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The impact of making music on aural perception and language skills: A research synthesis

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Abstract

This paper provides a synthesis of research on the relationship between music and language, drawing on evidence from neuroscience, psychology, sociology and education. It sets out why it has become necessary to justify the role of music in the school curriculum and summarizes the different methodologies adopted by researchers in the field. It considers research exploring the way that music and language are processed, including differences and commonalities; addresses the relative importance of genetics versus length of time committed to, and spent, making music; discusses theories of modularity and sensitive periods; sets out the OPERA hypothesis; critically evaluates research comparing musicians with non-musicians; and presents detailed accounts of intervention studies with children and those from deprived backgrounds, taking account of the importance of the nature of the musical training. It concludes that making music has a major impact on the development of language skills.

Keywords: music; language; aural perception; interventions; education

Introduction

In recent years, in most of the developed world, music education has been under threat as governments and those responsible for education locally have focused on the importance of developing academic excellence in science, technology, mathematics and the local language. For young children, the emphasis has been on developing numeracy and literacy skills, and in the UK a rigorous testing regime has been introduced (Roberts, 2016). Test outcomes at age 11 have taken on particular significance for children, as they often determine placement in an ability group at secondary school. They are also important for the school, as poor test outcomes can lead to a school being placed in special measures, with implications for staff, particularly head teachers. Inevitably head teachers in schools where academic outcomes are not strong are reluctant for children to spend time on subjects that are not tested. A further challenge for music is that many primary classroom teachers do not feel that they have the necessary skills to teach it (Hallam *et al*., 2009) and are often reluctant to engage in musical activities with their class. Pressure on school budgets means that head teachers are not always able to buy in specialist primary music teachers to ensure that children receive an appropriate music education. Collectively, these issues have threatened the place of music in UK schools and led to a need for the place of music in the curriculum to be justified.

Independently of these concerns, music psychologists and neuroscientists have long been interested in whether actively making music can impact on intellectual and other skills. As

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early as 1975, Hurwitz and colleagues explored the impact of active music-making on general intelligence. They showed that a group engaged in music-making scored significantly higher than a control group on three of five sequencing tasks, four of five spatial tasks and had higher reading achievement scores. More recent neuroscientific research has demonstrated that active engagement with music produces cortical reorganization, which, if it occurs early in development, can produce hardwired changes in the brain affecting the way information is processed (Schlaug *et al.*, 1995a; Schlaug *et al.*, 1995b; Hudziak *et al.*, 2014). Musicians who have actively engaged in making music over many years have increased neuronal representation for the processing of the tones of the musical scale. The largest cortical representations are found in those who have played instruments for the longest periods of time (Pantev *et al.*, 2003). The neuronal changes are specific to the particular musical activity undertaken, including the instruments played (Münte *et al.*, 2003; Pantev *et al.*, 2001). Overall, the neuroscientific evidence shows that active engagement with music has a significant impact on brain structure and function (Merrett *et al.*, 2013; Norton *et al.*, 2005).

Several academic disciplines have been involved in research that has attempted to establish the impact of music-making on other skills. Different research designs and methodologies have been adopted. Sample sizes have varied, as has the length of time of musical interventions. Early research tended to be based on correlation studies that assessed musical ability and established its relationship with other skills (Milovanov *et al.*, 2008). Other research has compared the performance of musicians (at varying levels of expertise) with non-musicians (Parbery-Clark *et al.*, 2012). Neither of these approaches can establish causality. While advanced statistical techniques can control for possible confounding variables, the strongest research designs are interventions, where the outcomes of those participating in musical activities are compared with control groups. Such studies vary in the length of the intervention, the range of measures adopted to assess outcomes and the ages of the participants. These differences can make interpretation of findings difficult.

The purpose of the current paper is to consider the research that has been undertaken relating to the impact of actively making music on aural perception and language. It draws on research in a variety of disciplines adopting a range of methodologies. The paper explores the way that music and language are processed, including differences and commonalities; addresses the relative importance of genetics versus length of time committed to, and spent, making music; discusses theories of modularity and sensitive periods; sets out the OPERA hypothesis; critically evaluates research comparing musicians with non-musicians; and presents detailed accounts of intervention studies with children and those from deprived backgrounds, taking account of the importance of the nature of the musical training.

