learning in which language input is mapped in detail by the infant brain. The central notion is that by simply listening to language infants can acquire sophisticated information and perceptually "map" critical aspects of ambient language in the first year of life, even before they can speak, and this perceptual abilities are universal, but not domain specific or species specific. Further, contrary to the notion that development is based on selection and maintenance of a subset of those units triggered by language input with subsequent loss of those that are not stimulated, infants exhibit a genuine developmental change; furthermore, adults, submitted to techniques that minimize the effects of memory and extensive training, can increase their performance on non-native language phonemes indicating that there is not an immutable loss of phonetic abilities for non-native units (Kuhl, 2000).

Gincias Jognicão

Recent neuropsychological evidences show that inferior parietal and temporal regions comprising the Wernicke's area (BA22/39/40), traditionally considered as a specific language area for the processing of phonetics and semantics, was even more important for processing non-verbal than verbal sounds, suggesting that the semantic processing of auditory events, either verbal or non-verbal sounds, relies on the shared neural resources (Saygin, Dick, Wilson, Dronkers & Bates, 2003).

Finally, pitch contour and interval are also used in language (Zatorre, Evans, Meyer & Gjedde, 1992), and when impaired the deficits extend to its processing in both domains (Nicholson *et al.*, 2003; Patel *et al.*, 1998; Steinke, Cuddy & Jakobson, 2001). In fact, prosodic deficits in language previously verified in right brain-lesioned patients with amusia are also found in individuals diagnosed with congenital amusia (Ayotte, Peretz & Hyde, 2002; Hyde & Peretz, 2004). Taken together, behavior, developmental and neuropsychological data clearly confirm that brain specificity for music or language is more relative than absolute. The relative dissociation between music and language relies on the fact that speech intonation contours normally use variations in pitch that are larger than half an octave to convey relevant information, whereas mostly of melodies use small pitch intervals, of the order of 1/12 (the pitch difference between two adjacent keys on the piano) or 1/6 (the pitch difference between two keys separated by only one key on the piano) of an octave. Therefore, a degraded pitch perception system may compromise music perception but leave basic aspects of speech prosody practically unaffected. Congenital amusia are elucidative here.

In the pitch discrimination tasks, congenital amusic subjects are unable to detect a small pitch deviation in either isolated tones or monotonic and isochronous sequences, such as pitch changes lesser than two semitones (normal acuity lies in the order of a quarter of a semitone), a performance that could not be improved even under practice (Peretz et al., 2002), but they perform like controls in detecting a slight time deviation in the same contexts (Ayotte et al., 2002). It indicates that their deficits appear to reside in the pitch dimension. In contrast, pitch variations in speech are well perceived by congenital amusic individuals because they are very coarse compared to those used in music. The final pitch rise that is indicative of a question is normally larger than half an octave (the pitch distance between two notes on the piano separated by twelve keys) (Hyde & Peretz, 2004). These facts are consistent with the notion that, rather than a deficit specific to musical domain, congenital amusia reflect a more elemental problem in the low level processing of auditory information, resulting in deficits on fine-grained discrimination of pitch much in the same way as many language-processing difficulties arise from deficiencies in auditory temporal resolution (Zatorre et al., 2002). Thus, although there are claims that language impairments arise from failures specific to language processing (Studdert-Kennedy & Mody, 1995), language deficiencies may also result from a more elemental problem on the perception of fine acoustic temporal changes (Tallal, Miller & Fitch, 1993). Indeed, difficulties for processing time in its different dimensions is an amazingly universal characteristic in dyslexia, a congenital language deficit present in 5-10% of school-age children who fail to learn to read in spite of normal intelligence, adequate environment and educational opportunities, and which likely relies on the left hemisphere difficulty to integrate rapidly changing stimuli (Habib, 2000).

However it is worthy emphasizing that, jointly with congenital amusia, the existence of *associative* music agnosias in which patients cannot recognize previously familiar melodies neither detect out-of-key notes purposely inserted on melodies (tonal encoding) (Peretz, 1996; Peretz *et al.*, 1994) despite completely preserved both music perception (pith and melodic discrimination) and general linguistic abilities (including intonational prosody), both represent spectacular cases of isolation of music components in the brain whose common deficit is an impairment of the tonal encoding of pitch due to alterations in an anterior frontotemporal

network (Peretz, 2006), perhaps more due to insensitivity to dissonance than to to consonance (Peretz, Blood, Penhune & Zatorre, 2001; Tramo, Cariani, Delgutte & Braida, 2001). Congenital amusia is characterized by little sensitivity to dissonance (a sensitivity that is already present in infants) and, differently from acquired associative amusias, impaired fine-grained pitch perception, both deficits that are devastating for the development of tonal encoding and long-term musical representations, but not for the development of linguistic abilities (Hyde & Peretz, 2004). Although evidence points to shared cognitive mechanisms and neural substrates involved in the fine-grained pitch perception between music and language, there is an increasing consensus that ability is of crucial relevance only for the development of a putative *tonal module* but not for linguistic abilities (Peretz, 2006).

Taken together, these findings support the notion that at least one cognitive component of music, the tonal encoding, could be an evolved *tonal module* in a broader concept of modularity, according to which domain-specificity is better characterized in terms of a functional specialization; i.e. computational mechanisms that evolved to handle biologically relevant information in specialized ways according to specific input criteria such as fine-grained pitch perception, but "No mechanism is either encapsulated or unencapsulated in an absolute sense" (Barret & Kurzban, 2006, p. 631; see also Peretz, 2006). Therefore, although music and language appear to be clearly dissociated in functional terms at the level of fine-grained pitch perception both domains can interact in the pitch dimension.

