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Music and the brain: a review of neuroscientific and clinical applications

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Abstract

My research examines the relationship between neuroscience and music, exploring its clinical applications. I extensively review the specific neuroanatomic structures implicated in musical perception. Knowing the function of each brain structure as it relates to musical perception provides insight as to how music is able to elicit certain physical and emotional responses. As music interacts with the human brain, it is also able to provide social, cognitive, and emotional benefits. Given these benefits, my research argues that music is an effective therapeutic intervention for vulnerable populations. I examine the impact of music therapy on preterm infants, hearing impaired individuals, intellectually disabled individuals, and Parkinson's and Alzheimer’s Disease patients. My research also proposes that continuous musical exposure throughout the lifespan may prevent the acquisition of neurodegenerative disorders later in life. As the literature generally appears to support this proposition, I ultimately urge for an increased emphasis on music-based education programs.

Introduction

For centuries, music has played a significant role in the lives of humans. Many individuals take pleasure in learning certain instruments or engaging in vocal training, while others merely use music for background stimulation when going about daily tasks. In however way music is used, it should be thought of as far more than a simple leisurely activity. Of particular interest is the interaction between music and the human brain. Viewing music through this lens might encourage one to question what it is about musical expression that is so compelling to humans. Perhaps the reason that music continues to remain a timeless aspect of human lives is because it provides some level of benefit to the human brain. The following literature review will examine the multitudinous ways in which music interacts with the brain and how this interaction can be clinically applied to various populations. With music providing a wide range of physical, psychological, and emotional benefits, there should be increased advocacy for musical educational programs.

Music and Brain Structures

Music perception

In order to fully understand the relationship between music and the brain, it is primarily important to identify the brain processes that underlie musical perception. When music is processed, auditory associated areas of the brain are logically involved. These areas of the human brain have a hierarchical organization, where areas lower in the hierarchy pass on increasingly complex information to higher areas (Warren, 2008; Wessinger et al., 2001).

Musical processing initially begins in the inner ears, as the sound is converted into an electrical signal (Geisler, 1998; Sarkamo et al., 2013; Weinberger, 2006). This signal then travels to the brain stem and then subsequently towards the thalamus, and out to auditory cortex and limbic areas (Ledoux, 2000; Weinberger, 2006). This processing is concerned with the coding of elementary attributes of individual sounds and sound components (Lotto & Holt, 2010; Warren, 2008). These include fundamental frequency, harmonics, and duration and loudness of individual notes in the melody.

Following auditory cortex activation, musical perception activates a wide variety of neuroanatomic structures in the temporal lobe (Patterson et al., 2002; Warren, 2008; Weinberger, 2004). As brain regions involved with musical perception are so widely distributed, no one single brain structure is exclusively dedicated to music (Perretz & Zatorre, 2005; Warren, 2008). The activation of brain structures is dependent on various factors; including the type of music, previous experience with the music (Pereira et al., 2011), and how actively the individual is participating in the musical experience (Weinberger, 2004). Each of these factors are taken into consideration when determining the extent to which an individual processes more complex musical components.

A network of auditory "association areas" process certain properties of complex sounds (Warren, 2008). This includes the planum temporale, which analyzes the acoustic patterns of spoken syllables, timbre of the voice or musical instrument, and information about pitch patterns (Griffiths & Warren, 2002). Another relevant structure involved in the more complex aspects of musical perception is the superior temporal gyrus. This region is involved with determining pitch changes and tracking the changes in a melody (Patterson et al., 2002). When perceiving and identifying familiar melodies, bilateral anterior portions of the temporal lobes, superior temporal regions, and parahippocampal gyri are activated (Satoh et al., 2006).

When it comes to perceiving higher order musical features (e.g harmonies, intervals, and rhythms) the inferior and medial prefrontal cortex, premotor cortex, superior temporal gyrus, and the inferior parietal lobe are involved (Janata et al., 2002). These structures are predisposed to mediate interactions between sensory, cognitive, and affective information. With that, they maintain "tonality maps," helping to shape expectations about the pitches that will be heard, given a preceding musical input. An experimental study conducted by Maess et al. (2001) also found that harmonically inappropriate chords activated Broca's area and its right hemisphere homologue. With these areas being involved with syntactic analysis during auditory language comprehension, this finding illustrates that they may also be involved with the processing of musical syntax.

The ability to keep track of the music as it is played over time involves attention and working memory systems. These systems are spread over prefrontal areas, the cingulate cortex, and inferior parietal areas (Sarkamo et al., 2013). A study conducted by Janata et al. (2002) illustrates this phenomenon. In the first experiment of the study, participants were instructed to listen to musical passages either globally/holistically (i.e. where the focus was on the piece as a whole) or selectively (i.e. where the focus is on one part played by a single instrument). No significant differences were found in the pattern of BOLD signal increases regardless of whether the participants listened to the musical excerpts globally or holistically. During both selective and global music listening, bilateral blood oxygen level dependent signals increased in the superior temporal gyrus, intraparietal sulcus, precentral sulcus, inferior sulcus and gyrus, and the frontal operculum. This activation did not occur during passive rest without musical stimulation. The study thus demonstrated that brain areas serving working memory, attention, semantic processing, target detection and motor imagery also enable attentive listening to music. These brain areas may therefore be involved with attending to music as it is played over time.

When a listener hears music that is familiar to him or her, this triggers processing in episodic memory-associated areas such as the hippocampus, medial temporal areas, and parietal areas (Janata, 2009; Patel et al., 2003). A study conducted by Patel et al. (2003) examined the neural networks underlying the semantic and episodic memory of music. When completing an episodic musical memory task, participants in the study exhibited bilateral activations in the middle and superior frontal gyrus and precuneus. For semantic tasks, activation was shown in the medial and orbital frontal cortex bilaterally, the left angular gyrus, and predominantly the left anterior part of the medial temporal gyri. These findings illustrated that music can elicit activation in distinct brain regions depending upon whether semantic or episodic memory is involved.

Sensorimotor networks of the brain such as the cerebellum, basal ganglia, and the motor and somatosensory cortices are accredited for the ability of the listener to perceive the rhythm of music, move to the beat, and produce music (Sarkamo et al., 2013; Zatorre et al., 2007). The cerebellum may specifically be involved with the ability to move to the beat at the correct time. Sakai et al. (2002) provide evidence for this possibility, finding activation in the lateral cerebellum during the learning of a timing sequence. Patients with cerebellar damage have also been found to exhibit an impaired ability in completing perceptual motor timing tasks, suggesting that proper cerebellum function is necessary for the perception of event timing (Ivry et al., 2002).

There is also evidence to suggest that the basal ganglia is involved with movement timing. A neuroimaging study conducted by Rao et al. (2001) found early activation in the basal ganglia, as well as the right inferior parietal cortex during a time perception task. This activation occurred during the time at which time intervals were encoded. Therefore, it suggested that the basal ganglia is involved with formulating representations of time. Findings from Pope et al. (2005) also suggest that the basal ganglia is involved with controlling force, which contributes to accurate timing. In the experiment, Pope et al. (2005) found that time modulation of force in repetitive thumb-finger squeezes activated the basal ganglia, along with the primary motor cortex, supplementary motor area, thalamus and cerebellum.