The relationship between the processing of music and language

Communication in everyday life requires the implementation of complex linguistic and musical systems (Kraus and Slater, 2016). Music and speech both depend on perceptual categorization. In speech the focus is primarily on timbral contrasts, while in music it is on distinguishing differences in pitch. Vowel sounds and sound frequencies are spread along continua. Acquiring musical and language skills requires individuals to learn to separate the sounds in each continuum into separate vowels or pitches. The auditory analysis skills used in language processing (phonological distinctions, blending and segmentation of sounds) are similar to the skills necessary for the perception of rhythmic (Lamb and Gregory, 1993; Lipscomb *et al.*, 2008), harmonic and melodic discrimination (Anvari *et al.*, 2002; Barwick *et al.*, 1989; Lamb and Gregory, 1993). Given this level of commonality, it is unsurprising that the evidence suggests that the processes involved in the perception of music and speech overlap (Besson *et al*., 2011; Bidelman *et al*., 2013; Chandrasekaran *et al*., 2009; Gordon *et al*., 2015; Kraus and Chandrasekaran, 2010; Kraus and White-Schwoch, 2017; Overy, 2003; Patel and Iversen, 2007; Rogalsky *et al*., 2011; Sammler *et al*., 2007; Schulze *et al*., 2011; Tallal and Gaab, 2006; Wong *et al*., 2007). The ease with which these shared processes operate depends on the individual's prior experiences with sound, including music (Bigand and Poulin-Charronnat, 2006; Elmer *et al*., 2014; Krishnan *et al*., 2005; Krizman *et al*., 2012; White-Schwoch *et al*., 2013).

Despite the commonalities between the processing of music and language, there continues to be debate about the exact nature of the relationship. One area of controversy is whether the brain networks involved are separate or whether neural resources are shared (Kunert and Slevc, 2015; Peretz *et al*., 2015; Norman-Haignere *et al*., 2015). Neuroscientific research has focused on anatomical overlap, transfer effects and functional interaction between cognitive processes (Jentschke, 2016). Experiments using neuroimaging have revealed common brain regions (Koelsch *et al*., 2002; Herdener *et al*., 2014) but this may not mean that there is shared processing circuitry. The outcomes of more sophisticated research methods are also open to different interpretations (see Kunert and Slevc, 2015). Other areas of interest include involvement in structural processing (Patel, 2003), general attention (Perruchet and Poulin-Charronnat, 2013), and cognitive control (Slevc and Okada, 2015). For instance, Jung and colleagues (2015) demonstrated that rhythmic expectancy is crucial to the interaction of processing musical and linguistic syntax, while a meta-analysis of 171 neuroimaging studies concluded that neural overlap might be task-dependent. Task effects may therefore limit the nature of any conclusions that can be drawn about the neurobiology of music and speech (LaCroix *et al*., 2015). Research with individuals classed as 'tune deaf' has shown that poor musical performance tends to be associated with deficits in processing speech sounds (Jones *et al*., 2009). Taken together, the research indicates that music and language share some cognitive processing mechanisms, although the specific underlying mechanisms have not yet been established (Patel, 2017).

The role of genetics versus length of time spent making music

A further debate concerns the extent to which observed differences between musicians and non-musicians have a genetic underpinning or are the result of extended musical training. Studies comparing the performance of musicians with non-musicians is unable to establish whether differences might be pre-existing (Corrigall *et al*., 2013; Hyde *et al*., 2009; Moreno *et al*., 2009; Schellenberg, 2004). Schellenberg (2015) argues that children who actively participate in making music may differ from other children on a range of cognitive, personality and demographic variables. Some of these may, at least in part, be determined by genetics. For instance, Corrigall and colleagues (2013) showed that children exhibiting high levels of 'openness to experience' on the Big Five personality test were more likely to continue with music lessons. Their findings indicate that individual differences influence who takes music lessons and to what extent they persist. They also suggest that personality variables can be important predictors of the outcomes of musical training. However, there is also considerable evidence that musical training enhances auditory processing in children who, prior to training, had no pre-existing differences (Chobert *et al*., 2014; François *et al*., 2013; Hyde *et al*., 2009; Kraus, Slater *et al*., 2014; Moreno *et al*., 2009; Moreno *et al*., 2011b; Norton *et al*., 2005; Tierney *et al*., 2013).