4.2. Evidences against modularity I: Language and music can meet in rhythm

Consistently with our contention that is in the time domain where there is the most conspicuous and greater amount of sharing between language and music, the temporal deficits of dyslexic children are not confined to language but also extend to the musical domain, and in an interesting way: they are confined to temporal dimension (meter and rhythm) of music. This link between language and musical temporal deficits in dyslexic children led to a testable hypothesis of musical therapeutics based on group music lessons consisting of singing and rhythm games which, although apparently did not help reading, had a positive effect on both phonologic and spelling skills (Overy, 2003; Overy, Nicolson, Fawcett & Clarke, 2003). Children aged between 4-5 years old show that music have a significantly positive effect on both phonological awareness and reading development, and music perception skills can reliably predict reading ability (Anvari, Trainor, Woodside & Levy, 2002). Thus, in relation to the temporal structures of music, the dissociations between language and music are much less consistent then in the pitch dimension.

Another important temporal feature is rhythm which has been found to be impaired more often in cases of lesions in the left hemisphere which, in turn, are also more activated in the imaging studies. If rhythm is preferentially processed in the left hemisphere, the meter as well as rhythm tasks that require the extraction of exact durations of auditory events, in contrast, are often disturbed by lesions in the right temporal lobe (Penhune *et al.*, 1999; Wilson & Davey, 2002) and/or right fronto-parietal lesions (Harrington, Haaland & Knight, 1998; Steinke *et al.*, 2001), a pattern also consistent with imaging studies (Parsons, 2001; Sakai *et al.*, 1999). In fact, left hemisphere lesions which induce to Broca's aphasia (Efron, 1963; Mavlov, 1980; Swisher & Hirsh, 1972), or conduction aphasia (Brust, 1980; Eustache Lechevalier, Viader & Lambert, 1990), or anomic aphasia (Pötzl & Uiberall, 1937) are also likely to induce to musical disturbances, mainly in the temporal domain. Normally, the deficits in discrimination of musical rhythms or temporal ordering are due to left hemisphere lesions, mainly left anterior lesions affecting prefrontal cortices, and have been associated with deficits in verbal working memory (Erdonmez & Morley, 1981), deficit in the

phonological short-term memory (Peretz, Belleville & Fontaine, 1997), and Broca's aphasia (Efron, 1963; Swisher & Hirsh, 1972), although left prefrontal damage also cause deficits in active listening to pitch variations, such as pitch contour and intervals (Ayotte, Peretz, Rousseau, Bard & Bojanowski, 2000) or to judge if a comparison tone pair was higher or lower than a standard tone pair (Harrington *et al.*, 1998). Imaging studies on health individuals provide additional evidence that rhythm is processed in left hemisphere, more specifically in left inferior frontal areas such as Broca's area.

Interestingly, the relations between music and language on the temporal dimension are consistent with a long held notion among musicologists that have recently received empirical support: the rhythm of a nation's music reflects the rhythm of its language. New methods have allowed to directly compared rhythm and melody in speech and music, and between different languages such as British English and French (Patel, 2003b; Patel & Daniele, 2003), and reveal that the greater durational contrast between successive vowels in English vs. French speech was reflected in greater durational contrast between successive notes in English vs. French instrumental music. But languages differ not only in their rhythmic prosody (temporal and accentual patterning) but also in the way voice pitch rises and falls across phrases and sentences ("intonation," which refers to speech melody rather than speech rhythm), and, recently, it was found that pitch intervals in the music of a given culture reflect the intonation of its language. In sum, instrumental music does indeed reflect the prosody of the national language, thus showing that the language we speak may influence the music our culture produces (Patel, Iversen & Rosenberg, 2006).

4.3. Evidences against modularity II: syntax in music and language

Music, like language, is an acoustically based form of communication with a set of rules for combining limited number of perceptual discrete acoustic elements (pitches in music, and phonemes in language) in an infinite number of ways (Lerdahl & Jakendorff, 1983). In both domains, the sequential organization of basic auditory elements consists in a strong rule-based system of a generative nature, where the complexity is built up by the rule-based permutations of a limited number of discrete elements allowing a potentially infinite range of high-order structures as sentences, themes and topics, and this combinatorial capacity is referred as to recursion or discrete infinity (Hauser, Chomsky & Fitch, 2002). The set of principles governing the combination of discrete structural elements (such as phonemes and words or musical tones) into sequences is called syntax. Brain responses reflecting the processing of musical chord-sequences are similar, although not identical, to the brain activity elicited during the perception of language, in both musicians and nonmusicians (Koelsch *et al.*, 2002; Patel *et al.*, 1998).

The sharing between music and language of the cognitive mechanisms involved on abstraction of rules present in syntax is striking. Recent studies reveal brain responses related with music-syntactic processing that were localized in Broca's area and its right homologue (Koelsch *et al.*, 2002; Maess, Koelsch, Gunter & Friederici, 2001), areas also known to be involved in language-syntactic processing (Dapretto & Bookheimer, 1999; Friederici, Meyer & von Cramon, 2000), thus suggesting that the mechanisms underlying syntactic processing are shared between music and language (Levitin & Menon, 2003; Patel, 2003a). Detection of musical deviations lead to bilateral activation not only in frontal regions comprising anterior-superior insular cortex and inferior fronto-lateral areas involved on language syntax but also in temporal regions including Wernicke's area (BA22, 22p) and PT (BA42) (Koelsch *et al.*, 2002), areas known to support auditory language processing. These indicate that sequential auditory information is processed by brain structures which are less domain-specific than

