Musical minds

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Music might be described as just a special form of noise, but evidence is accumulating to show that listening to it can lead to pronounced physiological and emotional responses. In a recent article, Trainor *et al.* have shown that specific aspects of musical structure are processed automatically in the human brain, raising the question of whether our response to music has specifically evolved or merely occurs as a side-effect of neural architecture.

If you are a true connoisseur of music then you won't need to be convinced about the powerful influence it can have upon the human psyche. You might, however, have had frustrating conversations with less musically sensitive friends who just don't have the same response, and can't believe that music has any measurable and consistent physiological effect. In that case, you will be happy to hear about the increasing number of studies that link music to emotion, sometimes merely by describing the consistency and immediacy of self-reported happy or sad judgements about musical content [1], at other times reporting specific, replicable, low-level physiological reactions (changes in blood pressure, skin conductance, body temperature, respiration rate, and blood transit time and amplitude) in response to music [2]. 'Higher-level' physiological signs (such as tears, a lump in the throat, or shivers down the spine) have also been consistently reported [3]. Most recently, a neuroimaging study using fMRI has shown increased activity in brain areas associated with reward and positive emotions in response to intensely pleasurable experiences of music [4].

These results should be enough to convince even the most amusical scientist that the special patterns of sound that constitute certain musical passages do more than just stimulate the auditory system. But, what is the missing link between auditory input and emotional response, and is this something that develops with practice and exposure to music, or is it a more basic property of brain organization? A recent article by Laurel Trainor *et al.* has attempted to tackle this question [5]. The authors examined responses to specific aspects of music structure in non-musicians in order to determine whether they are learned or hardwired. Although 'pitch contour' (the relative pitches of sounds, in terms of higher and lower frequencies) is important for speech as well as music processing [6], 'pitch interval' (the absolute difference in pitch between a pair of sounds) is thought to be specific to music [7]. In Trainor *et al.*'s study, subjects listened to auditory patterns that were structured predictably, in terms of either pitch contour or pitch interval, in both attended and non-attended circumstances. The essential finding was the observation of event-related brain potentials (ERPs) in response to oddball trials that violated either of these dominant structures, even under non-attended conditions. These potentials show that the brain registered the difference between the expected stimulus and the unexpected one it actually heard. Because non-musicians were used, these results show that encoding of both pitch contour and pitch interval is automatic even in the absence of musical training, which implies that the human auditory system is set up to process music specific information automatically.

Although Trainor *et al.*'s findings do not directly address the question of whether brain mechanisms for automatic music processing have actively evolved, they certainly suggest that the issue is worthy of consideration. In fact, the debate over an adaptive, actively evolved music appreciation is an old one, with proponents on both sides. Steven Pinker, for example, argues that music is no more than a sort of 'auditory cheesecake', our enjoyment of it arising from properties of the auditory system and brain that have evolved for other reasons [8]. Other authors have used various arguments as evidence that music appreciation might have evolved specifically. Some of these were presented in a recent synopsis by David Huron [9].

Any aspect of human physiology that has evolved must have been around in some form for a very long time. In 1995 a bone flute, dated between 43 000 and 82 000 years old, was discovered in Slovenia [9,10]. As the flute represents a relatively complex form of music production, it could be argued that simpler forms, such as singing, are likely to have predated it by as much as 200 000 years [9]. This line of logic suggests that music is very ancient, and is almost certainly old enough to have had an impact on the evolving human brain.

A second factor worth noting is the amount of time dedicated to music. In the United States, for example, the music industry is currently economically larger than the pharmaceutical industry, and it has been argued that people spend more time and money on music than on sex [9]. Looking to less-developed societies, we see that this apparently disproportionate allocation of resources to music-making and consumption is not a recent phenomenon. In some hunter–gatherer cultures adult men are *required* to devote as much as two hours per day to ritualistic singing [9,11].

If the argument for evolved music appreciation is to be convincing, some demonstration of how this type of response can be adaptive must be found. Suggestions for music's adaptive role vary widely, from involvement in sexual selection and mate choice to aiding the development of perceptual and motor skills [9]. Perhaps the most compelling proposal is that music acts as a social lubricant, facilitating the harmonious perpetuation of small social units through communal mood modification. Support for this hypothesis includes the known physiological effects of music. For example, listening to music has been shown to reduce testosterone levels in males [12], a particularly relevant finding given that male testosterone levels correlate with aggression so reducing them might also reduce social conflict. Certain types of music are also known to reduce stress, lowering cortisol levels or at least minimizing the increase in cortisol associated with stressful stimuli [13]. There is even some evidence that music listening stimulates the release of oxytocin, a neurotransmitter associated with social bonding between mother and child, between sexual partners, and among larger social groups [14,15].