Schlaug (2015) suggests that the repetition of motor actions, alongside the processing of aural and visual stimuli, while receiving multi-sensory feedback, may strengthen neural connections. Supporting this, there is evidence that years of musical practice increase auditory processing abilities and confer an advantage on musicians not only for musical sounds but also for speech

(Besson *et al*., 2011; Kraus and Chandrasekaran, 2010; Strait *et al*., 2010). Indeed, the longer the period of musical training the greater the benefits, suggesting that music experience is the cause (Forgeard *et al*., 2008; Ho *et al*., 2003; Norton *et al*., 2005; Pantev *et al*., 1998; Seither-Preisler *et al*., 2014; Strait and Kraus, 2014). Further, it is not only the overall number of months or years during which music-making has taken place, but also the actual time spent making music, practising or rehearsing (Kraus, Hornickel *et al*., 2014).

Modularity and sensitive periods in development

Speech and music processing have been shown to rely on overlapping neural substrates in early life (Kotilahti *et al*., 2010; Perani *et al*., 2011). Brandt and colleagues (2012) have argued that without the ability to hear musically it would not be possible to acquire language. They describe language as a special type of music and suggest that music serves as a scaffold to learn speech. This process is ongoing as the infant interacts with the mother, who communicates using motherese, a relatively high pitched, slow and rhythmic form of speech with a larger pitch range and more exaggerated melodic contours than typical adult-directed speech (Fernald, 1989). To explain some of the neuroscience research findings outlined earlier, Koelsch (2011) suggests that there is an emergent modularity, in that musical and language processes might be modularized in adults, but have similar developmental underpinnings in infants and children. Since newborns do not understand the syntax and semantics of words, they focus instead on the acoustic features of voices and the prosodic features of language (rhythm, speed, pitch and relative emphasis). As they become more familiar with speech and cognitive maturation occurs, the processing systems may become differentiated (Koelsch and Siebel, 2005: 582).

Related to the possibility of an emergent modularity is the notion of a sensitive period for musical training. This has been proposed because musicians who begin training early show better task performance and greater changes in auditory and motor regions of the brain than those who start later in childhood (Penhune, 2011; Bengtsson *et al*., 2005; Elbert *et al*., 1995; Gaser and Schlaug, 2003; Koeneke *et al*., 2004; Schneider *et al*., 2002), although auditory learning and plasticity are possible during and after a sensitive period (Strait *et al*., 2010). During a sensitive period, learning is largely a bottom-up process that is triggered by exposure to auditory input and is optimal because underlying neural circuits have not yet been fully specified and are extremely sensitive to input received. After a sensitive period, learning is largely a top-down process that depends on attention to enhance the salience of features in order to encode them. It is a process of changing the structure and efficiency of pre-existing circuits to process more optimally a new input source. Music training may expedite the developmental trajectory of top-down control over speech processing (White *et al*., 2013; Strait *et al*., 2014). Further evidence for this comes from those with absolute pitch, the ability to identify or produce musical pitch without recourse to any reference tones. Typically, those with absolute pitch begin training before the age of 6, almost all before the age of 9. It is rare for absolute pitch to be acquired later than this (Baharloo *et al*., 1998).

The OPERA hypothesis

Patel (2011) proposed the OPERA hypothesis to explain the way that music training can benefit language skills. The model includes Overlap (subcortical and cortical networks); Precision (the music must place higher demands on the networks than language); Emotions (the music must elicit strong positive emotions); Repetition (the musical activity must be repeated frequently); and must be associated with Attention. This hypothesis suggests that there is an anatomical overlap of the neural areas that process acoustic features in both speech and music, and that music requires greater precision than speech and places higher demands on these overlapping neural areas. It also suggests that musical training requires repetition so that the neural areas are continually activated. This in turn is related to enhancement in attention. This theoretical position has considerable implications for music education. For instance, it suggests that to benefit language skills music tasks must stretch the capabilities of the learner; invoke positive, strong emotions; provide opportunities for repetition; and demand focused attention.