previously believed. Interestingly, earlier imaging results are consistent with recent neuropsychological data on language processing. Recent studies investigating cognitive deficits in agrammatic aphasia (Dominey & Lelekov, 2000; Lelekov *et al.*, 2000; Keurs, Brown, Hagoort & Stegeman., 1999) in conjunction with healthy subject data (Lelekov-Boissard & Dominey, 2002) also suggest that the role of this inferior frontal region in the language syntax are more related to the processing of supramodal, linguistic and non-linguistic, abstract rules. For instance, agrammatic patients also display non-linguistic deficits such as the processing of sequence of letters such as 'ABCBAC' and 'DEFEDF', which have different serial order or serial structure but share the same abstract structure '123213'; Broca's aphasic patients with agrammatism did not show a specific deficit in grammatical, closed-class words but, instead, have a working memory related deficit reflected by delayed and/or incomplete availability of general word-class information (Keurs *et al.*, 1999).

These data are not fully surprising if we take into account that linguistic and musical sequences are created by combinatorial principles operating at multiple levels, such as in the formation of words, phrases and sentences in language, and of chords, chord progressions and keys in music (i.e., 'harmonic structure), making us to perceive in terms of hierarchical relations that convey organized patterns of meaning. In language, one meaning supported by syntax is 'who did what to whom', that is the conceptual structure of reference and predication in sentences. In music, one meaning supported by syntax is the pattern of tension and resolution experienced as the music unfolds in time (Lerdahl & Jakendorff, 1983); for a review see (Patel, 2003a).

Andrade, Andrade, Gaab, Gardiner & Zuk (2010) aimed at investigating the relations between music and language at the level of "patterned sequence processing" in a novel music task called Musical Sequence Transcription Task (MSTT). To control for fine-grained pitch processing we asked to forty-three seven years old brazilian students to listen to four-sound sequences based on the combination of only two different sound types: one in the low register (thick sound), corresponding to a perfect fifth with fundamental frequencies 110Hz (A) and 165 Hz (E), and the other in the high register of (thin sound), corresponding to a perfect fourth, with 330Hz (E) and 440Hz (A). Children were required to mark the thin sound with a vertical line ']' and the thick sound with an 'O', but were never told that the sequences only consist of four sounds. Performances on MSTT task were positively correlated with phonological processing and literacy skills.

These observations are also in line with recent findings in both human newborns and non-human primates (tamarins) which are capable to discriminate non-native languages that pertain to different classes of rhythmic prosody, but do not discriminate languages from the same rhythmic class (Ramus *et al.*, 2000; Tincoff *et al.*, 2005). These lead to a more general proposal that infants build grammatical knowledge of the ambient language by means of 'prosodic bootstrapping', with rhythm playing one of the central roles; it is consistent with the frequent co-occurrence of agrammatism and rhythm deficits in aphasic patients with left prefrontal damage (Efron, 1963; Mavlov, 1980; Swisher & Hirsh, 1972), and provides further support for the link between music and language in the temporal and sequencing domain, hence, for shared cognitive mechanisms on syntactical processing.

5. Music cognition and cross-modal processing

While discussing the sharing of neurocognitive mechanisms between music and language, jointly with the fact that music is embodied and polysemic, we automatically adopt a cross-modal approach of music cognition. As we have already pointed out that music is, in fact, as much about action as it is about perception. Simply, music 'moves' us. When one

plays music, or tap, dance, or sing along with music, the sensory experience of musical patterns is intimately coupled with action.

Regarding the neuroimage data to infer eventual overlaps between musical processing and other domains it is important to keep in mind that similar brain activation patterns alone are not necessarily accepted as overlapping because distinct but intermingled neural pathways very close to each other can be seen as the same activations, reflecting the resolution limits in standard 3 X 3 X 4 mm voxels of the fMRI method. Therefore, our comparisons of neuroimaging data used to argue for overlapping between music and other domains were based mainly, but not only, on the criteria adopted in the meta-analysis on auditory spatial processing conducted by Arnott, Binns, Grady & Alain (2004). The authors analyzed data from peer-reviewed articles of auditory studies, including 27 studies on nonspatial sounds and 11 on spatial sounds, that incorporated either PET or fMRI recordings with normal, healthy adults. We then compared activations of many neuroimaging studies on the pitch pattern perception in music with the reported activations under spatial pitch processing in the study by Arnott *et al.* (2004) often within ~ 4 mm cubic. This same criterion was applied in the comparisons between music and language. Furthermore, when we put together both imaging and lesion data, i.e. showing the same overlap from either brain activations in the neuroimaging of healthy subjects and the patterns of deficit and spared cognitive function in lesion data, we interpret this evidence as a strong support for crossmodal processing.