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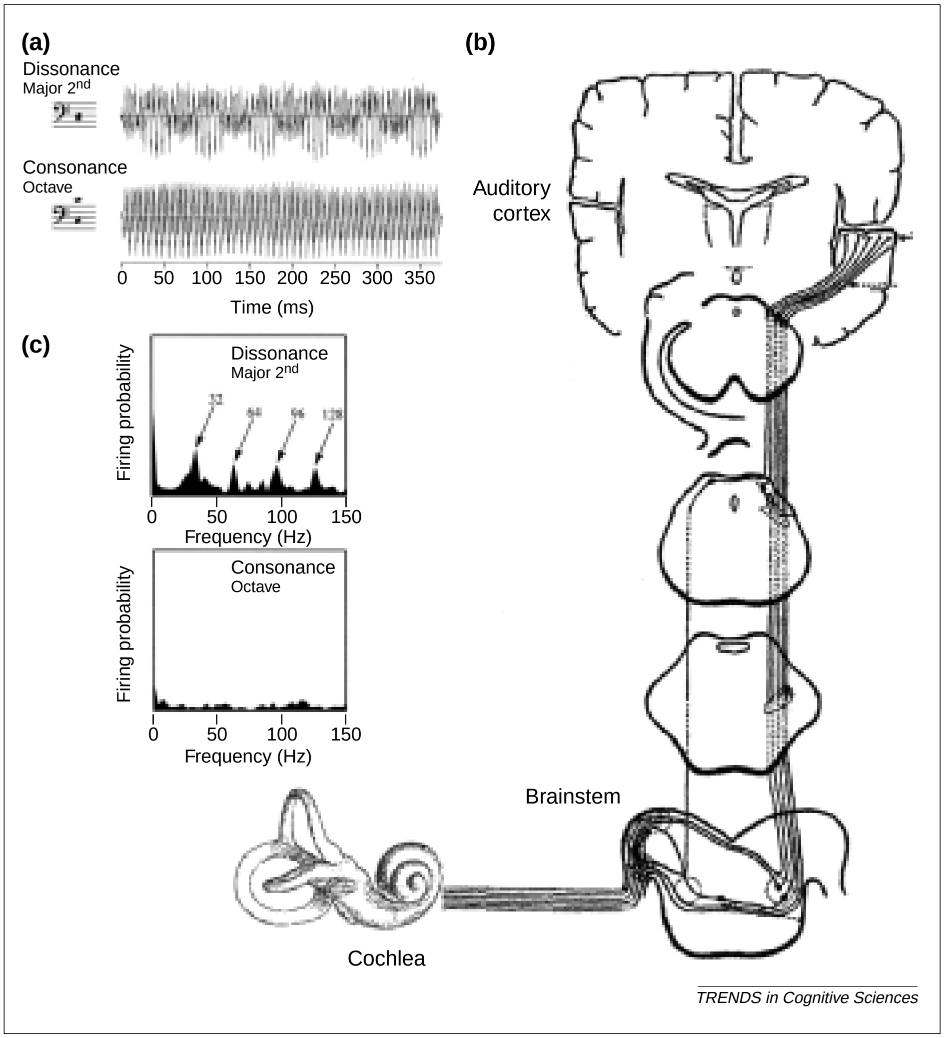

Fig. 1. (a) The acoustic waveforms for a dissonant chord (major 2nd), which contains low-frequency amplitude modulations or 'roughness', and a consonant chord (octave), which has a comparatively smooth amplitude at low frequency. (b) These waveforms pass via the cochlea and brainstem to arrive at the primary auditory cortex, whose neurons have been shown to phase-lock with the 'roughness' of dissonant chords. (c) Population recordings from monkey primary auditory cortex show this phase-locking pattern to dissonant but not consonant waveforms. Data and figures reproduced with permission from Ref. [19].

Regardless of whether our physiological responses to music have evolved, or simply occur as a side-effect of neural circuitry, a further question remains to be answered: just how does music elicit the observed reactions? A recent neuroimaging investigation showed that brain areas associated with reward processing using the dopamine (nucleus accumbens) and opioid (periaqueductal grey) systems show increased activity during intensely pleasurable experiences of music [5]. In another study, the same investigators used unpleasantly dissonant musical extracts as stimuli to reveal activity in a different set of regions (parahippocampal gyrus, precuneus, orbitofrontal cortex, medial subcallosal cingulate, and frontal pole) that correlated with the degree of unpleasantness [16]. These results suggest that different networks are involved in modulating the brain's response to pleasant and unpleasant musical sounds.