As very simple rhythms were used in these studies, the findings may not apply to the perception of more complex rhythms and melodies. Still, they illustrate the basic properties of perceptual and motor timing that may provide a basis for more complex levels of processing (Zatorre et al., 2007). In examining the perception and reproduction of more complex music rhythms, Chen et al. (2008) found that during a finger tapping task, the pre-supplementary motor area, dorsal premotor cortex, dorsolateral prefrontal cortex, inferior parietal lobule, and cerebellum lobule VI were modulated with increasing metrical complexity of rhythms. This provides evidence to suggest that these brain regions are involved with processing more complex rhythms. Additionally, this network of brain areas may be relevant for intricate action plans that are required for music performance. Compared to non-musicians in the study, musicians also recruited the prefrontal cortex to a greater degree, possibly due to a superior ability to track, retrieve, manipulate and organize a rhythm's temporal information.

Music and emotion: *The amygdala*

Studies have found that music activates brain areas associated with emotion. Through a meta-analysis of functional neuroimaging studies on music-evoked emotions, Koelsch (2014) outlines specific information about the ability of music to modulate activity in emotion-associated areas of the brain. According to studies on humans, the superficial part of the amygdala is particularly sensitive to music that is perceived as pleasant or joyful (Blood & Zatorre, 2001; Koelsch et al., 2013). Koelsch (2014) postulates that this is due to the fact that music is perceived to have social significance, acting as a form of communication when playing an instrument, singing, or dancing in a social context. Even when simply listening to music, social cognition is still involved (Steinbeis & Koelsch, 2009) as the individual interprets the music as a communiticative signal (Cross & Morley, 2009; Koelsch, 2014). In general, the superficial amygdala is sensitive to signals that encourage approach, which may be further emphasized by joyful music (Koeslch et al. 2005).

An interaction with the auditory cortex may be what allows the amygdala to elicit an emotional response to music. Through a single case study, Liegeois-Chauvel et al. (2014) examined the interaction between the auditory cortex and the amygdala, in relation to musically-induced emotion. In this case study, a 45 year old woman with epilepsy had pre-surgical chronic depth EEG electrodes implanted. She was asked to attentively listen to 40 musical excerpts and passively listen to a sequence of pure tones. Most of the musical excerpts involved emotions belonging to four main categories: happy, sad, angry, or peaceful. There was a functional coupling between the auditory cortex and the amygdala, however this coupling took place differently according to the nature of the auditory stimuli. The musical excerpts that the participant experienced as happy, sad, or peaceful elicited a right-lateralized coupling between the auditory cortex and amygdala. Conversely, excerpts that the participant experienced as angry and disliked were associated with a decorrelation between these structures. These findings suggest that the auditory cortex and amygdala build a functional connection during the listening period, which is influenced by the emotion that the listener is experiencing.

An experimental study conducted by Koelsch et al. (2013) provides additional information about the connections between the amygdala and the auditory cortex, in relation to music-evoked emotion. They specifically investigated the role that these structures and their functional connections play in music-evoked fear responses compared to music-evoked joy and neutral stimuli. Results indicated that the blood-oxygen-level-dependent (BOLD) signals in the bilateral auditory cortex and the bilateral superficial amygdala were strongest during joy and weakest during fear, with neutral in between. In accordance with the findings of Liegeois-Chavel et al. (2014), Koelsch et al. (2013) found a functional connectivity between the amygdala and the auditory cortex, but only during the music-evoked joy condition.

These studies illustrate a prominent role of the relationship between the auditory cortex and the amygdala in the emotional processing of auditory stimuli. Interestingly, Koelsch et al. (2013) is the first to show that the auditory cortex functions as a central hub of an affective-attentional network, forming connections with the not only the amygdala, but also with the insula, cingulate cortex, and visual and parietal attentional structures. The authors suggested that the fear stimuli were not socially rewarding, and this could explain the weaker activation of the superficial amygdala to these stimuli. By contrast, the joyful music possibly activated the superficial amygdala due to having social significance. Therefore, it is suggested that the superficial amygdala is sensitive to incentive social signals at the same time it is involved with fear responses. Importantly, this study demonstrates that these social signals and fear responses are able to be evoked by music.

Music and emotion: The hippocampus and nucleus accumbens

The hippocampus, a brain structure that is known to be involved with stress regulation (Sapolsky et al. 1984) is also associated with music-evoked emotion. Prior studies conducted by Trost et al. (2011) and Mitterschiffthaler et al (2007) have identified hippocampal activity in response to music-evoked emotions, including tenderness, joy, peacefulness, sadness, and nostalgia. These emotions play a role in attachment formation and maintenance, which has been identified as an emotional function of the hippocampus (Liu et al. 2010). Based upon these findings, Koelsch (2014) implies that the evocation of attachment-related emotions is related to the social functions of music.

Music has also been found to interact with the nucleus accumbens (NAcc), another emotion-associated area of the brain. This part of the brain is generally sensitive to primary rewards (e.g. food, drink, sex) as well as secondary rewards (e.g. money and power; Koelsch, 2014, Secousse et al., 2013). Several studies have found activity in the NAcc at points when music is experienced as pleasurable (Brown et al., 2004; Koelsch et al., 2005; Menon & Leviton, 2005; Trost et al., 2011). These are points at which a person might experience responses such as “chills" upon listening to a piece of music. This experience of pleasure may be the result of the listener’s response to “musical surprises,” which are linked with NAcc activation (Shany et al., 2019)

“Musical surprises” refer to expectancy violations, which are encoded by mesocorticolimbic regions of the brain (Gebauer et al., 2012; Salimpoor et al., 2015). These brain regions, which include the NAcc, are usually triggered upon the anticipation or consumption of primary and secondary rewards. It is thought then, that music-induced feelings of pleasure are the result of this reward pathway being activated. (Vuust and Kringelbach, 2010; Gebauer et al., 2012; Vuust and Witek, 2014; Salimpoor et al., 2015; Koelsch et al., 2018).

A study conducted by Gold et al. (2018) provides direct evidence of musically-elicited reward prediction errors within the NAcc. These reward prediction errors were apparent as participants in the study learned to find their preferred musical endings during a reinforcement-learning task. On the other hand, participants who derived less reward from the musical stimuli reflected musical reward prediction errors less reliably. Interestingly, reward prediction errors appeared to motivate learning, as those whose NAcc reflected reward predictions more reliably tended to show the most improvement.

As musical reward prediction errors appear to integrate cognitive and emotional processing in the NAcc, this provides a possible explanation as to why so many individuals find music to be engaging and pleasurable. It specifically appears as if music is a rewarding property in and of itself, as it engages the same mechanisms used to learn about concrete rewards such as food, money, and sex.