There has been a significant overlap between neural substrates for the generation of visuo-spatial tasks and music perception. For example, occipital and frontoparietal cortical areas, traditionally involved in visuo-spatial tasks, including the precuneus in medial parietal lobes called the "mind's eye" for being crucially involved in generation of visuo-spatial imagery (Mellet et al., 2002; Mellet et al., 1996), are among the most frequently and significantly activated regions in perception of music either in naïve listeners or in musicians (Mazziotta et al., 1982; Nakamura et al., 1999; Platel et al., 1997; Satoh, Takeda, Nagata, Hatazawa & Kuzuhara, 2001; Satoh, Takeda, Nagata, Hatazawa & Kuzuhara, 2003; Zatorre, Evans & Meyer, 1994; Zatorre, Perry, Beckett, Westbury & Evans, 1998), and even in subjects mentally imagining a melody (Halpern & Zatorre, 1999). These imaging data are consistent with three well documented cases of amusia associated to deficits in spatialtemporal tasks in both visual and auditory modalities (Griffiths et al., 1997; Steinke et al., 2001; Wilson & Pressing, 1999), as well as associated deficits in pith perception and visuospatial tasks in left prefrontal damage patients (Harrington et al., 1998). Bilateral frontal and inferior frontal activations, mainly premotor frontal areas BA6, dorsolateral prefrontal areas (BA8/9), as well as inferior frontal areas as Broca (BA44/45), insula, and more anterior middle and inferior frontal cortices (46/47), are frequently observed in either non-musicians (Platel et al., 1997; Zatorre et al., 1994) or in musicians (Ohnishi et al., 2001; Parsons, 2001; Zatorre et al., 1998). Activations of premotor-posterior parietal network in pitch tasks are not surprising if we take into account that, functional neuroimaging studies in humans suggest premotor-posterior parietal networks involvement not only in motor control but also for cognitive processes such as mental object-construction task (Mellet et al., 1996) and other visuo-spatial tasks involving spatial working memory either implicitly (Haxby et al., 1994) or explicitly (Smith, Jonides & Koeppe, 1996).

When non-musicians were asked to tell if the second of two melodies presents a change or not, all activation foci were in the left hemisphere with the most significant activations were in the left precuneus/cuneus (BA 18/19/31), a region traditionally involved in visual imagery tasks (Platel *et al.*, 1997). It could be argued that the analytic pitch tasks tap into visual imagery in terms of 'high' and 'low' in relation to a notational mental base line or



a mental stave, what was suggested by the subjects themselves during debriefing. Left superior parietal lobes activations, particularly in the parieto-occipital junction, was activated when professional pianists were reading musical scores without listening or performing (Sergent, Zuck, Terriah & Macdonald, 1992), and this was interpreted as the participation of the dorsal visual system in spatial processing for reading scores, once musical notation is based on the spatial distribution and the relative height separation of the notes on the scores, forming 'pitch intervals'. Other imaging studies have frequently reported superior parietal lobes (Zatorre et al., 1998) and precuneus activation also in perceptual tasks (Satoh et al., 2001). Halpern & Zatorre (1999) found that musicians when asked to mentally reproduce a just heard unfamiliar melody yield significant activations in several left inferior prefrontal (BA 44, 47, 10) and middle/superior frontal gyrus (BA 8, 6), as well as in premotor (BA6), visual association cortex (BA19), and parietal cortex and precuneus (BA40/7), but no activations in temporal lobes were found. Musicians with both absolute pitch (AP) and relative pitch (RP) both showed bilateral activations of parietal cortices in judging a musical interval, but with stronger left parietal activations in RP musicians whose cognitive strategies rely more on the maintaneance of pitch information on auditory working memory for pitch comparison on a mental stave (Zatorre et al., 1998), whereas AP musicians rely more on longterm memory (Zatorre et al., 1998). Finally, an important revelation of imaging studies in music perception and production are the significant activations of the cerebellum (Parsons, 2001; Zatorre et al., 1994) in either pitch or rhythm tasks.

As pointed by Janata & Grafton (2003), three research domains in psychology and neuroscience are particularly pertinent to understanding the neural basis for sequencing behaviors in music: they are timing, attention and sequence learning. In fact, music can be thought of as a sequence of events that are patterned in time and a 'feature space' that is multidimensional and consists of both motor and sensory information. Motor patterns determine how we position effectors in space, such as fingers on piano keys, whereas sensory patterns reflect the organization of auditory objects, such as notes or sets of notes in time when we hear melodies and chords, respectively. Temporal and spatial sequence production in humans yield activations in many brain regions including the cerebellum, SMA, PMC, basal ganglia and parietal cortex, which are richly interconnected. There possibly lies a core circuit underlying sequenced behaviors in which different levels of complexity show considerable overlap in some regions such as the SMC and SMA, whereas higher levels of complexity are related with overlap and greater activations in the cerebellum, basal ganglia, thalamus, PMC (premotor cortex), VLPFC (ventrolateral prefrontal cortex), IPS (intraparietal sulcus) and precuneus. All these regions have also been related with music processing (Janata & Grafton, 2003).

Given that music inherently consists of sequential auditory and motor information, it is quite expected to find shared cognitive mechanisms and neural networks between music and sequencing behavior.

6. Universalities in music

Infant research and cross-cultural comparisons are the two main approaches to studying the contribution of universal and cultural cues in music perception. Infant research helps to clarify the culture-transcendent predispositions for processing music and to describe how the culture-specific properties develop (for a review see (Trehub, 2003)). Cross-cultural investigations compare the responses of listeners from culturally separate musical backgrounds searching for culture-transcendent and culture-specific factors in music. The topics in cross-cultural studies of music have ranged from the emotional responses to music

(Balkwill, Thompson & Matsunaga, 2004), to melodic expectancies (Castellano, Bharucha & Krumhansl, 1984; Krumhansl *et al.*, 2000), to pulse-finding (Toiviainen & Eerola, 2003), and to interval discrimination (Burns, 1999).

