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What are the implications of neuroscience for musical education?

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Background: In this paper, we consider music education in a broad sense – not merely pertaining to the development of exceptional levels of artistry in talented performers, but also to notions of musical listening and appreciation enjoyed by the casual listener.
Purpose: This review cannot be exhaustive, but aims to illustrate what we already know about the neuroscience of how music is perceived, appreciated, learned and performed, and the implications that this knowledge has for music education in this broadly defined sense.
Design and methods: Extant studies from across the fields of neuroscience, psychology, education and music were surveyed using mainstream Internet databases (e.g., PubMed), as well as specific Internet cites promoting interdisciplinary exchange among musicians and scientists (e.g., Music and Science Online: http://www.science.rcm.ac.uk). The result is a review of some 50 studies from across this relatively young field.
Conclusions: To date, examples of tangible, practical advice from neuroscience that can be applied directly to musical learning and performance are relatively scant. However, the field is growing rapidly, and collaborations between musicians and scientists are becoming more common. We argue that the scope for neuroscience research to inform and shape musical education is ripe for development, particularly when musicians and scientists work together to address questions of musical relevance with scientific rigour.

Keywords: neuroscience; music education; music perception; music cognition; music performance

How musical am I?

The idea of what counts as musical ability is heavily influenced by culture. In societies where communal music-making forms an important aspect of everyday life, such as in the Venda people of South Africa, making music is as natural as breathing, and the notion that someone could be 'unmusical' would be considered absurd (Blacking 1995). In Western cultures, by contrast, music is typically performed by individuals or small groups for the appreciation of large audiences, giving rise to the view that musical ability is the preserve of the formally trained. A study conducted by Cuddy and colleagues (2005) showed that 14% of undergraduates in an American university believed themselves to be tone-deaf, even though testing of their musical perception using a standardised battery (Peretz, Champod, and Hyde 2003) showed that only a small percentage of these individuals scored outside the normal range.

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For many, the ability to sing in tune represents a key index of one's musicality (Sloboda et al. 2005). But the control of the vocal chords and breathing apparatus required to sing in tune is arguably as complex as the technical proficiency required to play a musical instrument, and we should not expect to be able to sing proficiently without some level of training and practice (Welch 2006). The individual differences in the physiological maturation of the vocal apparatus ensures that, in any class of children, there will be some who can hit the right notes, and others who must strive to do so. Unfortunately, this developmental stance is not always appreciated by classroom teachers and peers, and it is frequently heard that adults who self-define as 'tone-deaf' started off as children who were instructed to mime in school assembly. Labelling such children as tone-deaf and requesting that they do not sing has the self-defeating effect of arresting further development of singing, thus ensuring that such individuals will never hit the right notes and will carry the belief into adulthood that they lack musical ability. The damage that such early experiences can have must not be underestimated. Not only do individuals find themselves alienated and often embarrassed from social situations in which singing plays a role, but this often erroneous belief that they are unmusical will exclude them from other potentially fulfilling opportunities to engage with music.

Music-making, *per se*, can really be viewed as the icing on the cake of musicality. The feat of making sense of the music we hear is already a vastly sophisticated behaviour, but the ease with which most of us do this belies the complexity of the process. Music does not exist in the outside world or even at the point at which it hits the eardrums. The patterns of vibrations caused by hitting, plucking and blowing an instrument are made sense of by multiple brain areas across both hemispheres (see for a review of case studies of disordered musical listening Stewart et al. 2003). The frequency and intensity of vibrations are translated into our perceptions of pitch and loudness, while other information in the vibration patterns allows us to deduce which instrument is the source of the sound. But when we listen to an orchestra, or even a string quartet, each instrument generates a different pattern of vibrations at the ear. In a process known as 'streaming', the brain groups the patterns of vibrations from each sound source allowing us to distinguish among interwoven melodic lines. This explains something of how the moment-to-moment patterns of vibrations can be interpreted as musical sound, but to truly make sense of music, we must integrate musical events over time, unify features with those that have gone before and build expectations about those which will follow. The brain is supremely adapted for making links, seeking patterns and creating order from chaos.