Music and emotion: General discussion

The general relationship between music and the limbic structures illustrates the underlying neurological processes that occur when an individual experiences an emotional response to a particular piece of music. These neurological processes tie back to broader evolutionary functions relating to the avoidance of pain and the seeking of pleasure. The amygdala specifically plays a role perceiving whether or not a musical stimulus is socially rewarding. The hippocampus also responds to music that is perceived as socially rewarding, with it being more specifically associated with attachment related emotions. Further, The NAcc is involved in the listener's pleasure response to musical stimuli, which appears to be linked to surprise related activations. Whether it be perceived as aversive or pleasurable, music possesses a clear power to activate various structures within the human brain. While specific brain structures actively respond to musical stimuli, it is also true that the physical attributes of brain structures, themselves, are implicated in musical perception.

Involuntary musical imagery

The concept of involuntary musical imagery (INMI) offers one way of observing how music impacts the physical attributes of brain structures. Involuntary musical imagery refers to the experience of having music "stuck in one's head"-- that is, the listener "hears" the music in their mind without it being explicitly played (Liikkanen, 2008). Interestingly, there are found to be structural brain differences between those with increased versus decreased frequencies of INMI episodes. These structural differences are apparent in terms of cortical thickness.

A study conducted by Farrugia et al. (2015) showed that the frequency of INMI episodes negatively correlated with cortical thickness in the right Heschl's Gyrus, a region that is associated with auditory perception and voluntary musical imagery. There was also found to be decreased cortical thickness in the right inferior frontal gyrus, a region that is associated with pitch memory in individuals with increased INMI episodes. The authors suggest that the inferior frontal gyrus plays a role in suppressing unwanted INMI episodes, due to its inhibitory mechanisms. It is thought then that reduced cortical thickness in this area is linked to less inhibition of INMI episodes, therefore explaining the negative correlation.

In addition, higher gray matter volume in the right temporopolar and parahippocampal cortices was found in participants who reported higher disturbance by their INMI experiences.

These structures are thought to be involved with affective processing and to communicate with other emotion-related areas of the brain (Farrugia et al., 2015). Overall, these results exemplify the unique ability of music to interact with brain networks, even when it is not explicitly being played.

It is important to note that individual differences can influence the frequency, emotional characteristics, and emotional experience of INMI. A study conducted by Negishi and Sekigushi (2020) assessed obsessive-compulsive tendencies, Big Five personality traits, and musical expertise in relation to the frequency and emotional quality of INMI episodes. A positive effect was observed for intrusive thoughts (obsessions) on the frequency of INMI, meaning that the more participants experienced obsessions, the more they experienced INMI. Further, the more obsessive-compulsive tendencies were reported, the less INMI experiences were reported as pleasant and likeable.

Personality impacted INMI experience as well. Participants who scored high for neuroticism were more likely to experience INMI. No personality trait was found to affect the rated pleasantness of INMI experiences; however, individuals who scored higher on the openness-to-experience trait were more likely to like music in general. Musical expertise was not found to affect the emotional characteristics of INMI, however the general musical sophistication score on the Goldsmith Musical Sophistication Index (Gold-MSI) measure positively affected the occurrence of INMI.

The effects of happiness, sadness, and worrisome moods were significant with respect to the pleasantness of INMI experiences. Positive moods were generally correlated with the pleasantness of INMI experiences. With regards to activity, it was found that INMI experiences were more likely to occur when participants were engaged in activities that required less concentration and effort and were less difficult. Each of these findings demonstrate that individual traits are able to impact the experience of INMI. Perhaps these individual differences might explain why some individuals experience INMI episodes more often than others and thus display structural brain differences.

Music and Neuroplasticity

Given the ability of music to activate brain structures and influence their physical attributes, it is important to assess the ability of music to promote general neuroplasticity (Miendlarzewska & Trost, 2013; Stegemoller, 2014). Neuroplasticity refers to the ability of the nervous system to change and modify in response to external signals. Neuroplasticity is particularly relevant to brain development, as it deals with changes in connectivity within the maturing brain (Wells, & Wells, 2006).

Dopamine, a neurotransmitter that is involved with motivation, reward (Wise, 2004), working memory, and reinforcement learning, has been found to play a vital role in neuroplasticity (Nitsche et al. 2009). Neuroimaging studies have revealed that pleasurable music stimulates dopaminergic areas of the brain (Koelsch et al., 2006; Salimpoor et al., 2011). Given that dopamine is associated with neuroplasticity (Nitsche et al. 2009), music is argued to provide neuroplastic benefits in this way (Stegemoller, 2014).

Neuroplastic benefits of music: Preterm infants

The relationship between music and brain development offers one way of observing the neuroplastic benefits of music. These benefits are especially pertinent to preterm infants, who are in great need of developmentally enhancing experiences. Problematically, the neonatal intensive care (NICU) environment deprives the infant brain of meaningful sensory experiences, such as hearing the rhythm of the mother's heartbeat and the sound of her voice, (Haslbeck and Bassler, 2018) thus leading to later neurodevelopmental impairments (Sa de Almeida et al., 2019).

At the same time, the general environment of the NICU can be auditorily overwhelming to the premature brain. For example, infants are exposed to high-frequency, loud, and unpredictable stimuli from different machines and monitors within the NICU setting. These stressful noises may then lead to adverse short-term effects on the cardiovascular and respiratory systems of the infants (Haslbeck & Bassler, 2018). In an attempt to address these issues, various studies have examined the contributions of music therapy towards the brain development of preterm infants.

The relevance of music to brain development

Before discussing these contributions, it is primarily important to establish why music is relevant to brain development, particularly among preterm infants. Music may be an effective means of intervention for preterm infants due to the fact that it is able to be processed very early on in life. Infants are able to respond to sounds in utero as early as 25 weeks of gestation (Chorna et al., 2019). At 25-27 weeks, fetuses respond to low frequency (250 or 500 Hz) tones. By 29-31 weeks, they are able to respond to higher frequency (1000-3000 Hz) tones (Hepper & Shahidulla, 1994). Music that is high in intensity has been found to accelerate heart rate and increase motor responses in utero, whereas low intensity music induces an opposite effect (Lecanuet, 1996). Upon birth, infants continue to form responses to music; a number of behavior experiments have revealed an ability of both preterm and full term infants to synchronize their sucking, mouth movements, respiration, and vocalizations to match musical contours (Provasi et al., 2014).

Studies have also examined specific brain responses of fetuses in response to music and other sounds. Through the use of pure tones, single tones, and syllables, studies have found differences in response latency (i.e. length of time taken to respond) to low, middle, and high rates of amplitude modulation (Draganova et al., 2006; Holst et al., 2005). This finding suggests that fetuses are able to differentiate between both intensity and frequency changes of sounds. Fetuses at 33 weeks gestation have demonstrated responses to pure tones in the left temporal lobe, near the location of the primary auditory cortex (Pasman et al., 1991).