There is evidence of common features, across different music styles, in the principles underlying melody (Krumhansl & Toiviainen, 2001) and in response to features such as consonant/ dissonant intervals, pitch in musical scales and meter (Drake, 1998; Drake & Bertrand, 2001). The way an infant processes musical patterns is similar to that of adults (Trainor & Trehub, 1992); infants respond better to melodic as well as to harmonic consonant patterns, and to complex metric rhythms (Trainor, McDonald & Alain, 2002a; Zentner & Kagan, 1996). There is reason to believe that infants possess absolute pitch early in life but change to relative pitch later (Saffran & Griepentrog, 2001), and that they have long-term musical memory (Saffran, Loman & Robertson, 2000). The widespread use of scales of unequal steps, comprised of 5 to 7 notes based around the octave (the most consonant interval corresponding to 12 semitones and formed by the first and the eighth final note of the scale), is another universality of music which is preferred even by infants when compared to scales of equal steps between notes (Burns, 1999; Trehub, Schellenberg & Kamenetsky, 1999; Trehub, Thorpe & Trainor, 1990).

Expectations formed by the listeners when listening to music are also universal across cultures. Expectation is a basic component of music perception, operating on a variety of levels, including melodic, harmonic, metrical, and rhythmic, and it addresses the question "what" and "when", that is, what tones or chords are expected to occur and when, in a given musical sequence. It is not only presumed to play an important role in how listeners group the sounded events into coherent patterns, but also to appreciate patterns of tension and relaxation contributing to music's emotional effects. Both cognitive and emotional responses to music depend on whether, when, and how the expectations are fulfilled. The main method used in cross-cultural comparisons of musical expectations is the probe tone task, first developed by Krumhansl and Shepard (1979) for quantifying the perceived hierarchy of stability of tones.

In experiments on melodic expectations a melody is presented to the listeners many times, but followed on each occasion by a single probe-tone with varying degree of fitness. Using a rating scale, the listeners assess the degree to which the probe-tone fits their expectations about how the melody might continue (Krumhansl et al., 2000). Cross-cultural studies comparing the fitness ratings given by Indian and Western listeners to North Indian ragas (Castellano et al., 1984), and by Western and Balinese listeners to Balinese music (Kessler, Hansen & Shepard, 1984), as well as native Chinese and American listeners' responses to Chinese and British folk songs (Krumhansl, 1995) found strong agreement between listeners from these different musical cultures. A remarkable consistency is found between (South Asian) Indian and Western listeners (Castellano et al., 1984) in giving higher ratings to the tonic and the fifth degree of the scale, tones that were also sounded most frequently and for the longest total duration, which, theoretically, are predicted to be important structural tones in Indian ragas. Interestingly, the western listeners' responses did not correspond to tonal hierarchies of major and minor keys, according to the Theory of Harmony in Western music (Krumhansl, 1990), but rather to theoretical predictions for Indian music. Additionally, it was shown that all listeners can appreciate some aspects of different musical cultures by attending to statistical properties of the music, such as the number of times that different tones and tone combinations appear in the presented musical contexts, although there were some residual effects of expertise depending on the listeners' familiarity with the particular musical culture (Castellano et al., 1984). Recent cross-cultural works on melodic expectancies, with Korean music (Nam, 1998) and music of indigenous people of the Scandinavian Peninsula (Eerola, 2004; Krumhansl et al., 2000), have provided additional



evidences for the universal reliance on the hierarchical arrangement of pitches, indicating that music draws on common psychological principles of expectation even if musical cultures have a distinct effect in these principles, although the exact way it is accomplished varies with culture.

Listeners ranging from experts to completely unfamiliar, namely Sami yoikers (experts), Finnish music students (semi-experts) and Central European music students (Krumhansl *et al.*, 2000) as well as traditional healers from South Africa (non-experts) (Eerola, 2004) rated the fitness of probe-tones as continuations of North Sami yoik excerpts, a musical style from indigenous people (Sami people sometimes referred to as Lapps) of the Scandinavian Peninsula that is quite distinct from Western tonal music (Krumhansl *et al.*, 2000; Eerola, 2004). All groups, consistently with previous studies, showed strong agreement (Castellano *et al.*, 1984; Kessler *et al.*, 1984; Krumhansl, 1995). Further support was also provided by the event-frequency models (statistical properties of tone distributions) according to which listeners seem to extract the frequently occurring events in the melody which act as cognitive reference points that are established by repetition (Eerola, 2004). In fact, sensitivity to the statistical properties of music also influences listeners's expectations (Oram & Cuddy, 1995; Krumhansl *et al.*, 2000), and is apparently a universal process, exhibited by even 8-month-old infants (Saffran, Johnson, Aslin & Newport, 1999).

Today is generally agreed that in addition to cultural cues, listeners' possess innate general psychological principles in auditory perception such as sensitivity to consonance, interval proximity, and, finally, the statistical properties, which have been extensively shown to influence listeners' expectations (Oram & Cuddy, 1995; Krumhansl *et al.*, 2000). Early on development, consonance is preferred even by 2-4 months old infants in relation to dissonance (Trainor, Tsang & Cheung, 2002b) and sensitivity to statistical properties of music are apparently a universal process exhibited by even 8-month-old infants (Saffran *et al.*, 1999, Trainor *et al.*, 2002a).

Finally, in the temporal organization of auditory sequences two universal processes have been identified (Drake, 1998): (i) segmentation sequence into groups of events, accomplished in terms of changes in pitch durations and salience, and already present in early infancy (Krumhansl & Juscsyk, 1990), and (ii) the extraction of an underlying pulse through the perception of regular intervals (Drake & Baruch, 1995), which allows to infer the steady pulse (meter) from patterns of temporal grouping (rhythm) and categorize unique rhythmic and melodic patterns, a cross-cultural ability present in adults (Toiviainen & Eerola, 2003), and also in infants (Hannon & Johnson, 2005).

7. Music and emotions

As we have pointed above, the emotional response to music depends on whether, when and how the expectations are fulfilled (for a review see (Eerola, 2004)), and music's extraordinary ability to evoke powerful emotions is likely the main reason why we listen to music and why music is generally referred to as the "language of emotions".