Research comparing musicians with non-musicians

There is a considerable body of research that compares musicians with non-musicians. In such research, musicians tend to be identified in terms of playing an instrument or being involved in formal singing activities. Non-musicians are defined as not engaging in music-making in these ways, although they may engage with music in other ways. Despite the crudity of this categorization, much research has been undertaken on this basis with participants of all ages, from children to seniors (Milovanov *et al*., 2008; Parbery-Clark *et al*., 2012). Overall, musicians show improved performance on a range of listening skills (Hyde *et al*., 2009; Pantev *et al*., 2001; Patel and Iversen, 2007; Tallal and Gaab, 2006). They have been shown to have enhanced abilities to process pitch and temporal sound information (Kraus and Chandrasekaran, 2010; Magne *et al*., 2006; Micheyl *et al*., 2006; Moreno *et al*., 2009; Musacchia *et al*., 2007; Parbery-Clark *et al*., 2009b; Parbery-Clark *et al*., 2011; Schön *et al*., 2004; Strait *et al*., 2010; Zendel and Alain, 2009), and exhibit enhanced cortical evoked potentials to deviations in pitch and meter (Chobert *et al*., 2011; Chobert *et al*., 2014; Marie *et al*., 2011a; Marie *et al*., 2011b; Marques *et al*., 2007; Tervaniemi *et al*., 1997; van Zuijen *et al*., 2005). Overall, the findings comparing musicians with non-musicians have shown that participation in music-making activities improves language processing as it leads to the further development of neural networks (Besson *et al*., 2007; Moreno and Besson, 2006; Parbery-Clark *et al*., 2009b; Schön *et al*., 2004; Shahin, 2011; Thompson *et al*., 2003). Strait and Kraus (2011a; 2011b) argue that the auditory expertise gained over years of music training fine-tunes the auditory system. It strengthens the neurobiological and cognitive underpinnings of speech and music processing, including enhancing neural responses to changes in pitch, duration, intensity and voice onset time (Chobert *et al*., 2011; Jentschke and Koelsch, 2009; Magne *et al*., 2006; Marie *et al*., 2011a; Marie *et al*., 2011b; Schön *et al*., 2004). This increased sensitivity and attention to speech seems to be supported, in part, by right-hemisphere processing (Jantzen *et al*., 2014).

Musician's pitch expertise appears to extend from music to the language context with no significant differences between domains, thus supporting the tracking of language (Alexander *et al*., 2005; Bidelman *et al*., 2011; Delogu *et al*., 2010; Lee and Hung, 2008; Marie *et al*., 2011a; Mok and Zuo, 2012; Weidema *et al*., 2016). Musicians demonstrate more robust and quicker auditory brainstem responses to speech (Bidelman *et al*., 2009; Bidelman and Krishnan, 2010; Kraus and Chandrasekaran, 2010; Musacchia *et al*., 2007; Parbery-Clark *et al*., 2009a; Parbery-Clark *et al*., 2009b; Patel and Iversen, 2007; Wong *et al*., 2007; Zendel and Alain, 2009). Their enhanced perceptual skills play a role in enhancing language skills (Bever and Chiarello, 2009; Gaab *et al*., 2005; Hutka *et al*., 2015; Jakobson *et al*., 2003; Strait *et al*., 2014; Tallal and Gaab, 2006; Zatorre and Belin, 2001; Zatorre *et al*., 2002). They are also better at phoneme perception (Kühnis *et al*., 2013; Ott *et al*., 2011; Pinheiro *et al*., 2015). There is a positive relationship between phonological awareness and musical ability in preschoolers, children aged 5 to 6 years and those in older childhood (Anvari *et al*., 2002; Lamb and Gregory, 1993; Milovanov *et al*., 2008; Milovanov and Tervaniemi, 2011; Peynircioğlu *et al*., 2002). Cross-sectional studies have shown that preschool, school-aged children and adults with musical experience are able to make stronger distinctions between speech syllables than non-music students (Kraus and Nicol, 2014; Parbery-Clark *et al*., 2012; Strait and Kraus, 2014; Zuk *et al*., 2013).