Studies with infants reveal that we are born with the ability to extract the rules of music. Just as with language, musical perceptual ability is driven by innately specified brain mechanisms and by the input provided in the environment (Streeter 1976). It is widely known that infants are sensitive to non-native speech sounds that adults simply fail to perceive (Werker and Tees 1984). Similar principles apply within music. Elegant studies using a 'preferential looking paradigm' demonstrated that infants are equally sensitive to deviations in a native and a non-native metre. Metre can be thought of as a grouping unit of pulses. In a waltz, for instance, pulses are grouped in threes: **one**, two three, **one**, two, three; in a march, they are grouped in fours: **one**, two three, four; **one**, two, three, four. By contrast, in much Eastern European folk music, pulses are organised in fives or sevens, giving the music a distinctly irregular feel to Western ears. Hannon and Trehub (2005a, 2005b) played Canadian infants both Western and Balkan rhythms, and introduced a metrical deviation to both. While adults could only detect a deviation to their native metre; children of 6 months and younger were equally sensitive to deviations in both, while infants of 12 months were, like Canadian adults, only sensitive to deviations in their native metre. The older infants had undergone a 'perceptual narrowing', making them more adept at discerning the musical structure of their own environment. However, with repeated exposure to Balkan folk music, the older infants (but not the adults) started to behave similarly to the younger infants, revealing that perceptual abilities are not irreversible and are intimately related to environmental input.

Musical affinities

The affinity humans have for music appears to be universal: no culture in recorded history has been without some form of music which invariably forms a crucial part of rituals and ceremonies. But its survival value is not obvious, leading some to suggest that music is a spandrel: 'Music is auditory cheesecake. It just happens to tickle several important parts of the brain in a highly pleasurable way, as cheesecake tickles the palate' (Pinker 1997, 525). Others disagree and suggest that the pleasure is merely part of music's adaptive role in mother–infant bonding, an extension and development of our language abilities or a product of sexual selection, (see Cross 2007 for a review) depending on which theory one supports.

Regardless of music's evolutionary origins, the power of music to move us is considerable. At one extreme, some listeners experience the phenomenon of 'shivers down the spine', an episode of intense physiological arousal, triggered by a particular piece or passage in a piece. One of the classic brain imaging studies to look at the emotional responses to musical listening was conducted by Blood and Zatorre (2001). These authors used functional magnetic resonance imaging (fMRI) to scan listeners as they experienced a shiver episode. A clever feature of the design was that one person's 'trigger' piece was another person's control piece, since the pieces which trigger shivers tend to be idiosyncratic. When the brain activity involved in listening while experiencing a shiver was compared with the brain activity involved in just listening, activity was seen in the same areas that are involved in other pleasurable activities: sex, eating and the consumption of illicit substances (chiefly cocaine).

What precisely is it about music that we are responding to emotionally? One popular idea, first suggested by Meyer (1956), posits that the building of expectancies during musical listening is key to appreciation and emotion. Through a lifetime of exposure to the music of our culture, we become sensitive to the regularities used by composers of different genres, and we effortlessly and unconsciously predict how the music we are listening to will unfold. The skills of the composer are all-important in crafting our expectancies, and because music is such a multidimensional stimulus, expectancies can be formed at many different levels (pitch and rhythm being two obvious examples).

This multidimensionality may explain why individuals who are compromised with respect to one aspect of music (e.g., pitch), may still derive pleasure from listening to some types of music. Congenital amusia is a disorder in which individuals with normal hearing nevertheless have difficulty in making sense of music (Ayotte, Peretz, and Hyde 2002). The core impairment seems to be in pitch processing (Foxton et al. 2004; Hyde and Peretz 2004), with many of them showing normal processing of rhythmic information. However, although anecdotal reports have focused on those amusics who find music 'aversive', a recent study showed that, within a group of 21 amusics, a subgroup of individuals report levels of engagement with music that are equivalent to those shown by non-amusic controls (McDonald and Stewart 2008). The ability to engage in music and appreciate it despite diminished perception of a key aspect of music is likely to depend on deliberate and conscious exposure to forms of music that involve dimensions in addition to the one that is compromised, facilitating the building of expectancies upon which musical appreciation can be based.

Does practice make perfect?

Turning from the perception and appreciation of music, we now focus on musical performance, which many consider to be the epitome of musical achievement. Two questions to consider are whether neuroscience supports the notion that musical achievement can be explained by notions of giftedness and talent and whether neuroscience, to date, has offered musicians ways of facilitating and optimising their musical learning and performance.