Consistent with results on musical expectancies (Eerola, 2004), recent empirical findings suggest that emotional meaning in music is conveyed by universal acoustic cues, such as complexity, loudness, tempo, whose interpretation does not require familiarity with culture-specific musical conventions (Balkwill *et al.*, 2004). Cross-culturally, increases in perceived complexity appear to be consistently associated with the negative emotions of anger and sadness, while decreases are associated with joy and happiness. Further, increases in perceived tempo are associated with joy, whereas decreases in tempo are associated with sadness. Finally, increases in loudness are frequently associated with anger (Balkwill *et al.*, and the sadness of the sadness

2004), and create displeasure even in nonhuman primates (McDermott & Hauser, 2004). Consonance and dissonance certainly play a role in the musical emotions related to positive and negative affective values, respectively (Peretz *et al.*, 2001; Blood & Zatorre, 2001; Trainor *et al.*, 2002b).

Music is capable of inducing strong emotions with both positive and negative emotional valence consistently across subjects (Krumhansl, 1997) and cultures (Balkwill *et al.*, 2004; Eerola, 2004). For example, Jaak Panksepp (1995) asked several hundred young men and women why they felt music to be important in their lives and 70% of both sexes said it was "because it elicits emotions and feelings", in the second place came "To alleviate boredom".

Today, we already know that music elicits emotions rather than merely express an emotion that the listener recognizes. Most people experience a particularly intense, euphoric response to music, frequently accompaniment by an autonomic or psychophysiological component, described as "shivers-down-the-spine" or "chills". Listening to music automatically elicits physiological changes in blood circulation, respiration, skin conductivity and body temperature, which are autonomic responses of the sympathetic nervous system (Krumhansl, 1997). Khalfa, Isabelle, Jean-Pierre & Manon (2002) demonstrated that SCRs (electrodermal activity measured by Skin Conductance Response to measure the stimulus arousal) can be evoked and modulated by musical emotional arousal. Similarities in the event-related measures of musical and visual emotions suggests that the processing of musical emotions may not be domain-specific, that is, it may not be different in nature from the emotions elicited by other events such as words and pictures (Khalfa *et al.*, 2002).

Imaging and lesion studies reveal the deep subcortical foundations of emotional musical experiences in many brain areas that are homologous between humans and all of the other mammals (Blood & Zatorre, 2001; Brown, Martinez & Parsons, 2004; Gosselin et al., 2005). Pleasant/consonant music directly affects paralimbic areas such as insula, orbitofrontal cortex and ventromedial prefrontal cortex associated with reward/motivation, emotion, and arousal, as well as the mesolimbic system, the most important reward pathway (Blood & Zatorre, 2001; Blood, Zatorre, Bermudez & Evans, 1999; Menon & Levitin, 2005). In contrast, umpleasent/dissonant music directly affects the parahippocampal gyrus (Blood et al., 1999), a paralimbic structure activated during unpleasant emotional states evoked by pictures with negative emotional valence jointly with amygdale (Lane et al., 1997), which, in turn, is a key structure in fear processing and with which parahippocampal gyrus has strong reciprocal connections (Bechara, Damasio & Damasio, 2003; Mesulam, 1998). Recently it was demonstrated that unilateral damage to amygdale selectively impairs the perception of emotional expression of fear in scary music (minor chords on the third and sixth degrees and fast tempos), while recognition of happiness (major mode and fast tempo) was normal, and recognition of peacefulness (major mode and intermediate tempo played with pedal and arpeggio accompaniment) and sadness (minor mode at an average slow tempo) in music was less clearly affected by the medial temporal lobe resection (Gosselin *et al.*, 2005).

There are also evidences for the double dissociation between musical cognition and emotional processing. Bilateral damage to the auditory cortex caused severe, irreversible deficits in musical expression, as well as perception on both pitch and temporal dimensions, such as tasks requiring `same-different' discrimination for musical sequences, including consonant and dissonant musical material (Peretz *et al.*, 2001), yet the patients could appreciate and enjoy the affective/emotional meaning (Peretz *et al.*, 1997) and classify melodies as 'happy' and 'sad' as normal controls (Peretz & Gagnon, 1999). Conversely, loss of emotional response to music in presence of completely preserved musical perception abilities is reported in a patient with infarction in the left insula, extending anteriorly into the left frontal lobe and inferiorly into the left amygdale (Griffiths *et al.*, 2004), all areas with a close correspondence with left hemisphere areas activated during emotional response to music in normal subjects (Blood & Zatorre, 2001). Both studies offer an important double dissociation between musical cognition and emotional processing, i.e., between the perceptual and emotional components of music processing, the first involving the superior temporal and inferior frontal and parietal areas, and the second engaging a distributed brain network that is also recruited by other powerful emotional stimuli that produce autonomic arousal and includes bilateral medial limbic structures, insula, ventral striatum, thalamus, midbrain, and widespread neocortical regions.

In sum, there are increasing evidences that music derives its affective charge directly from dynamic aspects of brain systems that normally control real emotions and which are distinct from, albeit highly interactive with, cognitive processes. The ability of music to stir our emotions rather directly is a compelling line of evidence for the idea that cognitive attributions in humans are not exclusively needed for arousing emotional processes within the brain/ mind. In other words, cognitive processing to decode cultural conventions is not absolutely essential to extract the emotional meaning in music, a notion supported by cognitive, cross-cultural studies, as well as by lesion and neuroimaging studies.

