THE BENEFITS OF MUSIC FOR THE BRAIN

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ABSTRACT

While it is clear that the power of music reflects its ability to activate the emotional and reward networks of the brain, its influence extends beyond this through its capacity to integrate multiple brain systems in the unified act of music making. This integrative role may endow music with unique benefits not inherent in other activities, underscoring its evolutionary significance. There are now more than 100 neuro-imaging studies showing that music activates multiple brain networks during music listening, responding and performance. As a result, when we compare musicians and non-musicians there are substantial differences in size, shape, density, connectivity, and functional activity that occur extensively throughout the musician's brain. It is not surprising then, that music has been dubbed the 'food of neuroscience', and provides a powerful model of how the brain can change in response to the environment. This discussion examines some of the core principles of brain plasticity derived from cognitive neuroscience, and the way in which music behaviour exemplifies these. It also considers how the brain can change in response to music and the broad range of cognitive processes and behaviours this may affect. Powerful amongst these is the ability of music to prime the brain for future learning, while more broadly promoting our individual and social wellbeing.

MUSIC MAKING INTEGRATES MULTIPLE BRAIN SYSTEMS

> *Playing, listening to and creating music … involves a tantalizing mix of practically every human cognitive function. (Zatorre, 2005, p. 312)*

Music occurs in every human society and forms part of our basic human design. In a paper entitled 'Music, the food of neuroscience?' Robert Zatorre proposed that music research

> *is beginning to illuminate the complex relation between cognitive–perceptual systems that analyse and represent the outside world, and evolutionarily ancient neural systems involved in assessing the value of a stimulus relative to survival and deciding what action to take. (2005, p. 315)*

This quote alludes to an emerging idea that music, as an art form, provides entry to an experience in which the many and varied functions of our mind can become integrated through the unified act of music making. This act is underscored by activation of the evolutionarily ancient reward system of the brain (the dopaminergic mesocorticolimbic system) that has a critical role in mediating arousal and attention, emotion, motivation, learning, memory and decision making. Both within an individual and between individuals, the concurrent activation of these multiple brain systems is presumably synchronised by the structure and temporal flow of music. This experience may underpin the personal and social power often ascribed to music, anecdotally described as experiences of transcendence or 'flow'. It also points to the adaptive and evolutionary significance of music, in terms of its multiple benefits for human learning and development.

As a complex task, music making provides a wealth of opportunities to study brain structure and function across multiple information processing systems, using both bottom-up and top-down approaches. Additionally, it allows investigation of isolable components or networks in either the intact or damaged brain in the context of specific parameters that may shape these networks. These include developmental factors fundamental to learning, such as the age when music training begins, or the extent of training to promote expertise. At present, our understanding of the multiple systems involved in listening to, responding to and performing music is based on the findings of more than 100 neuro-imaging studies that have been conducted with musicians and non-musicians (see Merrett & Wilson, 2011, for a detailed review), as well as behavioural and neuropsychological studies dating back more than 100 years (for example, see Stewart, von Kriegstein, Warren & Griffiths, 2006). Broadly, these findings indicate that music making draws on a range of highly developed and well-integrated sensory, perceptual and motor skills, as well as emotions, memory, and higher order cognitive and attentional functions (see Table 1). The motivation to engage in this complex state is driven by the reward system of the brain that activates in response to both the anticipation of and the experience of pleasure (Salimpoor, Benovoy, Larcher, Dagher & Zatorre, 2011). When combined with enhanced imitation or synchronisation with others (Spilka, Steele & Penhune, 2010), this may promote emotional sensitivity, empathy and social cognition (Hallam, 2010).

The well-established neuroscience and behavioural literature surrounding music making offers a strong platform from which to explore its many and varied reported benefits. Stated simply, this platform is based on the observation that music makes connections at multiple levels, including the following:

- the level of the brain, in terms of its structure and function
- the level of the mind, for transfer of cognitive skills that are shared or similar
- at a personal level, in terms of integrating our thinking and emotions and regulating our wellbeing
- at a social level, for building social cohesion.

These connections have been shown to translate to academic benefits, including improved literacy, numeracy, spatial abilities, executive functioning and intelligence, as well as greater school attendance and participation. They also extend to psychological benefits for self-confidence and self-discipline, and social benefits for teamwork and social skills (Hallam, 2010; Rickard & McFerrin, 2011).