Although the imaging data reveal a link between musical stimuli and systems involved in emotional processing, they provide no solution to the question of how auditory stimuli lead to this high-level brain activity, and why different responses should be elicited by different types of music. For dissonant chords, which are consistently judged as unpleasant, and consonant chords, which are consistently judged as pleasant, it is tempting to conjecture that this link could be provided by differential firing patterns in auditory cortex elicited by the two kinds of auditory input. Consonant chords comprise simultaneous tones that relate to each other in simple frequency ratios, such as 2:1 (an octave) or 3:2 (a perfect 5th). By contrast, dissonant chords comprise simultaneous tones that relate to each other in complex integer ratios, such as 256:243 (a minor 2nd) or 243:128 (a major 7th). The classic framework of Helmholtz [17] suggests that the perception of dissonance is due to the low-frequency modulations in amplitude of the auditory waveform (Fig. 1a), which are described as 'roughness' or 'beats' and caused by interaction between component tones. Consonant chords, by contrast, involve comparatively little amplitude modulation at low frequencies (Fig. 1a). Recent physiological work has shown that neurons in the primary auditory cortex can become phase-locked to low-frequency amplitude modulations [18,19] (Fig. 1c), although this does not occur at higher frequencies owing to limitations of cell firing rates [19]. Thus, whole populations often fire in time with the low-frequency amplitude modulations of dissonant chords, but no such synchronized behaviour is observed in response to consonant chords, which lack these low-frequency modulations. Information about these 'rough' or 'smooth' firing patterns could easily be relayed from auditory cortex to the dopamine and opioid systems, and to the parahippocampal gyrus, all of which appear to play a role in emotional responses to pleasant or unpleasant sounds.

Whether music has an adaptive function or not is still a question for investigation, but the recent work of Trainor *et al.* shows that processing of specific elements of music occurs automatically in the brain, and therefore provides support for the possibility of brain structures specific to music. Combined with data showing that music reliably elicits a variety of physiological reactions, some of which are emotionally linked, this research is gradually showing that we truly have musical minds.

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Meeting Report

Imaging brain in search of mind

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The fourth annual fMRI Experience was held at the National Institutes of Health (NIH), in Bethesda, Maryland, USA, on 3–14 May 2002. The conference was organized jointly by research fellows at the NIH and Institute of Psychiatry (IoP) in London, and benefited from financial support from the National Institute of Mental Health (NIMH) Intramural Research Program, the NIMH Division of Intramural Training, and the Guarantors of *Brain* in association with the IoP.

In just over a decade, functional magnetic resonance imaging (fMRI) has emerged as a promising and exciting tool for understanding the functional neuroanatomy of sensorimotor and cognitive processes in the human brain. Given that the technique is only now growing out of its infancy, a clear demand exists for meetings dedicated to the dissemination of basic knowledge about fMRI technology to newcomers in the field, while also promoting the exploration of novel methods of analysis. In meeting this demand, With this support, competitive travel awards enabled over thirty international delegates to attend the meeting, some of whom presented among the most innovative studies on the program. The logistic and tactical differences of the many disciplines that collaborate to carry out fMRI research was apparent at the meeting, where experts in neuropsychology, neurology, physics, mathematics, electrophysiology, biology and cognitive psychology merged to deliver presentations about the strengths and limitations of the technique, and its relevance in exploring the functional architecture of the healthy and disordered brain.

'Where' and 'how'

The meeting began with a brief introduction by Robert Desimone (National Institute of Mental Health – NIMH, USA), who described the explosion of fMRI research in recent years, and noted the refreshing movement from questions about 'where' specific processes happen in the brain, to questions about 'how' neural systems operate and interact to perform specific cognitive functions. Three of the most outstanding presentations followed, beginning with a summary of the basic principles of magnetic resonance physics, by Steve Williams (IoP, UK). Unfortunately for the beginner (and speaking as psychologist rather than physicist!), the 'primer' on physics was somewhat analogous to being thrown in at the deep end of a haemodynamic whirlpool. However, a breath of fresh air for the more statistically minded delegates was subsequently offered by Robert Cox (NIMH, USA), who delivered an overview of the principles and practice of fMRI data analysis. Here, it became obvious to the novice that there exists no one tried and true technique with which to analyse neuroimaging data: Cox described the need to test the efficacy of more than one mathematical model due to signal fluctuations of the blood-oxygen level dependent (BOLD) response. This message was reiterated by Peter Bandettini (NIMH, USA) who posed a challenge for neuroscientists in the coming years to make progressively more precise inferences using fMRI without making too many assumptions about the methodology upon which these inferences are based. Without doubt, these introductory sessions set the scene for an exciting two days of discussion about the existing knowledge of fMRI methods, and the (as yet) unmet potential of this means of enquiry into structure–function relationships in the human brain.

The following presentations by both students and keynote speakers served to illustrate the enormous progress that has already taken place in terms of experimental design, statistical analysis, and interpretation of fMRI data. One of the obvious advances in analysis and interpretation concerned the recent

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