The link between music and the deep subcortical structures of emotion in the human brain is reinforced by the relation between music emotions and the neurochemistries of specific emotions within the mammalian brain. Panksepp predicted that opiate receptor antagonists such as naloxone and naltrexone can diminish our emotional appreciation of music (Panksepp, 1995). Indeed, preliminary data provided by Goldstein (1980) have long indicated that such manipulations can reduce the chills or thrills that many people experience when they listen to especially 'moving' music.

8. Discussion: role of music in development

Contrary to the belief that music is a mere cultural byproduct and its appreciation necessarily involves the appropriation of cultural conventions, the growing body of scientific research reveals that, in addition to the observed universal cognitive processes involved in music perception, the music could not be a meaningful and desired experience without the ancestral emotional systems of our brains. Besides, although the existence of some crucial and particularly music-relevant neural networks in the right hemispheres, the neurocognitive processes involved in music and language do not appear to be music or language specific, neither encapsulated. Music, particularly, has been proved to be a supramodal cognitive domain involving cortical areas traditionally involved in language, spatial and motor processing, as well as subcortical areas involved in basic emotional processing.

Emotionally speaking, unlike many other stimuli, music can often evoke emotion spontaneously, in the absence of external associations and our ability to decipher the neural underpinnings of aesthetic responses may turn out to be easier for music than for the visual arts (Ramachandran & Hirstein, 1999), and, like biologically relevant visual stimuli, activates primitive structures in the limbic and paralimbic areas related to fear and reward, including waking arousal control systems such as those based on norepinephrine (NE) and serotonin that regulate emotional responses, as well as generalized incentive seeking system centered on mesolimbic and mesocortical dopamine (DA) circuits, which are important also in the intracerebral estimation of the passage of time and likely related to rhythmic movements of the body which may be ancestral pre-adaptation for the emotional components of music (Panksepp & Bernatzky, 2002). In this sense, well constructed music is uniquely efficacious in resonating with our basic emotional systems, bringing to life many affective proclivities



that may be encoded, as birthrights, within ancient neural circuits constructed by our genes, many of which we share homologously with other mammals (Panksepp & Bernatzky, 2002). Therefore, ultimately, our love of music possibly reflects the ancestral ability of our mammalian brain to transmit and receive basic emotional sounds that can arouse affective feelings which are implicit indicators of evolutionary fitness.

Conversely, cognitively speaking, music, unlike many other stimuli, is abysmally supramodal, involving auditory, motor, spatial, numerical and emotional and linguistic neural networks.

The central question here is "Why"? The data reviewed here appear to have two important implications. First, that music may be based on the existence of the intrinsic emotional sounds we make (the animalian prosodic elements of our utterances) and on the rhythmic movements of our instinctual/emotional motor apparatus, both evolutionarily designed to index whether certain states of being were likely to promote or hinder our well-being (Panksepp & Bernatzky, 2002). Second, that these emotional and supramodal characteristics of music are also evolutionary important to promote stimulation and development of several cognitive capabilities (Cross, 2001, 2003a).

We have seen that crucial aspects of pitch perception in music are likely shaped by relatively basic auditory processing mechanisms that are not music specific and can be studied in experimental animals (Hauser & McDermott, 2003). In social creatures like ourselves, whose ancestors lived in arboreal environments where sound was one of the most effective ways to coordinate cohesive group activities, reinforce social bonds, resolve animosities, and to establish stable hierarchies of submission and dominance, there should have been a premium on being able to communicate shades of emotional meaning by the melodic character (prosody) of emitted sounds (Panksepp & Bernatzky, 2002). Therefore, sound is an excellent way to help synchronize and regulate emotions so as to sustain social harmony, and we can think that the capacity to generate and decode emotional sounds should be excellent tools for survival. Our brains' ability to resonate emotionally with music may have a deep multidimensional evolutionary history, including issues related to the emergence of intersubjective communication, mate selection strategies, and the emergence of regulatory processes for other social dynamics such as those entailed in group cohesion and activity coordination.

The principles of evolutionary psychology proposes that the brains of humans and other species are adapted to process and respond to three general classes of information: social, biological, and physical. The higher the species in the evolutionary hierarchy, the more important are the psychological traits related to social behavior. Theory of mind is especially salient in humans and represents the ability to make inferences about the intentions, beliefs, emotional states, and likely future behavior of other individuals (Meltzoff, 2002), and plays a central role on all socio-cognitive competences. From a comparative perspective, language and theory of mind are the most highly developed sociocognitive competencies in humans (Pinker, 1999) and are hypothesized to be the evolutionary result of the complexity of human social dynamics. We propose that the links between music and imitation are striking. Let's begin with a better notion of the principles underlying imitation.

Striking convergences among the cognitive and neuroscientific findings indicate that imitation is innate in humans and precedes mentalizing and theory of mind (in development and evolution), and, finally that behavioral imitation and its neural substrate provide the mechanism by which theory of mind and empathy develop in humans. It is argued that in ontogeny, infant's imitation appears to be the seed of the adult's theory of mind. Newborns as young as 42 minutes old are capable of successful facial imitation. Further, small infants with 12–21 day-old could imitate four different adult gestures: lip protrusion, mouth opening,

tongue protrusion and finger movement and confused neither actions nor body parts (Meltzoff, 2002). Infants can link self and other through what was termed a 'supramodal' representation of the observed body act. Early imitation appears to provide the first instance of infants making a connection between the world of others and the infants' own internal states, the way they feel themselves to be. Infants recognize when another acts 'like me' and the high emotional value of this experience. Further, infants look longer at the adult who was imitating them; smiled more at this adult; and most significantly, directed testing behavior at that adult (Meltzoff & Decety, 2003).