Table 1 Information processing systems engaged by music making

Highly developed sensory processing	Multi-modal: auditory, visual, tactile, kinesthetic
Auditory perceptual processing	Auditory recognition, fine-grained pitch perception, auditory streaming and syntactic processing
Fine-motor skill learning	Bimanual coordination, digit and vocal control
Sensory-motor integration	Performance monitoring and correction
Visual and spatial processing	Visuo-spatial perception, mental rotation and spatial awareness
Executive functions and attention	Auditory and spatial working memory and imagery, selective and sustained attention, planning, creativity, problem solving and decision making
Emotional processing	Emotional awareness and expression, anticipation and the experience of reward
Memory processing	Procedural, semantic and episodic memory, including autobiographical memory
Social cognition	Imitation and empathy, theory of mind

This table summarises key findings in the literature and is not intended as an exhaustive list. The area of social cognition has received limited research attention.

MUSIC MAKING EPITOMISES CORE PRINCIPLES OF NEUROPLASTICITY

> *The large amount of natural variation in the training, practice, and skill acquisition of musicians creates a 'formidable laboratory' for studying experience-dependent neuroplasticity. (Peretz & Zatorre, 2005, p. 102)*

The adaptive capacity of the central nervous system, otherwise known as neuroplasticity, is considered to underpin learning in the intact brain, as well as relearning in the damaged brain. It is now well established that neurons and other brain cells, 'possess the remarkable ability to alter their structure and function in response to a variety of internal and external pressures, including behavioral training' (Kleim & Jones, 2008, p. S225). This implies that neuroplasticity is the brain mechanism used to encode experience and to repair itself by means of morphologic and physiologic responses. These responses are commonly studied at the level of change in expressed neurotransmitters of neurochemical systems, and at the level of cell assemblies or networks in terms of changes in brain morphology and patterns of connectivity.

In a recent review, Kleim and Jones (2008) identified 10 fundamental principles of neuroplasticity that have derived from decades of basic neuroscience research (see Table 2). These principles do not constitute an exhaustive list but have rather been chosen to highlight factors relevant to experience-dependent neuroplasticity in models of learning and recovery from brain damage. The obvious applicability of these principles to music making is clear and, for the sake of argument, they have been expressed in terms of training in Table 2. In fact, training in music making has been hailed as an ideal model for examining experience-dependent neuroplasticity as it embodies many of the prerequisites for inducing neuroplasticity: repetition of, intensity of and specificity of training against a background of high emotional salience and reward.

Table 2 Core principles of experience-dependent neuroplasticity

Use it or lose it	Neural networks not actively engaged in training can degrade
Use it and improve it	Training can induce dendritic growth and synaptogenesis within specific brain regions that enhance task performance
Specificity	The nature of training dictates the nature of the plasticity
Repetition matters	Repetition is required to induce lasting neural change (skill instantiation)
Intensity matters	A sufficient intensity of stimulation is required to induce plasticity
Time matters	Different forms of plasticity occur at different times during training
Salience matters	The training experience must be sufficiently rewarding to induce plasticity
Age matters	Training-induced plasticity occurs more readily in the younger brain
Transference	Plasticity induced by one training experience can enhance the acquisition of similar behaviours
Interference	Plasticity induced by one training experience can interfere with the acquisition of similar behaviours

This table summarises key principles identified by Kleim and Jones (2008) and is not intended as an exhaustive list.

THE MUSICIAN'S BRAIN AS A MODEL OF NEUROPLASTICITY

The heterogeneity of music training and skills in the general population provides a distinct advantage for researchers seeking to understand the mechanisms of experience-dependent neuroplasticity. Varying the task, the level of training, age of commencement and instrument played create many permutations and combinations from which precise experiments can be designed to answer a range of questions about the adaptation of the human brain. Already, this has identified a number of salient variables that appear to moderate the relationship between music training and neuroplasticity. In keeping with the core principles of Kleim and Jones, these include the age when training begins, the presence of the specific skill of absolute pitch and the exact instrument studied, as well as sex differences (Merrett & Wilson, 2011).