Overall, the evidence shows that musicians develop enhanced processing of sound. This has many benefits, including enhanced auditory attention (Strait and Kraus, 2011a; Strait and Kraus, 2011b; Strait *et al*., 2014), better processing of the metric structure of words when they are presented in sentences (Marie *et al*., 2011b) and the discrimination and identification of moraic language features (units of timing) (Sadakata and Sekiyama, 2011). Musicians can classify speech sounds (vowels) more easily and quickly than non-musicians (Bidelman *et al*., 2014), have advantages in relation to the processing of linguistic syntax (Fiveash and Pammer, 2014) and in making judgements about grammar (Patston and Tippett, 2011). They are better able to distinguish rapidly changing sounds (Gaab *et al*., 2005), harmonic differences (Corrigall and Trainor, 2009; Musacchia *et al*., 2008; Zendel and Alain, 2009) and tonal variations in non-native speech sounds (Chandrasekaran *et al*., 2009; Cooper and Wang, 2010; Kühnis *et al*., 2013; Marie *et al*., 2011a; Marie *et al*., 2011b; Marques *et al*., 2007; Martínez-Montes *et al*., 2013; Perfors and Ong, 2012; Slevc and Miyake, 2006; Wong *et al*., 2007; Wong and Perrachione, 2007; Yang *et al*., 2014).

When speech is accompanied by noise, musicians are able to perceive it more easily than non-musicians (Parbery-Clark *et al*., 2009a; Parbery-Clark *et al*., 2009b; Parbery-Clark *et al*., 2011; Parbery-Clark *et al*., 2012; Strait *et al*., 2012) and they can more easily identify syllables when spectral information is degraded (Elmer *et al*., 2012). They are also better than non-musicians at the perception and processing of vocally expressed emotion (Bhatara *et al*., 2011; Lima and Castro, 2011; Strait *et al*., 2009; Thompson *et al*., 2004). In comparison with non-musicians, their memory for lyrics (Kilgour *et al*., 2000), short excerpts of speech (Cohen *et al*., 2011) and novel words is enhanced (Dittinger *et al*., 2016). They also have an advantage in correctly pronouncing irregularly spelt words (Jakobson *et al*., 2008; Stoesz *et al*., 2007) and tend to have a larger vocabulary (Forgeard *et al*., 2008).

The longer the period of time over which individuals engage with making music, the greater the benefits (Wong *et al*., 2007; Musacchia *et al*., 2008; Lee and Noppeney, 2014). However, the nature of the requirements of particular musical activities may also be important. Rauscher and Hinton (2011) used four discrimination tasks with adults aged 16 to 63, musicians and non-musicians. They found that auditory discrimination was better in the musicians, particularly the string players as compared with percussionists. They suggested that this was likely to be a consequence of the many years of subtle tonal discrimination that are required to play a stringed instrument.

The benefits of musical training have been shown to continue throughout the lifespan. Bidelman and Alain (2015) showed that musical training can offset the decline in auditory brain processing that accompanies normal aging. They recorded brainstem and cortical neuro-electric responses in older adults as they classified speech sound along an acoustic–phonetic continuum. Those who had had only modest musical training had higher temporal precision in speech-evoked responses and were better at differentiating phonetic categories. It seems that even limited musical training can preserve robust speech recognition late in life. Overall, there is compelling evidence that musicians have enhanced auditory processing skills, which support the processing of language in a range of different ways.