Music comes into the scene when we take into account that, due to its supramodal nature, including emotion, music perception appears to be an innate behavior that stimulates, among others things, the supramodal representation underlying imitation. A common observation in the social-developmental literature is that parent-infant games are often reciprocally imitative in nature. When parents shake a rattle or vocalize, infants shake or vocalize back. A turn-taking aspect of these games is the "rhythmic dance" between mother and child. Imitation is often bidirectional because parents mimic their infants as well as infants imitate parents (Meltzoff, 1999). Adults across cultures play reciprocal imitative games with their children that embody the temporal turn-taking (Trevarthen, 1979; Trevarthen, 1999). The links between protomusical behaviors in infants and imitation are becoming increasingly evident. We know that imitation games with music and dance are universal, and the tribal dances itself can be seen as one of the most frequent forms of imitation game, used to develop the in-group sense, the feeling of both "being like the other" and "the other is like me", and thus pertaining to a group. Perhaps not coincidentally, the developmental precursors of music in infancy, and through early childhood, occur in the form of proto-musical behaviours which are exploratory and kinesthetically embedded, being closely bound to vocal play and to whole body movement.

Human infants interact with their caregivers producing and responding to patterns of sound and action. These temporally-controlled interactions involve synchrony and turntaking, and are employed in the modulation and regulation of affective state (Dissanayake, 2000) and in the achievement and control of joint attention also referred as to 'primary intersubjectivity' (Trevarthen, 1999). This rhythmicity is also a manifestation of a fundamental musical competence, and "...musicality is part of a natural drive in human sociocultural learning which begins in infancy" (Trevarthen, 1999, p. 194) and also allows infants to follow and respond in kind to temporal regularities in vocalization, movement, and time, to initiate temporally regular sets of vocalisations and movements (Trevarthen, 1999). It makes music inextricably involved in the acquisition of language. Protomusical behaviors are so intimately intertwined with protoverbal behavior that "preverbal origins of musical skills cannot easily be differentiated from the prelinguistic stages of speech acquisition and from the basic alphabet of emotional communication" (Papousek, 1996b), and the musical elements that participate in the process of early communicative development pave the way to linguistic capacities earlier than phonetic elements (Papousek, 1996a). In the pitch dimension, infantcaregiver interactions tend to exhibit the same range of characteristics such as exaggerated pitch contours on the caregiver's part ('motherese'), and melodic modulation and primitive articulation on the infant's part, all in the context of an interactive and kinaesthetic rhythmicity. On the part of the infant, these activities develop into exploratory vocal play (between 4 and 6 months) which gives rise to repetitive babbling (from 7 to 11 months) from which emerges both variegated babbling and early words (between 9 and 13 months) (Kuhl et al., 2001; Papousek, 1996a, 1996b). Linguistic behavior begins to differentiate from infant proto-musical/proto-linguistic capacities as the infant develops, when the parent/infant interactions increasingly make use of vocalizations and gestures to communicate affect in the



exchange of 'requests' further supporting the development of referential gestures and vocalizations, orienting the attention of both participants to objects, events and persons outside the parent-infant dyad (Cross, 2001).

The biological role of musical behavior appears to fit not only with the development of socio-affective capacities and language, but also with the cognitive flexibility of human infants. Music can be viewed as a kind of multimodal or multimedia activity of temporally patterned movements. The polysemic nature of music and its characteristic of being a consequence-free means of exploring social interaction and a "play-space" for rehearsing processes appear to provide an ideal way of achieve cognitive flexibility, beyond its role in the socialization of the child. The role for music in the development of the child's individual cognitive capacities appears to be well supported by one of the main characteristic of neural processing in music, cross-modality. In fact, to listen and to make music appear to be a perfect means of forming connections and inter-relations between different domains of infant and childhood competence such as the social, biological and mechanical.

9. Conclusion

Now we can say that music is not only polysemic by also polymodal. Music is universal among human cultures, extant or extinct, and "binds us in a collective identity as members of nations, religions, and other groups" (Tramo et al., 2001).

Although at least one component of music, the tonal encoding of pitch, appears indeed to be domain-specific it results from fine-grained pitch perception, a mechanism that is music- relevant but not domain-specific in a strict fodorian sense. The evolved behaviors such as music and language, spatial processing, indeed share many common neurocognitive modules, whereas the selectivity observed in lesion studies appears to be to a result of the differential profile of relevance of these set of shared neural modules for each domain. In fact, the deficits are not completely selective, the apparently selective deficits in pitch processing in music, for instance, can be accompanied by deficits in spatial processing and language, they just appear to be more detrimental to music compared to other cognitive domains. On the other hand, the rhythm processing in music is clearly linked with language processing as shown by lesion and imaging studies.

In fact the universality of music jointly with its main characteristic, cross-modality, suggest that different cultural manifestations of music are cultural particularizations of the human capacity to form multiply intentional representations through integrating information across different functional domains of temporally extended or sequenced human experience and behaviour, generally expressed in sound. We differentiate from our relatives by an immense leap in cognitive flexibility and in our capacity to enter into and sustain a wide range of social relationships and interactions. The polysemic nature and cross-modality of musical behaviour can provide for the child a space within which she can explore the possible bindings of these multidomain representations.

The scientific research on music help us not only to understand the marvelous and mysterious functioning of our brain, but also shed light on the essence of human behavior, and hence the humankind.

Acknowledgements

We are thankful to Prof. Joydeep Bhattacharya who helped to improve this text considerably by providing valuable comments on an earlier version of this article.

10. References

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