Considering that the brains of fetuses are responsive to sound, it is logical to speculate that the fetal brain can process more complex auditory stimuli, such as music. Of interesting note is that exposure to music in utero can have a sustained effect through early infancy. Partanen et al., (2013) found that fetuses exposed to a lullaby 5 times per week, starting from the 29th week of pregnancy, displayed significantly stronger amplitude-event related potential (ERP) responses when exposed to these lullabies again at birth. A stronger ERP response indicates that the infants were more responsive to the musical stimuli because neural representations for these stimuli were already formed in their brains. These findings demonstrate that the effects of prenatal musical exposure can impact the neural responsiveness to sounds several months later, during early infancy. Due to this lasting impact, it can be argued that music has plastic effects on the developing fetal brain.

Brain activity of preterm infants in response to music

Despite its underdeveloped state, the preterm infant brain should be able to activate in response to musical stimuli. This may be true, considering that the brain appears to be wired for musical response even before birth. Studies have, in fact, revealed brain responses to music among preterm infants. Specifically, there has been found to be brainstem responses to auditory stimuli at around 27-29 weeks of gestation. For preterm infants at 33 weeks gestation, auditory evoked potentials have shown early cortical activity with the nearly mature biomechanical function of the cochlear signal (Mortlet et al., 1995; Pasman et al., 1991).

EEGs have also been used to assess the effect of music on the sleep-wake cycle of preterm infants. A study on the effect of Brahms lullaby on preterm infants between 33 and 37 weeks gestation found fewer interruptions of quiet sleep and increased post conceptional age sleep patterns as the result of musical exposure (Stokes et al., 2016). Cortical responses to speech sounds have also been examined in relation to vocal musical exposure in the NICU. Chorna et al. (2018) compared preterm infants exposed to lullabies sung in their mothers' voices versus lullaby recordings of a standard female voice. Both groups displayed an increased speech sound differentiation response on ERP. Those who listened to their mother's voice, however, displayed greater increase in spoken (standard) speech sound differentiation.

Music and preterm infants: developmental contributions

Due to the ability of preterm infants to respond to auditory stimuli, music is assumed to be an effective means of intervention for this population. Intervention is necessary to help preterms infants thrive physically and emotionally in the long term. There are various identified health consequences to being born preterm, including immunocompromisation, (Melville & Moss, 2013) and medical disabilities, such as cerebral palsy and intellectual disability (Dag et al., 2008). As music has been found to enhance overall brain development and maturation of preterm infants, perhaps music interventions may decrease the risk for preterm infants to acquire serious medical issues.

Cranial ultrasonography has been used to examine the effect of music on brain development among preterm infants. Webb et al. (2015) found significantly larger auditory cortices bilaterally in preterm infants who were exposed to the mother's speech, singing, reading, and heartbeat for 3 hours per one month, compared to controls receiving standard care. Preterm infants who were exposed to music at 33 weeks gestation until term equivalent age have shown increased functional connectivity between the primary auditory cortex, thalamus, middle cingulate cortex, and the striatum when listening again to the known music (Lordier et al., 2019).

Further evidence suggests that music is able to enhance the maturation of auditory and emotional processes preterm infants. Sa de Almeida et al. (2019) found that preterm infants exposed to a specially composed musical intervention displayed significantly improved white-matter maturation and amygdala volume, in comparison to those who were not exposed to the intervention. In comparison to full-term infants, preterm infants receiving the control treatment displayed reduced white matter maturation. There was no significant difference found between preterm infants exposed to the treatment and full term infants in terms of amygdala volume and white matter maturation. Thus, the maturity of preterm infant brains were similar in maturity to full term infant brains, as a result of the music intervention. Based upon these findings, it appears that musical interventions allow the preterm infant brain to mature at a similar rate to full-term infants. As a result, preterm infants may become less at risk for further medical complications when given continual musical exposure.

Preterm infants: music therapy components

For musical interventions to be most effective to the preterm infant population, there are specific components necessary to implement. Lowey & Jaschke (2020) reviewed various studies regarding the effectiveness of musical interventions for preterm infants, with a focus on specific musical elements. “Timbre” is one musical element given important consideration for intervention purposes. Timbre refers to the quality of a sound that enables a listener to distinguish certain sounds from others (Wessel, 1979). Some studies have used timbre meant to replicate the intrauterine environment (Burke et al. 1995; Chou et al., 2003). These included the womb-sounds of the placenta, the maternal pulse, and synthesized female voices.

Burke et al. (1995) examined the effectiveness of music in reducing agitation and physiological instability in infants with Bronchopulmonary Dysplasia (BPD), after they received a stressful suctioning procedure. When these infants were exposed to womb-like timbre, oxygen saturation and sleeping time significantly improved. Chou et al. (2003) used the same soundscape among infants who required endotracheal intubation and suctioning. In comparison to controls, the infants exposed to the musical intervention displayed significantly higher oxygen saturation and recovery time after the procedure. The success of this soundscape in both studies illustrates that timbre is important to consider when implementing musical interventions for preterm infants.

Lowey & Jaschke (2020) also identify repetition as a central component of musical interventions for preterm infants. The mother’s heartbeat is one specific source of repetition that helps the human brain formulate structure in the womb. Generally, infants are able to recognize familiar voices, melodies, and language patterns, illustrating that their brains are wired for forming structure (Lebedeva & Kuhl, 2010; Mai et al. 2012). Repetition is also linked to the development of specific motor abilities. Zentner & Eerola (2010) found that cued timing related to the effectual mood of songs vs. speech was linked to greater rhythmic coordination in young infants. Based on this information, there appears to be clear benefits in employing repetitive, highly predictable music for the general infant population.

Additionally, Lowey and Jaschke (2020) emphasize the importance of using melodies and song sequences that are familiar to the neonate. For example, if the parents are unavailable, it is important to use sounds that are similar in range to the mother and/or father's voice. The "Song of Kin" model (Lowey et al., 2013; Lowey, 2015) aids parents in creating natural, easily sung melodies that have meaning for the parents. This song does not have to be one that was heard in utero, or have any spiritual/historical connections to the infant's family. Instead, it should be a song that is generally appreciated by the parents and broader culture. With acapella being well-suited for neonates, applied accompaniment can be minimal (Lowey & Jaschke, 2020). Generally, it is advised to employ aspects of simplicity when developing melodies for infants and caregivers. These aspects include slow tempo, minimal instruments and harmonies, quiet and stable dynamics, repetition, consistency, rocking meters, limited change in pitch direction, and emphasis on descending tones to engage relation processes (Stewart, 2009).

Touch and emotional closeness through vocalization are particularly pertinent to infants. In this way, musical interventions not only enhance the physical health of preterm infants, but also work to strengthen their attachment relationships (Goutlet et al., 1998). To further enhance attachment, intimate and personal aspects can be applied to the musical intervention. For example, the infant's name can be used in the song, the parent can sing a tone at the same pitch as the infant's voice, or the parent can hide the infant's face and "find" it when he or she makes a sound (Lowey, 1995, 2015). All of these strategies allow for a personalized connection within the musical intervention, in turn helping to sustain the attention and expectancy factors necessary for brain development (Lowey & Jashkey, 2020).