Intervention studies

Intervention studies, where participants are divided into control and experimental groups, provide the most powerful evidence for the impact of musical activities on language skills because they are able to demonstrate causality. One strand of research has focused on the development of musical skills and auditory discrimination in young children (Elbert *et al*., 1995; Hutchinson *et al*., 2003; Pantev *et al*., 2001; Pantev *et al*., 2003; Pascual-Leone, 2001; Schlaug *et al*., 1995a; Schlaug *et al*., 1995b). Making music has been shown to strengthen children's auditory encoding of speech (Chobert *et al*., 2014; Magne *et al*., 2006; Strait *et al*., 2011, Strait *et al*., 2013; Tierney *et al*., 2013), their auditory discrimination and attention (Chobert *et al*., 2011; Koelsch *et al*., 2003; Moreno *et al*., 2009; Putkinen *et al*., 2013) It has also been shown to lead to structural changes in auditory cortical areas in the brain (Hyde *et al*., 2009; Seither-Preisler *et al*., 2014). This section of the paper provides detailed accounts of recent examples of intervention research.

Intervention studies with young children and infants have demonstrated considerable auditory benefits. For instance, Zhao and Kuhl (2016) examined the effects of a randomized laboratory-based intervention on music and speech processing in 9-month-old infants who were exposed to music in triple time (a waltz) in a social context. Infants, with the aid of caregivers, tapped out the musical beats with maracas, or their feet, and were often bounced in synchronization to the musical beats. After 12 sessions, to test whether the intervention enhanced infants' general ability to extract temporal structure and enhance predictions about future stimuli in complex auditory sounds, their neural responses to temporal structure violations in music and speech were assessed. Compared with infants in the control group, the infants exposed to the intervention improved their detection and prediction of auditory patterns, demonstrating enhanced temporal structure processing in music and speech, musical pitch and meter processing.

In a study with older children aged 2 to 3, Putkinen and colleagues (2013) found a relationship between informal musical activities with parents at home and auditory event-related potentials linked to sound discrimination and attention. The findings demonstrated that children with higher levels of musical activity had heightened sensitivity to temporal acoustic changes, more mature auditory change detection and less distractibility. Children within the study who also attended a music play school until the age of 4 or 6 displayed more rapid development of neural responses than those who gave up the activity. Similarly, the Soundplay project in the UK (Pitts, 2016) worked with children of a similar age, 2 to 4, using a combination of observation, music and language tracker tools, interviews and written reports from early years practitioners, parents and workshop leaders. The research found that there was higher than average development in language skills among those children who had been identified as being at risk of developmental delay (Pitts, 2016).

Research with children in the early years of schooling has shown similar benefits to those found by Putkinen and colleagues (2013) and Pitts (2016). Working with children aged 4 to 6, Fujioka and colleagues (2006) recorded auditory evoked responses to a violin tone and a noise-burst stimulus in four repeated measurements over a one-year period using magneto encephalography. Half of the children had participated in music lessons throughout the year, while the others had no music lessons. A clear musical training effect was found in response to the violin stimuli. Trainor and colleagues (2003) also found that 4-year-olds who had received Suzuki training had a better developed auditory cortex and were able to discriminate more accurately between sounds. Shahin and colleagues (2004) measured auditory evoked potentials (AEPs) in response to piano, violin and pure tones by two groups of 4- to 5-year-olds. One group were enrolled in Suzuki music lessons; the other group acted as controls. Where children were learning to play an instrument (piano or violin), AEPs observed for the instrument played were comparable to those of non-musician children approximately three years older in chronological age. This suggested that the neocortical synaptic matrix had been shaped by an accumulation of specific auditory experiences, and that this process had been accelerated in those children who had had musical training. The children playing the piano, but not the violin, also exhibited increased power of induced timbre-specific gamma band activity for piano tones in comparison with controls following one year of training (Shahin *et al*., 2008).

Some research has focused on the impact on sound processing as it specifically relates to phonemic awareness. In a series of studies, Rauscher and colleagues (Rauscher, 2009; Rauscher and Hinton, 2011) explored whether children receiving Suzuki violin instruction performed better on phonemic awareness tasks than control groups: 75 musically naive 5-year-olds participated, and lessons were provided for 45 minutes per week for 16 weeks. Prior to instruction, there were no differences in the children's performance on the Predictive Assessment of Reading test. The intervention group scored significantly higher on letter word calling and phonemic awareness than the controls. Gromko (2005) studied 5- to 7-year-old children who received four months of music instruction for 30 minutes once per week. The instruction included active music-making with movement emphasizing a steady beat, rhythm and pitch, as well as the association of sounds with symbols. The children who received the music instruction showed significantly greater gains in phonemic awareness when compared to the control group. Similarly, Degé and Schwarzer (2011) showed that children who were randomly assigned to intensive training in music – ten minutes each day, five days each week, for 20 weeks – showed improvements in phonological awareness that were identical to changes in other children who received lessons in perceiving and segmenting speech sounds. A control group who received sports training showed no improvement.