It is a commonly held belief that the ability to play music well requires a special gift or talent. Defining what is meant by the terms 'gifted' or 'talented' is critical to this argument, since a discussion of their contribution to the attainment of musical excellence can otherwise become circular (Question: 'How do you know someone is talented?' Answer: 'Well, just listen to how beautifully they play.'). One approach is offered by Gagné's *Differentiated model of giftedness and talent* (Gagné 1985, 1993, 2000, 2003). At the heart of the model is the distinction between domains of ability (gifts) and fields of performance (talent). Gagné uses the term giftedness to describe individuals in the top 10% of the population for their age who are endowed with natural *potential to achieve* that is distinctly above average in one or more aptitude domains. In this conception, aptitudes are natural abilities that have a genetic origin and that appear and develop more or less spontaneously in every individual. The mix of these aptitudes explains the major proportion of differences between individuals when the surrounding environment and practice are roughly comparable. However, aptitudes do not develop purely by maturation alone; environmental stimulation through practice and learning is also essential (see McPherson and Williamon 2006 for a review).

With these defining features in mind, the scientific evidence for natural gifts leading to specific musical talents has thus far been scant (see Howe, Davidson, and Sloboda 1998). Key to the argument against the existence of musical giftedness is the fact that high levels of musical achievement are rarely preceded by unequivocal signs of musical precocity, and the fact that individuals who are not deemed to be 'gifted' can, nevertheless, attain equal levels of excellence as those who are, given adequate provision of opportunity and encouragement. As a result, scientists have turned to investigations of musicians' early experiences, preferences, opportunities, habits, training and practice to understand the acquisition of performance skills.

Evidence from neuroscience provides key insight into the significance of these factors – particularly training and practice – in the attainment of musical excellence. Several studies have revealed structural differences in the brains of musicians: the corpus callosum (Schlaug et al. 1995) and certain auditory (Schneider et al. 2002) and motor (Amunts et al. 1997) regions have all been shown to be structurally enlarged. However, congruent with the behavioural evidence cited by Howe, Davidson, and Sloboda (1998), the brain imaging data supports the view that deliberate practice is the prime predictor of these changes. The structural alterations seen scale in magnitude with the age at which training commences (Elbert et al. 1995; Hutchinson et al. 2003) and the overall intensity of training over the lifespan (Gaser and Schlaug 2003; Hutchinson et al. 2003; Schneider et al. 2002). Although neuroscientific research may not exactly confirm the time-honoured adage that 'practice makes perfect' (indeed, very little in music can be classified as 'perfect'), it does support the notion that 'practice makes better' and offers clear and observable evidence for how the brain adapts to the demands of extensive training, enabling musical skills to flourish.

Learning in action

Given the pre-eminent role of learning in the development of musical excellence, it becomes pertinent to ask how musicians acquire and integrate the requisite cognitive, motor, perceptual and social skills that enable the most eminent among them to redefine the upper limits of human intellectual and motor achievement.

The work of the first author (L. Stewart) has focused specifically on one aspect of a musician's repertoire: music reading. A longitudinal study conducted with a group of adult non-musicians revealed that after three months of piano lessons, the brains of these individuals showed a different pattern of activation in response to musical notation. Specifically, there were separate learning-related changes for the melodic and rhythm aspects of the notation (Stewart et al. 2003). The changes seen for melody were in the parietal cortex, an area involved in visuospatial processing, while the changes seen for the rhythmic aspects of notation were in early visual cortex, an area associated with performing visual discriminations. The intuitions of performing musicians are that the melodic and rhythmic information contained within single notes are processed simultaneously, while the findings suggest that they depend on different specialisations within the brain. This is true of our visual perception of the world in general: our experience is unified, even though the brain has to combine information processed from different functionally specialised areas.

A particularly interesting aspect of the study was that the changes in the brain's response to notation happened after only a short period of training and that, even at this early stage in learning, the brain had started to process musical notation automatically. The evidence for this was twofold. First, a 'musical-Stroop' task showed that after training, musical novices could not ignore musical notation in the context of a task that required them to make key presses on the basis of numbers. More precisely, a bar of musical notation was presented, on to which numbers between 1 and 5 had been superimposed. Instructed to ignore the musical notation and make key presses on the basis of the numbers alone (1 = thumb, 2 = index finger, etc.), the musical learners, post-training, were affected by the congruence of the number/note pairing. When both the note and the number conveyed the same action, they were faster; when the note and the number conveyed a different action, they were slower. A control group who had received no musical training were insensitive to this note/number pairing (Stewart, Walsh, and Frith 2004). The second line of evidence comes from the neuroimaging data (Stewart et al. 2003). During a condition where participants were instructed to search for a visual target amid bars of musical notation or bars of 'false notation' (visually complex but musically meaningless), they showed activation in the area of parietal cortex that was involved in the explicit melody reading condition. Simply seeing musical notes after a short period of musical training sets in motion a whole string of neural events related to the learned musical responses conveyed by the musical notation. Just like the results of the 'musical Stroop' experiment, these changes in brain activity show that musical training causes notes to acquire a significance that cannot be suppressed.