Creative Music Therapy (CMT) for preterm infants takes these strategies into consideration. The goal of CMT is to create an individual relationship between the parents and newborn (Haslbeck and Bassler, 2018). As it is non-invasive in nature, CMT allows the infants to become "active" rather than retaining a passive and receptive role. When administering CMT, the therapist first looks at the "music" of the infant. This "music" refers to the breathing patterns in conjunction with the infant's facial expressions and gesticulations. The music therapist then transforms this "music" into infant-directed humming, that is tailored to the infant's needs. For example, when the infant's eyebrows lift, the therapist will bring the melody upward, whereas when the infant fusses, the therapist will bring the melody downwards and slow the tempo.

An important aspect of CMT is that it is a family-integrated approach. The parents may be integrated in the therapeutic process by providing music therapy during skin-to-skin ("kangaroo care") holding time. CMT also takes cultural preferences into account, as the music therapist will assess the parents' musical heritage and favorite music styles/songs. During kangaroo care, the music therapist will use a single-stringed wooden instrument called a *monochord* and place it next to the kangaroo care chair. The vibro-acoustic stimulation of the instrument is able to effectively replicate deep live womb sounds, which is therapeutic for the infant. The parents are also able to achieve therapeutic benefit from this instrument, as they are able to touch it with their elbows and feel its relaxing vibrations. With the parents and infants being able to relax and perceive themselves more intensely, this may work to strengthen the attachment relationship (Haslbeck and Bassler, 2018).

Due to this strengthening of attachment, music is thought to influence socioemotional development in preterm infants. This speculation is also based on the general interaction between music and brain areas associated with emotion generation and regulation (Chorna et al., 2018; Koelsch, 2014). In a broader sense, this can also apply to full-term infants in terms of early social and emotional intervention. Chorna et al., (2018) argue that early experiences in music and singing may sensitize newborns to the dynamics of social interactions. When parents interact with their infants through different rhythmic patterns, this provides a dynamic structure that is contingent to the specific reactions of their newborns. For example, when the infant opens his or her eyes and smiles, the maternal voice may be perceived as more smiling and emotional.

Early exposure to the human voice may also have an impact on the relevance and importance of the human voice in social interactions. This is true, as the human voice has been shown to activate voice-sensitive areas of the brain including the middle-superior temporal sulci and gyri in adults (Belin et al., 2000). Given this finding, early exposure to music might have a long-term impact on the relevance and importance of the human voice in social interactions (Chorna et al., 2019). To provide further context for the socioemotional benefits of early music exposure, it is relevant to discuss the general impact of music on social development during infancy.

Infant music classes and social/emotional development

Music classes provide an opportunity for infants to receive musical exposure during early developmental stages. By attending these classes, infants are able to obtain emotional, communicative, language, and social benefits. The extent to which these benefits are apparent may depend on whether the classes are “active” or “passive” in nature. Active classes may involve movement, singing, playing instruments, and creating a repertoire of songs (Gerry et al., 2012; Jones, 2004). Passive classes, on the other hand, might involve the infant engaging in non-music related activities while music is played in the background.

Active music classes may be most beneficial to the early emotional and communicative development of infants. When comparing groups of infants who either attended passive or active music classes over a 6 month time period, Gerry et al. (2012) found that infants who attended the active classes showed lower distress levels to novel stimuli, compared to those who attended the passive classes. Infants who attended passive classes were found to show more significant decreases in smiling and laughter and were generally more difficult to soothe than those who attended the active classes. In terms of early communicative development, the use of gestures increased significantly over the 6 month time period, but more so for infants who attended the active music classes. Additionally, infants in the active music classes were found to demonstrate an advanced knowledge of Western tonality, compared to those in the passive group. Taken together, it appears that active music classes provide more developmental benefits during infancy than do passive music classes.

The differences in outcomes between active and passive music classes are apparent at the brain level. Trainor et al. (2012) found that infants who took part in active music classes for 6 months showed larger ERP’s in response to piano tones. Prior to taking these classes, the ERP’s were not significantly different between the active and passive class groups. These findings indicate that tone processing was more advanced for those in the active classes, as was apparent by faster responses and more synchronous neural firing.

Both the findings of Gerry et al. (2012) and Trainor et al., (2012) suggest that active musical experiences promote plasticity in the developing infant brain. The findings of these studies may also bring practical implications to the preterm infant population. Perhaps if preterm infants participate in active music classes as they grow older, they will become less vulnerable to developmental delays.

A study by Hamm et al., (2017) provides support for this proposition. This study sought to determine whether attending a music therapy program would improve the chances of NICU infants to reach developmentally appropriate milestones. It was found that participation in music therapy sessions was significantly associated with 12-month scores on cognition, communication, and motor domains. According to a post-hoc analysis, as the number of attended sessions increased, so did the cognitive and communication scores, but not the motor scores. It thus appears that music can continue to benefit infants upon NICU release, specifically in terms of infant-parent communication.

If music aids the development of communication processes in infants, perhaps early music intervention impacts the acquisition of speech skills. As infants learn to extract complex sound patterns through music, this ability may extend to the speech domain. Zhao & Kuhl (2016) found that 9 month old infants who received a musical intervention were more sensitive to temporal structure violations in both music and speech. This sensitivity was apparent through larger mismatch responses. As the pattern detection skills in the music condition were able to generalize to the speech condition, early music intervention may therefore aid language development.

In addition to enhancing speech skills, structured music classes may also boost the general social development of infants. Standley et al. (2011) found that infants and toddlers in a structured music class spent more time attending to their peers when engaging in musical activities. Therefore, it could be argued that structured musical activities may facilitate early interactions between infants and their peers. Structured music classes may also enhance the development of attention span, given that music was able to elicit attentional responses.

Based on the findings of the previously described studies, it is apparent that music classes benefit the developing infant brain. This is true, as infants have been shown to display enhanced musical perception, speech processing, and social development upon attendance of music classes. Knowing these positive impacts, parents may be encouraged to engage their infants in musical activities as early on as possible. To maintain healthy brain growth, infants should continue to receive musical exposure as they mature into young children.

Benefits of early musical training

Brain differences among musically trained vs. untrained children

An ideal way for young children to engage with music is by actively practicing a musical instrument, or receiving vocal training. Various studies have examined the impact of music training on the brain development of young children. This impact is most clearly observed by comparing brain differences between musically trained versus musically untrained children. Among the most obvious differences relate to enhanced development of auditory processes.

Habibi et al. (2016) found that children who received musical training displayed more robust changes in ERP components when completing tonal and pitch perception tasks, compared to those who were not musically trained. In accordance with the previously discussed findings of Putkinen et al. (2019), Habibi et al. (2016) also found enhanced pitch perception among musically trained children. Specifically, musically trained children were found to be more sensitive to devient tone pairs than those in the control group, at a later processing stage. These findings suggest that the auditory processing mechanisms of musically trained children mature at a more accelerated rate than those who do not receive musical training. This maturation is important for the general development of language, speech, and social interaction. Therefore, children may be given a developmental boost in these domains when they engage in musical training.