In a comparative study of the impact of second language (French) or musical training, Moreno and colleagues (2015) recorded event-related potentials (ERPs) for French vowels and musical notes in 36 4- to 6-year-old children. The children demonstrated improved processing of relevant (trained) sounds, and an increased capacity to suppress irrelevant (untrained) sounds in the relevant assessment for their training. After one year, training-induced brain changes persisted and new hemispheric changes appeared (Moreno *et al*., 2015). A 28-day longitudinal study of English-speaking 4- to 6-year-old children who were randomly selected to receive daily music or French-language training, showed that musical training was associated with increased EEG complexity at coarse temporal scales during music and French vowel tasks in widely distributed cortical regions. These findings demonstrated that musical training increased diversity of brain network states to support domain-specific music skill acquisition and music-to-language transfer effects (Carpentier *et al*., 2016).

Some research has studied the effects over longer time periods. Moreno and colleagues (2009) conducted a longitudinal study with 32 8-year-old children over nine months, recording event-related brain potentials while the children performed tasks testing pitch processing in music and speech. The children were randomly assigned to music or painting training for six months and were tested again after training using the same tests. After musical (but not painting) training, children showed enhanced reading and pitch discrimination abilities in speech. Six months of musical training influenced the development of neural processes as reflected in specific patterns of brain waves and demonstrated brain plasticity, showing that relatively short periods of musical training had strong consequences on function and on increased sensitivity to linguistic pitch processing (Moreno *et al*., 2009). Putkinen and colleagues (2014) conducted a longitudinal study of more than 120 school-aged children and showed that children who received formal musical training displayed enhanced development in responses related to pre-attentive neural sound discrimination and auditory attention. No evidence for pre-training in response amplitudes between musically trained and non-trained children was found.

Over a period of two years, François and colleagues (2013) assigned 8-year-old children (matched for cognitive abilities, sex, age, grade at school and socio-economic status) to music or painting lessons. Before the start of the study, the two groups of children performed similarly on a test where they had to identify whether three-syllable nonsense words were presented as part of a five-minute presentation of a string of syllables. After one year of training, the music group performed better than the painting group in speech segmentation skills, with the difference increasing over the two-year period. Slater and colleagues (2015) followed a cohort of 8- to 9-year-old school children for two years, assessing their ability to perceive speech in noise before and after musical training. After the initial assessment, participants were randomly assigned to one of two groups: one group began music training immediately and completed two years of training, while the second group waited a year and then received one year of music training. The research showed that speech in noise perception improved after two years of group music training.

In a study focusing on adolescents, Tierney and colleagues (2015) investigated the effects of in-school music training. Students were tested on neural responses to sound and language skills before they entered high school and again three years later. The in-school music training prolonged the stability of subcortical sound processing and accelerated maturation of cortical auditory responses. Although phonological processing improved in the music training and control groups, the enhancement was greater in the adolescents who underwent music training. The findings showed that music training initiated as late as adolescence can enhance neural processing of sound and confer benefits on language skills. The music training group exhibited the emergence of more adult patterns of cortical response earlier, suggesting that in-school music accelerated neurodevelopment. These changes benefitted literacy skills. Both groups improved in phonological awareness relative to the general population, but the music training group improved more.

Although much of the research has shown that interventions can be effective over long periods of time, musical training can also have an impact quickly. In one study, 8-year-old children with just eight weeks of musical training differed from controls in cortical event related potentials (ERPs) (Moreno and Besson, 2006). In another, training for 25 minutes over a seven-week period led to changes in electroencephalogram (EEG) frequencies associated with enhanced cognitive processing (Flohr *et al*., 2000).