Expert performance in action

Complementary to the work on musical learning in the beginner is research with musical experts. Given the methodological limitations of collecting data during *actual* performances, where musicians must physically manipulate their instruments, move about on stage and interact with audiences, neuroscientists have turned to examining musicians' *mental* rehearsal and performance processes, asking them to think about specific performance situations and compositions without making corresponding physical movements. Findings reveal that brain areas hypothesised to be involved in the perception and actual performance of music show similar activation patterns during the mere imagery or mental practice of music. In an fMRI study with six adult musicians, Langheim et al. (2002) found that imagined performances of self-chosen musical excerpts activated a network of cortical areas that are supposed to integrate motor and musical-auditory maps in the brain (right inferior frontal gyrus) and musical and motor timing aspects (bilateral lateral cerebellum), as well as spatial features of motor and pitch representations (right superior parietal lobule). In an EEG study, Petsche, Von Stein, and Filz (1996) analysed the pattern of brain activity in one cellist during different experimental tasks. Their results suggest that the supplementary motor area (SMA) is most engaged with mentally playing scales and, less so but still observable, with imagining playing the piece and even with mere listening. Similarly, Halpern (2001) found that the SMA is involved in musical imagery and has suggested that the SMA may provide rehearsal mechanisms such as imaginary humming along with the imagined music.

Nevertheless, such studies have yet to examine one of the key elements of music performance: how, and to what extent, do changes in brain activation correspond to rehearsal, retrieval and expressive mechanisms employed at different points *throughout* a performance? Knowing, for instance, that networks of cortical activation are the same for an entire mental performance as for an entire physical performance is valuable, but in relation to how expert musicians learn and prepare music, the natural next step is to explore how these networks change *within* comparable mental and physical performances. This would divulge significant insight into whether the psycho-physiological processes that enable both are actually the same and, if so, could provide a stronger justification for integrating well-targeted mental rehearsal techniques into the education and training of skilled musicians (e.g., as a preventative measure for musculoskeletal problems resulting from too much physical practice).

However, detecting such changes, especially given that music performance is an inherently physical activity, is no trivial feat. Using current neuroimaging techniques, movement by participants can lead to artefacts in the data, in some cases, rendering them useless. Nevertheless, recent neuroscientific research has employed innovative experimental protocols and data analysis techniques to overcome such methodological obstacles. These have included *in vivo* measurements of musicians playing keyboard instruments (e.g., Parsons et al. 2005). Other studies have systematically extracted hypotheses from behavioural research for systematic testing in the laboratory.

For instance, musicians' apparent ability to transcend the limitations of memory during performance has long since captured the public's imagination. A series of studies by the second author (AW) set out to examine how musicians come to learn and memorise music for performance (Williamon and Valentine 2000, 2002; Williamon, Valentine, and Valentine 2002). Results of this research suggest that musicians, irrespective of their skill level, frequently start and stop their practice on bars in the music that they identify as integral to the music's structure (or form). Moreover, the prevalence of this practice strategy apparently increases as musicians learn a piece, from their initial practice session to a polished performance. This pattern is most pronounced for musicians at the highest levels of skill, and as such, the data appear to confirm some key predictions of psychological theories of expert memory – namely, that exceptional memory relies on the formation and exploitation of highly ordered retrieval structures and that these structures are most stable when rehearsed extensively throughout the learning process (Ericsson and Kintsch 1995).

None the less, these behavioural studies say little about the neural substrates of musical memory, and given that so much behavioural data has confirmed the prevalence of musical structure in musicians' encoding and retrieval processes, a follow-up study using laboratory-based, psycho-physiological measures was designed to investigate whether structurally important bars in a piece (as defined by performers themselves) were indeed integral to the encoding and retrieval of that piece from memory (Williamon and Egner 2004). A recognition memory task was devised that required a group of advanced pianists to identify bars from a piece of music they had recently learned to play from memory. The pianists were asked simply to provide a 'yes/no' response when presented with individual bars on a computer screen – that is, to distinguish bars belonging to the piece from similar bars not belonging to the piece, using a verbal response. Of interest was whether responses to hypothesised 'structural' bars would differ, in terms of response times and event-related potentials (a form of EEG activity), from bars that also belonged to the piece but were presumed to be 'non-structural'. Thus, even though structural and non-structural bars belonged to the same response category in the recognition task (piece versus non-piece), different behavioural and cortical responses to these stimuli were expected. The results confirmed this hypothesis. The recognition of structurally crucial moments in the music was accomplished with greater ease, and they were distinguishable from other segments of the music in terms of the brain activity underlying their retrieval. Although the recognition task involved was itself unmusical, the tested hypothesis was derived from studies that maintained ecological (and musical) validity. The concurrence of behavioural and psycho-physiological results thereby lends weight to the methods used and to the conclusions drawn in the research.