It has been repeatedly shown that the brains of musicians are differently organised from those of non-musicians, particularly if training began early in life. There are substantive differences in size, shape, density, connectivity and functional activity that occur extensively throughout the musician's brain, most notably in frontal, motor and auditory regions (Merrett & Wilson, 2011). Early training effects have been attributed to the benefits of environmental enrichment on the developing brain as well as its enhanced capacity for neuroplasticity, especially during sensitive periods when specialised skills may develop, such as absolute pitch (Wilson, Lusher, Martin, Rayner & McLachlan, 2012). It is also the case that different musical instruments provide unique sensory and motor experiences and can lead to differences in the type and location of neuroplastic changes (Bangert & Schlaug, 2006).

Notably, the first *in vivo* evidence of structural modification of the musician's brain was reported by Schlaug and colleagues, who observed a larger anterior corpus callosum in musicians who commenced early training (before the age of seven) (Schlaug, Jancke, Huang, Staiger & Steinmetz, 1995), and greater leftward asymmetry of the planum temporale in musicians with absolute pitch (Schlaug, Jancke, Huang & Steinmetz, 1995). The corpus callosum supports information transfer between the two cerebral hemispheres while the planum temporale is crucial to language and music processing. Subsequently, structural differences were demonstrated in many other brain regions, including sensori-motor and auditory cortices, the inferior frontal gyrus, the cerebellum and white matter tracts. These differences are generally bilateral and greater in musicians, as shown in Figure 1.

Commensurate with structural brain differences, music training has been linked to differences in brain function. While music processing typically engages the functioning of both cerebral hemispheres in musicians and non-musicians, there is evidence of increased left hemisphere specialisation in musicians for some tasks. These include passive music listening (Ohnishi et al., 2001), rhythm perception (Limb, Kemeny, Ortigoza, Rouhani & Braun, 2006) and imagined singing (Wilson, Abbott, Lusher, Gentle & Jackson, 2011), with the extent of left lateralisation potentially influenced by sex differences (Koelsch, Maess, Grossmann & Friederici, 2003). Generally speaking, differences in brain function have supported enhanced information processing and superior integration across different modalities in musicians, accompanied by more focal or efficient activation in functional imaging studies (Merrett & Wilson, 2011).

Enhanced information processing is evident in musicians even at early stages of processing for a variety of auditory stimuli, including clicks, tones, music and speech. This confers an advantage for encoding sound features, such as pitch and timing (McLachlan & Wilson, 2010), as demonstrated by superior auditory detection, pitch and temporal discrimination, and music and language processing in musicians (Merrett & Wilson, 2011). The sensory and motor systems of musicians also appear more tightly coupled particularly in musicians with early training, even after years of training, amount of music experience and current practice have been taken into account (Watanabe, Savion-Lemieux & Penhune, 2007). This superior sensori-motor integration is most evident for motor synchronisation tasks, which require the integration of motor information across multiple sensory modalities. Such cross-modal integration enhancements may vary between different types of musicians, depending on the instrument played (Merrett & Wilson, 2011).

Functional imaging studies have generally shown that while singing, playing instruments and improvising, musicians have more efficient representations and use fewer neural resources than non-musicians (Merrett & Wilson, 2011). Since these patterns of activation are typically accompanied by superior motor performance, they are considered to reflect greater recruitment of regions pertinent to task performance and decreased activation of areas that provide secondary support. These findings converge with transcranial magnetic stimulation studies that suggest enhanced motor information transfer along white matter tracts, such as the corpus callosum (Ridding, Brouwer & Nordstrom, 2000). More generally, there is good consistency between the structural, functional and behavioural differences found between musicians and non-musicians, confirming the presence of widespread neuroplastic changes associated with music training. These widespread changes have been supported by a number of recent longitudinal studies that show that music training can causally induce experience-dependent neuroplasticity across the lifespan (Hyde et al., 2009; Stewart et al., 2003), as well as enhance the capacity for further learning and neuroplasticity (Ragert, Schmidt, Altenmüller & Dinse, 2004; Rosenkranz, Williamon & Rothwell, 2007) in both healthy and brain injured individuals (Schlaug, Marchina & Norton, 2009).