Interventions with children from deprived backgrounds

Some research has focused on children who have been perceived as at risk because of their deprived backgrounds. As part of an ongoing five-year longitudinal study, Habibi and colleagues (2016) investigated the effects of a music training programme on the auditory development of children over the course of two years, beginning at age 6 to 7. The training was group-based and inspired by El Sistema. The children in the music group were compared with two groups of children from the same socio-economic background, one involved in sports training and another not involved in any systematic training. Prior to participating, children who began training in music did not differ from those in the comparison groups in any of the assessed measures. After two years, the children in the music group, but not in the comparison groups, show an enhanced ability to detect changes in tonal environment and an accelerated maturity of auditory processing as measured by cortical auditory evoked potentials to musical notes.

Similarly, Kraus, Slater and colleagues (2014) used a randomized control trial to investigate whether community music participation could induce a change in auditory processing in children from deprived backgrounds. The programme provided free music instruction to the children who were considered to be at risk. The participants were 44 children (mean age of 8 years) living in gang-reduction zones in Los Angeles. The children were randomly assigned to participate or defer musical participation for one year. Participants attended music classes twice weekly for three to ten months. Students began in music appreciation classes, learning pitch matching and rhythm skills, musical styles and notation, and basic vocal performance and recorder playing. Students then progressed to instrumental instruction. Students were given their own instruments and participated in group-based instrumental classes for four hours per week. The children who were more committed to the music intervention, attended more and participated to a greater extent in the classroom developed stronger brain encoding of speech than those who were less engaged. The children who completed two years of music training had a stronger neurophysiological distinction of stop consonants and neural mechanisms linked to reading and language skills. One year of training was sufficient to elicit changes in nervous system functions. Greater amounts of instrumental music training were associated with larger gains in neural processing. The research showed that participation reinforced literacy skills and enhanced the neural encoding of speech cues, important for reading, and the perception of speech in noisy backgrounds (Kraus, Hornickel *et al*., 2014; Kraus, Slater *et al*., 2014; Kraus and Strait, 2015; Slater *et al*., 2014). The musicians were also better than the non-musicians on assessments of auditory working memory and attention (Strait *et al*., 2014).

The nature of musical training

While the studies described above provide causal evidence of the role of music training and less formal musical activities in shaping the development of important neural auditory skills and the processing of language, there is also evidence that the type of musical training may be important in the extent of the impact (Hyde *et al*., 2009). For instance, children participating in private keyboard lessons for 15 months showed structural growth in the primary auditory cortex, which correlated with their improvement in melody and rhythm perception tasks, while a group who participated in school music classes each week learning basic singing and drumming skills did not show the same neural growth. This suggests that the type of musical input is crucial in any transfer of skills. The quality of the musical interventions is also important. This was illustrated in a three-year study to explore whether group music instruction could improve the test scores of economically disadvantaged elementary school children. The research included almost 600 children from 5 to 10 years old from four schools. During the first two years of the study there were difficulties in the implementation of the music programme and it was only at the end of the study, when the children had received one year of high-quality tuition, that there were any gains for the students (Rauscher, 2005).

Conclusion

There is evidence, from a range of research, of the complex overlap of neural systems for the processing of language and music, although the details of the relationship remain unclear. Overall, the evidence is overwhelming that actively making music plays a major role in developing aural perceptual processing systems. These facilitate the encoding and identification of speech sounds and patterns, which, in turn, enhance language skills. The earlier the exposure to active participation in music-making, and the greater the length of that participation, the greater the impact. These benefits occur without the conscious awareness of the participants. Musical experience and training also enhance emotion perception, and a range of cognitive skills (Jantzen *et al*., 2016).

The exact nature of the types of musical activities that may have the greatest benefits in terms of the development of a range of language skills is not yet understood. Research is needed to establish what kinds of music-making are most effective in developing language skills in younger children and whether children need to learn to play an instrument, read notation, and undertake individual practice for the greatest long-term benefits. There is also a need to establish what is required in terms of the quality of the teaching. This is particularly important in the context of primary school education in the United Kingdom, where much of the music teaching is undertaken by generalist, non-specialist teachers who may have limited musical knowledge and skills.

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