Optimising physical and mental skills for performance

Musicians are not only concerned with how best to rehearse, but how they can achieve an optimal state for performance on stage. Performance anxiety is commonplace among professional musicians and can be career-halting (Fishbein et al. 1988). Thus, research into the emotional as well as technical aspects of musical performance is necessary.

'Zoning In: Motivating the Musical Mind' was a Leverhulme-funded project based at the Royal College of Music from 1999 to 2002. Its aim was to enable music students to improve their performance skills and manage the high levels of stress that often accompany performance situations. Over 150 students at the College worked with a team of scientists and musicians to learn complementary mental and physical training routines drawn from four areas: (1) physical fitness, (2) Alexander technique, (3) neurofeedback and (4) mental skills training.

One of these interventions, neurofeedback, which refers to the monitoring of one's own brain activity with a view to influencing it, delivered marked improvements in the performance ability of the participating students (compared with control and other comparison groups). Moreover, the improvements were highly correlated with their ability to progressively influence neural signals associated with attention and relaxation (Egner and Gruzelier 2001; Gruzelier and Egner 2004). Similar results have subsequently been found with dancers (Raymond et al. 2005). This is an unusual example of a technique being borrowed from neuroscience to provide direct improvements for learners. Throughout the project, the team of collaborating scientists and musicians worked together to shape the delivery of each intervention and develop methods of assessing their effects. As such, one major outcome of the project, in addition to peer-reviewed articles and an edited book, has been a course unit now embedded in the RCM's undergraduate curriculum: *Psychology of performance* provides an introduction to performance enhancement research, along with theoretical seminars and practical training in select 'Zoning In' techniques (see Williamon 2004).

Future directions for neuroscience research and applications in musical education

The neuroscientific study of musical learning and performance is ripe for development, allowing insight into how people acquire and integrate the cognitive, motor, perceptual and social skills that can be at work during listening and performance. Clearly, neuroscience has much to gain from investigations of this distinctive and seemingly universal human behaviour. But what do musicians gain?

Williamon and Thompson (2004) have argued that current scientific research has begun to offer theoretical and pedagogical understanding of practical aspects of music learning and teaching and that the potential for further growth is now greater than ever. Moreover, several scientists have undertaken extensive programs of applied research with the aim of providing advice directly to musicians and their teachers on how to acquire specialised skills more easily and quickly (see Williamon 2004 for a review).

Given that music listening and performance are inescapably cognitive tasks, perhaps no other science promises more to music than cognitive neuroscience. In this paper, we have highlighted significant examples of how this field has already provided insight into processes and mechanisms that underpin musical listening, learning and performance. Nevertheless, there are distinct challenges that interested parties – neuroscientists, performers, music teachers, and so on – must overcome.

First and chief among these is the need to maintain ecological validity of scientific paradigms. We listen to music on the move, at the cinema, in concerts and elsewhere, and on occasion, it can have tremendous influence over us, both motionally and emotionally. Capturing that experience in the laboratory is not easy, and until such a time that laboratories are equipped to allow people to engage fully in *musical* experiences (be they solitary or social), we must endeavour to triangulate findings in the laboratory with those that emerge from behavioural and observational studies.

A second challenge for those interested in exploring the implications of neuroscience for musical education, and vice versa, is to conduct musically meaningful research with rigorous scientific outcomes. Research studies that aim to address musically relevant questions but that are, simply, empirically intractable will not lead to substantive conclusions. Likewise, research that endeavours to elucidate music cognition and perception without any remote connection to what musicians and listeners actually do will offer little by way of real-world application. In order to bridge this gap, research teams should strive to be, by default, interdisciplinary, where both scientists and musicians set the agenda, offer hypotheses, carry out day-to-day investigation and scrutinise results. Only then will the full and mutual benefits of true interdisciplinarity be realised.

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