MUSIC MAKING 'PRIMES' THE BRAIN FOR LEARNING

Through the core principles of neuroplasticity, the brain continually remodels its neural circuitry to encode new experiences and support behavioural changes that guide learning in the healthy and damaged brain (Table 2). These principles highlight that not only early music training but also its accumulation and recency

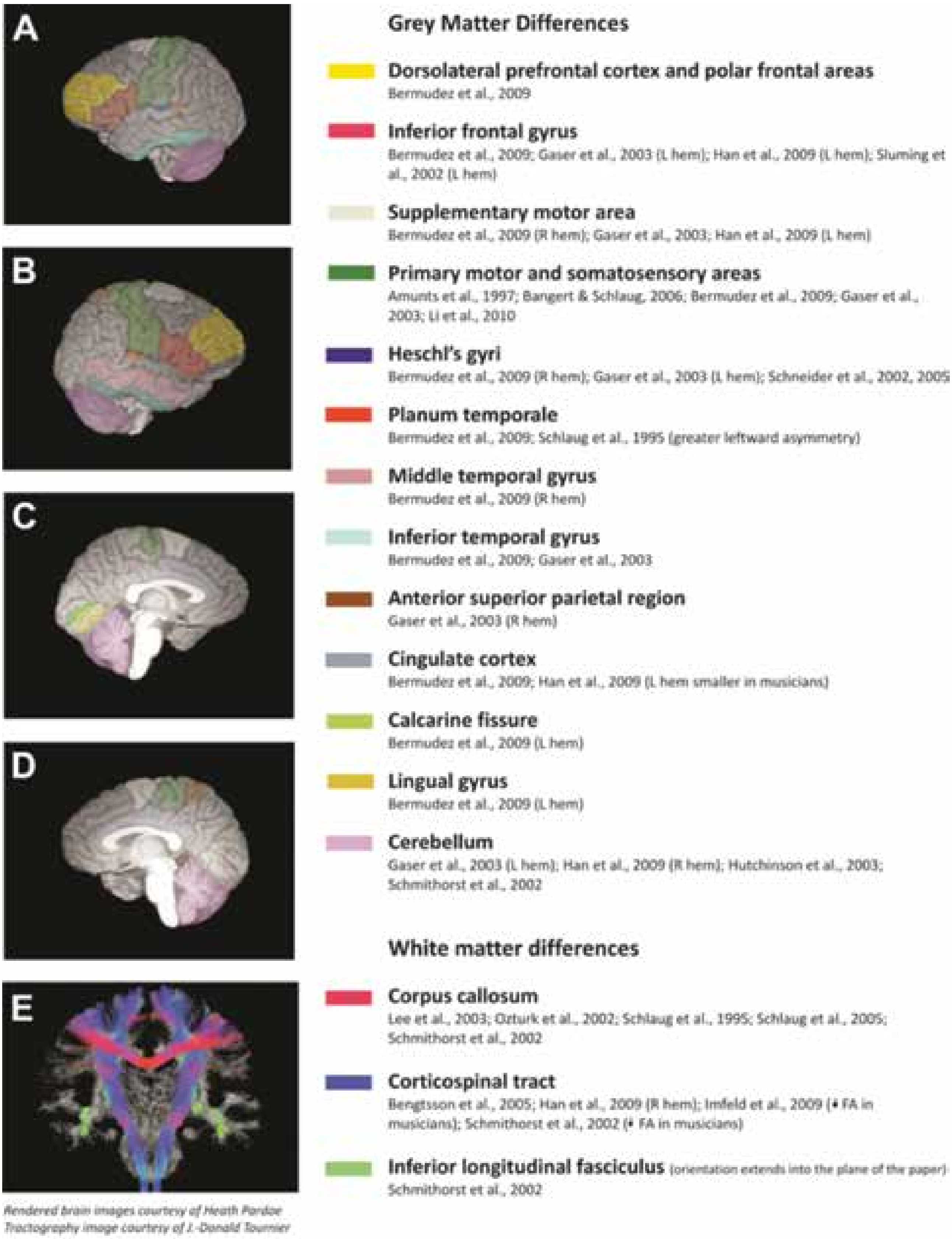

Figure 1 Approximate locations of structural brain differences in musicians compared to non-musicians for the left hemisphere (A lateral, C medial), right hemisphere, (B lateral, D medial), and white matter tracts (E). All differences are bilateral unless otherwise noted (L hem = left hemisphere; R hem = right hemisphere; FA = fractional anisotropy). Figure courtesy of Merrett & Wilson (2011).