Transferable benefits of early musical training: Working memory

There is clear evidence to suggest that skills gained through musical training can extend to non-music related domains. Fujiuoka et al. (2006) found that children who took part in a year of musical training showed enhanced behavioral performances in musical discrimination and non-musical working memory. These improvements were not apparent among comparison groups who did not take part in musical training.

This particular study is significant, as it is the first to show that brain responses and cognitive abilities of musically trained children can change over the course of a year. Therefore, one benefit to early musical training may be that it leads to long term benefits towards brain development. Due to the long-term and transferable benefits it provides, early musical training should be thought to maintain optimal brain growth throughout the course of development.

Further evidence suggests that musical training provides transferable benefits to working memory abilities. In accordance with the findings of Fujioka et al. (2009), Saarkivi et al (2019) found that children with a musical background outperformed children without a musical background on working memory tests. Working memory may be enhanced among musically trained children because learning a musical instrument utilizes working memory processes, such as learning and memorizing certain sequences of tones. Considering that Saarkavi et al. (2019) found the differences in working memory performance to be most profound among younger children, musical training may have the most significant impact during early stages of development. Perhaps if the working memory capabilities of children are boosted as a result of early musical training, they will ultimately lead to success in other learning domains. Language may be one of these domains, considering that previously discussed studies found enhanced language development among infants engaged in active musical training.

Transferable benefits of early musical training: Language development

Given that infants can learn to extract elements of speech through continual music exposure, it is logical to presume that musical training can enhance a child's ability to understand and articulate language. Dittinger et al. (2017) provides support for this possibility, finding that musical training positively influenced word learning among children ages 8-12. During a phonological categorization task, musically trained children were found to exhibit faster modulations of N200 and FN400 amplitudes after only a few minutes of picture-word associative learning. Based upon these quick modulations, it appears that musical training helps to speed the process of encoding the meanings of novel words. According to behavioral and electrophysiological data, musically trained children made fewer errors than controls in both the matching and semantic tasks, suggesting that they learned the meanings of novel words more efficiently than controls. Music training may also be associated with clearer and more stable phonological representations, since the level of performance in the phonological categorization tasks was higher in musically trained children. Therefore, it is arguable that musical training may boost a child's competence in language learning domains.

Music and speech/language development

With there being a potential relationship between musical training and language development, music interventions may be effective for individuals with language-related impairments. Before exploring this possibility, the relationship between music and speech and language processes should be examined in further depth. Although music and language involve distinct cognitive processes, both rely on a common pool of neural resources (Patel, 1998). Patel (1998) proposes these resources to involve structural integration in working memory. For example, both music and linguistic processing involve continuous prediction and integration of events into a perceived relational structure in working memory. Essentially, both processes require the mind to integrate incoming elements with previously remembered elements, in order to understand how new information relates to what is already known

Further, it appears that there are shared neural resources involved with music and language processing. This is true, as the P600 potential has been found to be involved with musical processing, in addition to language processing. The P600 potential is an ERP component that is elicited by words that are difficult to integrate structurally into sentences. When examining brain responses to incongruities in both language and music there have been found to be P600s that are similar in polarity, amplitude, and scalp distribution (Patel, 1998). This finding suggests that music and language processes involve the same neural mechanisms. Perhaps these shared neural mechanisms may serve to explain why music can enhance language development.

Incorporating verbal elements into musical interventions may be most effective with regards to enhancing a child's speech skills. A survey study conducted by Baclija (2019) found that preschool teachers perceived childens' speech development to be enhanced by musical activities containing verbal elements. These elements include singing, rhyming, counting, and repetition. For the most robust speech/language development, Baclija (2019) therefore suggests that musical interventions include rhythmic speech and melodies with accompanying singable text.

Singable text may be particularly effective in terms of enhancing speech perceptive abilities. This appears to be the case among hearing-impaired children. Torppa et al. (2010) found that children with cochlear implants who sang regularly at home and whose parents sang for them at an early age perceived speech in noise better than comparison children. Comparison children also used cochlear implants, however they did not have such singing experience. Hearing impaired children with singing experience also demonstrated faster attention shifting towards all changes in musical timbre. Thus, it is arguable that singing experience can improve the speech perception of children who use cochlear implants. It is possible that the motor movements involved with singing are what improves sensitivity to stressed syllables in speech. Further research may wish to inquire whether singing interventions enhance the general speech perceptive abilities of young children, in addition to those with specific impairments.

Beatboxing is another type of vocally produced sound that uses similar anatomical processes as singing. These anatomical processes involve fine control of the pharyngeal musculature and elongation of the vocal tract (Sapthavee et al., 2014). There is evidence to suggest that beatboxing can aid speech production. Icht (2018) found that individuals with intellectual disability (ID) demonstrated increased articulation accuracy when participating in a music intervention involving beatboxing. Controls who did not participate in the intervention did not display as profound improvements in articulation accuracy. The beatboxing intervention also led to a larger increase in scores for vocal loudness, shimmer (i.e. cycle-to-cycle variations of waveform amplitude for sustained phonation), and HNR (i.e. ratio of the harmonic part to the energy of the remaining part of the signal). Given the positive effects of both singing and beatboxing, it appears that the utilization of vocally produced sounds is generally effective with regards to enhancing speech processes.

Music and speech: Parkinson's Disease

Singing may be a particularly useful communicative intervention for individuals with Parkinson's Disease (PD). PD falls under the broad umbrella of dementia, which consists of disorders involving pervasive, progressive, and irreversible decline in cognitive function (Hamdy et al., 2019). PD specifically involves issues related to movement; these issues include tremors, bradykinesia, and rigidity (Dauer & Przedborski, 2003; Harris et al., 2016). It is also common for patients to exhibit a variety of speech impairments (Harris et al., 2016). Interestingly, these impairments are not apparent while patients are singing. Harris et al. (2016) found no significant linguistic differences between PD patients and healthy controls when both groups were asked to sing familiar and improvised melodies. This finding was true with respect to mean pitch, pitch range, pitch variability, and tempo. When asked to recite speech tasks, however, PD patients were found to exhibit significantly slower speech rates and decreased pitch variability in speech, compared to controls. Since language abilities appear to be preserved while a PD patient is singing, interventions involving singing may therefore help to facilitate the communicative functions of PD patients.

The findings of Harris et al. (2016) also highlight the important distinctions between speech/language and music processes. While it is true that speech/language and music processes share similar neural resources, they may be differentially impacted by motor control disorders, such as PD. Still, speech/language and musical processes may share enough resources so that music is able to act as an effective speech and language intervention. Much of the speech/language difficulties experienced by PD patients are linked with the broader motor impairments of the disease (Ramig et al., 2008). Given that music interventions appear to improve the speech/language impairments of PD, it may be further inquired whether similar interventions can facilitate the motor processes of PD patients.