can moderate the extent of brain plasticity. This raises a question about the stability of training-induced changes in the brain, and whether ongoing music training is required to maintain such changes. For example, would significant changes in the structure of the brain induced by early training remain even if music training ceased shortly afterwards? Studies outside the music domain have suggested that structural changes in the brains of adults can occur within one week of training on a complex motor task (for example, juggling), but return to baseline without ongoing training (Draganski et al., 2004; Driemeyer, Boyke, Gaser, Büchel & May, 2008). These studies also suggest that it is the act of learning the task rather than ongoing practice or maintenance of the task that induces neuroplasticity. For example, Driemeyer and colleagues (2008) found that within the first seven days, juggling training led to neuroplastic changes, whereas ongoing practice over the following month (with associated skill improvement) did not induce further plasticity. This suggests that different outcomes may follow learning methods that focus on training new tasks as opposed to repeated practice of learned tasks. Although the terms 'training' and 'practice' are often used interchangeably, perhaps these terms should be differentiated to indicate whether a learning paradigm includes novel, challenging tasks with corrective feedback (training) or repetition without external feedback (practice). This is important because neurobiological differences may exist between music 'training' and 'practice'.

Even before music training occurs, environmental differences may play a role in future training-induced changes in the brain. For example, a study in preschool children indicated that having more music exposure (such as another musician in the home) led to differences in auditory functioning that were already evident before training (Shahin, Roberts & Trainor, 2004). Moreover, a number of studies now suggest that the musician's brain seems more capable of neuroplastic change (Herholz, Boh & Pantev, 2011; Ragert et al., 2004; Rosenkranz et al., 2007; Seppanen, Hamalainen, Pesonen & Tervaniemi, 2012; Tervaniemi, Rytkönen, Schröger, Ilmoniemi & Näätänen, 2001). This phenomenon is known as 'meta-plasticity' and occurs when the activity of the brain regulates the expression of future plasticity at the level of both individual neuronal connections and connections between brain regions (Abraham, 2008). It suggests that plasticity begets plasticity, and that previous music exposure primes the brain for future learning. This supports the observation that training in music can influence learning in other fields, providing a potential mechanism for 'near transfer' effects, and the broader cognitive and behavioural benefits of engaging the brain in music.

CONCLUSIONS

From the perspective of neuroscience, music making has much to offer our understanding of the brain and the way its multiple systems can interact to produce benefits for mental health and social wellbeing, both by integrating our thinking and emotions and helping us to connect with others. Music provides a powerful tool to enhance learning because of its widespread effects on the brain and its ability to induce experience-dependent neuroplasticity. By harnessing the many and varied benefits of music making, it can create an enriched environment to stimulate the fundamental capacity of the brain to adapt to the ever-changing environment, thereby promoting our individual and social development. While not exhaustive, this discussion has attempted to draw together some key perspectives recently emerging from the field that are informed by advances in basic neuroscience research. These advances will continue to shed important insights into the power of music to integrate the mind and body and to heal the brain through the unified act of music making.

REFERENCES

Abraham, W. C. (2008). Metaplasticity: Tuning synapses and networks for plasticity. *Nature Reviews Neuroscience, 9*, 65–75.

Bangert, M., & Schlaug, G. (2006). Specialization of the specialized in features of external human brain morphology. *European Journal of Neuroscience, 24*, 1832–1834.

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: Changes in grey matter induced by training. *Nature, 427*, 311–312.

Driemeyer, J., Boyke, J., Gaser, C., Büchel, C., & May, A. (2008). Changes in gray matter induced by learning – revisited. *PLOS One, 3*, e2669.

Hallam, S. (2010). The power of music: Its impact on the intellectual, social and personal development of children and young people. *International Journal of Music Education, 28*, 269–289.

Herholz, S. C., Boh, B., & Pantev, C. (2011). Musical training modulates encoding of higher-order regularities in the auditory cortex. *European Journal of Neuroscience, 34*, 524–529.

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical training shapes structural brain development. *Journal of Neuroscience, 29*, 3019–3025.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech, Language, and Hearing Research, 51*, S225–239.

Koelsch, S., Maess, B., Grossmann, T., & Friederici, A. D. (2003). Electric brain responses reveal gender differences in music processing. *NeuroReport, 14*, 709–713.

Limb, C. J., Kemeny, S., Ortigoza, E. B., Rouhani, S., & Braun, A. R. (2006). Left hemispheric lateralization of brain activity during passive rhythm perception in musicians. *The Anatomical Record. Part A, Discoveries in Molecular, Cellular, and Evolutionary Biology, 288A*, 382–389.

McLachlan, N., & Wilson, S. J. (2010). The central role of recognition in auditory perception: A neurobiological model. *Psychological Review, 117*, 175–196.

Merrett, D., & Wilson, S. J. (2011). Music and neural plasticity. In N. S. Rickard & K. McFerran (Eds.), *Lifelong engagement with music: Benefits for mental health and well-being* (pp. 123–162). New York, NY: Nova Science Publishers.

Ohnishi, T., Matsuda, H., Asada, T., Aruga, M., Hirakata, M., Nishikawa, M., Katoh, A., & Imabayashi, E. (2001). Functional anatomy of musical perception in musicians. *Cerebral Cortex, 11*, 754–760.

Peretz, I., & Zatorre, R. (2005) Brain organization for music processing. *Annual Review of Psychology, 56*, 89–114.

Ragert, P., Schmidt, A., Altenmüller, E., & Dinse, H. R. (2004). Superior tactile performance and learning in professional pianists: Evidence for meta-plasticity in musicians. *European Journal of Neuroscience, 19*, 473–478.

Rickard, N. S., & McFerran, K. (Eds.) (2011). *Lifelong engagement with music: Benefits for mental health and well-being*. New York, NY: Nova Science Publishers.

Ridding, M. C., Brouwer, B., & Nordstrom, M. A. (2000). Reduced interhemispheric inhibition in musicians. *Experimental Brain Research, 133*, 249–253.

Rosenkranz, K., Williamon, A., & Rothwell, J. C. (2007). Motorcortical excitability and synaptic plasticity is enhanced in professional musicians. *Journal of Neuroscience, 27*, 5200–5206.

Salimpoor, V., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience, 14*, 257–264.

Schlaug, G., Jancke, L., Huang, Y. X., Staiger, J. F., & Steinmetz, H. (1995). Increased corpus-callosum size in musicians. *Neuropsychologia, 33*, 1047–1055.

Schlaug, G., Jancke, L., Huang, Y. X., & Steinmetz, H. (1995). In-vivo evidence of structural brain asymmetry in musicians. *Science, 267*, 699–701.

Schlaug, G., Marchina, S., & Norton, A. (2009). Evidence for plasticity in white-matter tracts of patients with chronic Broca's aphasia undergoing intense intonation-based speech therapy. *Annals of the New York Academy of Sciences, 1169*, 385–394.

Seppanen, M., Hamalainen, J., Pesonen, A. K., & Tervaniemi, M. (2012). Music training enhances rapid neural plasticity of N1 and P2 source activation for unattended sounds. *Frontiers in Human Neuroscience, 6*.

Shahin, A., Roberts, L. E., & Trainor, L. J. (2004). Enhancement of auditory cortical development by musical experience in children. *NeuroReport, 15*, 1917–1921.

Spilka, M. J., Steele, C. J., & Penhune, V. B. (2010). Gesture imitation in musicians and non-musicians. *Experimental Brain Research, 204*, 549–558.

Stewart, L., Henson, R., Kampe, K., Walsh, V., Turner, R., & Frith, U. (2003). Brain changes after learning to read and play music. *NeuroImage, 20*, 71–83.

Stewart, L., von Kriegstein, K., Warren, J. D., & Griffiths, T. D. (2006). Music and the brain: Disorders of musical listening. *Brain, 129*, 2533–2553.

Tervaniemi, M., Rytkönen, M., Schröger, E., Ilmoniemi, R. J., & Näätänen, R. (2001). Superior formation of cortical memory traces for melodic patterns in musicians. *Learning & Memory, 8*, 295–300.

Watanabe, D., Savion-Lemieux, T., & Penhune, V. B. (2007). The effect of early musical training on adult motor performance: Evidence for a sensitive period in motor learning. *Experimental Brain Research, 176*, 332–340.

Wilson, S. J., Abbott, D. F., Lusher, D., Gentle, E. C., & Jackson, G. D. (2011). Finding your voice: A singing lesson from functional imaging. *Human Brain Mapping, 32*, 2115–2130.

Wilson, S. J., Lusher, D., Martin, C. L., Rayner, G., & McLachlan, N. M. (2012). Intersecting factors lead to absolute pitch acquisition that is maintained in a 'fixed do' environment. *Music Perception, 29*, 285–296.

Zatorre, R. J. (2005). Music, the food of neuroscience? *Nature, 434*, 312–315.