Music and motor processes: Parkinson's disease

As was discussed previously in this review, music is able to interact with motor-associated areas of the brain. This interaction may allow for music interventions to facilitate the motor functioning of PD patients. The rhythmic qualities of music may be most beneficial to motor functioning. When assessing participants as they completed rhythm tapping tasks, Chen et al. (2006) found interactions between the posterior superior temporal gyrus and dorsal premotor cortex. They propose that activity in these posterior regions may be related to the detection of the emerging pattern of metric saliency. The superior temporal gyrus is suggested to encode the pattern of metric rhythms, while activity in the dorsal premotor cortex is suggested to integrate the auditory information with temporally organized motor actions. Taken together, the metric structure of a rhythm appears to be an effective cue in driving motor behavior. If certain rhythmic qualities are able to drive certain motor actions, it is plausible to speculate that music can aid motor control.

Rhythmic auditory stimulation

Prior studies have in fact assessed the ability of external rhythms to prime movement areas of the brain in PD patients (Rose et al., 2019). This assessment involves a therapeutic strategy called rhythmic auditory stimulation (RAS). RAS uses metronomes or rhythmically enhanced familiar music to provide external cues for improving gait. For example, an individual will try synchronizing their footsteps to a steady metronome or musical beat while walking (Ready et al., 2019).

Using RAS, Thaut et al. (1996) were able to increase cadence, stride length, and symmetry in gait patterns of PD patients. The RAS intervention consisted of walking a flat surface, stair stepping, and completing stop and go exercises to rhythmically accentuated music at three different tempos. On average, PD patients who underwent RAS training improved 25% in gait velocity for flat surface and incline walking. Participants who engaged in self-paced training also demonstrated improved gait velocity, however to a lesser extent than those in the RAS training group. Participants who did not receive training were not found to show any improvement. As improvements were apparent after only a 3 week period, RAS may provide benefits over a relatively quick span of time.

It is also important to note the neurophysiological mechanisms underlying the sustenance of gait improvement, following RAS intervention. Calabro et al. (2019) investigated these mechanisms by correlating EEG changes with behavioral (gait) changes following an RAS intervention. Observed clinical improvement in gait quality, balance, and number and length of strides was found to be associated with greater improvement of fronto-centro parietal/temporal electrode connectivity, compared to those who did not take part in RAS gait training. Thus, RAS may be a useful intervention for PD, specifically because it leads to long term improvement at the neurological level.

Beyond gait performance, RAS has also been shown to improve the entrainment and synchronization of individuals with PD. However, this improvement may only be apparent when musical melodies are implemented within the RAS intervention. When comparing different types of auditory cues and movements during RAS training, Rose et al. (2019) found that musical melodies were more useful than metronomes in regards to synchronizing movements and maintaining entrainment in the absence of heard cues. This finding may have been the case because the musical melodies were more memorable and therefore more predictable to listeners. Moreover, it is possible that the previously discussed concept of INMI played a role in this finding. The memorability and predictability of music may enable patients to experience an INMI episode, which consequently aids the process of entrainment in the absence of external stimulus. In this way, it is arguable that the clarity and familiarity of music, in addition to its underlying rhythm, are important to RAS interventions.

Musical Sonfication

Musical sonification (MS) can also be used to facilitate the motor behaviors of PD patients. MS involves transforming kinematic variables, such as handwriting into music. Its purpose is to improve perception of movement irregularities (e.g. when the music changes) and to provide auditory guidance (e.g. when the music does not change;Veron-Delor et al., 2019).

Veron-Delor et al. (2019) found that both background music and MS increased the movement frequency of PD patients during a handwriting task. When participants completed the task in complete silence without background music or MS, no such improvements were apparent. These findings further suggest that the most robust improvements in PD symptoms occur when music is incorporated within therapeutic interventions.

Music and Parkinson's disease: General discussion

Music can overall be thought to provide a wide range of benefits to PD patients, depending upon the manner in which it is implemented. It specifically appears that the rhythmic qualities of music are helpful in regards to enhancing the patient's movement synchronization, gait, and entrainment. As interventions involving music appear to have resulted in superior improvements for PD patients than those without musical components, music interventions should be advocated for in the treatment of PD. Given the apparent success of music therapy in the treatment of PD, it may be further explored whether music therapy is effective in the treatment of Alzheimer's Disease (AD), another neurodegenerative disease that falls within the umbrella of dementia.

Music and memory processes: Alzheimer's Disease

Alzheimer's Disease (AD) is the most common form of dementia and involves progressive disorientation, memory loss, speech disturbances, and personality disorders (Martone & Piotrowski, 2019). Although there is currently no found cure for AD, evidence suggests that music therapy can effectively manage its symptoms. Interestingly, music-induced emotions and memories have been found to be preserved in Alzheimer's patients. Through a series of studies, Cuddy et al. (2015) found that patients with mild to moderate AD preserve musical engagement and musical seeking, despite cognitive loss. For example, patients would demonstrate familiarity with a tune by correctly singing along with it and continuing to sing after the tune stopped. They also demonstrated an ability to detect pitch violations in familiar melodies by grimacing or frowning upon the occurrence of these violations.

Familiar music has also been found to evoke personal autobiographical memories for Alzheimer's patients. In one study, Cuddy et al. (2015) found that for AD patients, the percentage of tunes yielding music-evoked autobiographical memories (MEAMS) did not significantly differ from healthy controls. Additionally, Samson et al. (2012) found that AD patients exhibited impaired learning and recognition of unfamiliar melodies during immediate and delayed recognition tasks, however they were accurate in their initial familiarity judgements

Each of these findings suggest that the musical lexicon-- that is, a system containing the representations of specific musical phrases one has been exposed to during their lifetime (Peretz et al., 2009) may be spared in patients with AD. The musical lexicon is also linked with emotion expressive analysis, which may activate memories in the phonological lexicon. Music may thus serve as an effective tool for restoring memory in AD patients, whether this memory relates to knowledge about musical structure, or to more personal experiences.

There is neurological evidence to illustrate why some aspects of musical memory are preserved in AD patients. In an examination of the blood oxygen level-dependent (BOLD) activations of healthy patients, Jacobsen et al. (2015) found that the caudal anterior cingulate and the ventral pre-supplementary motor area play a significant role in the encoding of long-known music. In a second experiment, Jacobsen et al. (2015) sought to determine whether these identified brain regions were implicated in the progression of AD. It was found that these regions showed substantially minimal cortical atrophy and minimal disruption of glucose metabolism, compared to the rest of the brain. As these brain areas appear not to be implicated in the progression of AD, this may explain why some AD patients are able to sing along with familiar music and identify violations in pitch. Therapeutic interventions may thus wish to incorporate music into the treatment of AD patients, as doing so may help to exercise long term memory functions.

Musical interventions for dementia

Music has in fact been utilized as a therapeutic intervention for dementia patients, with there being various resulting benefits reported. Improved language functioning is one such benefit, perhaps due to the previously discussed interaction between music and language-associated brain regions. Brotons & Kroger (2000) found that AD patients who engaged in music therapy sessions exhibited more improved speech content and fluency compared to those who participated in conversational sessions. It may therefore be argued that music is more effective at facilitating the language abilities of AD patients than mere conversation. Music therapy may therefore be an optimal intervention for AD patients, as it appears to facilitate both their memory and language abilities.

Music therapy interventions also appear to improve the behavioral and psychological states of AD patients. Raglio et al. (2008) found that AD patients displayed improvement with regards to delusions, agitation, anxiety, apathy, irritability, and aberrant motor activity following music therapy interventions. AD patients receiving music therapy also demonstrated average improvement in empathetic behavior, as well as a decline in non-empathetic behavior respectively. This finding was evident as patients actively participated in the music therapy sessions and formed relationships with the music therapist.

Music therapy may be particularly beneficial for dementia patients in the long term, as Raglio et al. (2008) found that improvements persisted 4 weeks after the intervention was implemented. Chu et al. (2014) also found music therapy to be effective with regards to maintaining improved cognitive functioning and psychological state over time. Yet, this maintend improvement was only apparent among those with mild to moderate, rather than severe dementia. Music therapy may therefore be most effective in the long term for those for mild to moderate cases of dementia.

Still, music therapy may be able provide some physiological and cognitive benefits to those with more severe cases. Takahashi & Matsushita (2006) found systolic blood pressure to be significantly lower among patients with moderate to severe dementia, who had taken part in music therapy 2 years prior. By contrast, blood pressure was found to significantly increase over the 2 year period for those who did not receive music therapy. In addition, intelligence scores were maintained in the music therapy group 2 years after the intervention, whereas scores declined among those who did not receive the intervention. Although music therapy cannot cure dementia, it may effectively manage symptoms and allow for maintend improvement.

Music and dementia prevention

The efficacy of music therapy as an intervention for dementia prompts the question of whether music can be used to prevent the onset of dementia-related disorders. There is some evidence to suggest that dementia may be less common among those with a musical background. In an interview study with former orchestral musicians, Grant & Brody (2004) found that no participants indicated any awareness of a living current or former orchestral musician with either reported or suspected dementia. If dementia is truly less common in former musicians, there may be a possible protective effect of musical experience against the development of dementia.

Music does in fact appear to act as a protective factor for those who may be vulnerable to acquiring dementia. Through a cotwin control study, Balbag et al. (2014) found that twins who played a musical instrument in older adulthood were less likely to develop dementia and cognitive impairment. It is significant that discrepancies in dementia occurrence were found within twin pairs, despite the fact that these individuals shared genetic properties and were raised in the same environment. Musical engagement may therefore lessen the potential for dementia onset, even in spite of genetic and environmental vulnerabilities.

The cognitive benefits resulting from musical engagement may be what specifically prevents the onset of dementia. Hanna-Pladdy and MacKay (2011) found that elderly individuals with at least 10 years of musical training displayed more improved cognitive performance compared to age and education matched individuals with little to no such musical experience. Importantly, there was found to be a linear relationship between years of musical experience and cognitive functioning in advanced age. This finding implied that greater amounts of musical experience led to the most improved cognitive functioning. It is thus plausible to argue that with the more musical experience individuals receive throughout the lifespan, the more long term, age-related benefits they are provided with.

Conclusion: the valuable contributions of music

Each section of this review has outlined various ways in which music interacts with the brain. With these interactions, comes benefits that are applicable to various populations across different stages of the lifespan. By promoting neuroplasticity, music is particularly helpful to the maturing infant brain. Early musical exposure is especially beneficial to preterm infants, whose brains are in a vulnerable, underdeveloped state at birth. Among the general infant population, early musical exposure and activity is able to provide socioemotional and communicative benefits, as well as advanced musical knowledge.

Continuing to engage with music throughout childhood may allow for the maintenance of these benefits. Previously discussed studies have identified faster brain maturation among children who practice musical instruments. This increased maturation has specifically been found within auditory-processing areas of the brain. Childhood musical training has also been found to provide transferable benefits to working memory and language development.

With its ability to enhance language development and memory processes, music can be integrated within therapeutic interventions for individuals who exhibit deficits in these areas. Musical interventions involving vocalization have been associated with improvements in speech perception and production among hearing impaired and intellectually disabled individuals. Musical interventions have also been shown to benefit individuals with Dementia disorders such as Parkinson's and Alzheimer's diseases. While individuals with these diseases exhibit significant motor and/or cognitive impairments, a majority appear not to show preserved abilities within the musical domain. These findings may provide a possible explanation as to why music therapy appears to act as an effective intervention for neurodegenerative diseases.

In regards to Parkinson's Disease, musically-based therapies such as RAS and MS have been effective in improving the fine and gross motor skills of patients. Music interventions have also been found to improve memory process, language abilities, and psychological symptoms among general populations of dementia patients. Of important note is the finding that these benefits can be maintained in the long term, which urges for a particular emphasis on musical interventions for the dementia population. Perhaps most importantly, it appears that greater musical exposure throughout the lifespan lessens the potential for the acquisition of dementia. Thus, it is arguable that music contributes to proper brain functioning throughout the course of human development.

Implications: the future of music education

The argument that continual musical exposure is necessary for proper brain functioning brings practical implications in regards to advancing music-based education programs. Integrating music within the standard educational curriculum will provide children with developmentally enhancing experiences to promote optimal brain growth. Perhaps these early musical experiences may also lessen the potential for neurodegenerative diseases later on in life, as suggested by prior literature.

Unfortunately, many school boards fail to recognize the importance of early musical exposure, with music programs often being first in line to suffer budget cuts (Pergola, 2014). This is greatly due to the high cost of sheet music and instrument purchase and repair (Petress, 2005). In addition, as a result of the No Child Left Behind Act (NCLB) of 2001, music programs have suffered adverse consequences. These include the reduction and elimination of programs, music teachers having to assist with teaching other subjects, and exclusion of academically low-achieving students from music programs (West, 2012).

With music classes being regarded as "specials," school boards may also be less inclined to view them as essential to a student's educational experience. As of 2021, music programs may be in especial danger of budget cuts, due to the COVID-19 pandemic. With the world being largely reduced to virtual education, many children (particularly those without access to the internet) are unable to participate in music classes. Group musical performances also prove much difficulty in a virtual format, as the technology often lags and distorts sound (Manila, 2020).

Many music teachers have strategized ways for students to continue their musical engagement, such as by holding outdoor, socially distanced performances (Renken, 2020) and constructing instruments from homemade materials (Geigrich, 2020). Although students are unable to engage with music in the same manner as prior to the pandemic, music continues to remain a significant aspect of their education. For some students facing academic and social challenges, music and other arts function as their only means of an outlet. In addition, students unable to afford music lessons are completely cut off from musical engagement when the school no longer provides it. When music is cut out of a student’s educational experience, the student is problematically deprived of experiences that are optimal to their well-being. It is hoped then, that parents and educators will come to recognize the imperative place that music holds within a child’s developmental experience.

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