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Music and Its Effects on the Brain

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Abstract

This paper will discuss, in short, how music influences our brain, as well as some behavioral and physiological effects as a result. The brain consists of many regions responsible for different cognitive processes, such as learning, memory, recall, speech, and our emotions. It has been found that music helps to facilitate all of these cognitive processes, regardless of its emotional valence or whether the music is active or passive, such as singing or listening to it, respectively. It was discovered that music influences our ability to learn novel concepts related to mathematics, reading, and even language acquisition. It was also discovered that music supports dopaminergic responses related to reward and motivation, and inhibits stress responses due to an increase in cortisol levels, as well as activating regions associated with emotion regulation. Interestingly, music facilitates autobiographical recall and memory too, and decreases behavioral deficits in those with neurological degenerative diseases (like dementia). These findings implicate that music has rehabilitative and therapeutic benefits, supporting the notion that music therapy can be an effective form of therapy for cognitive, behavioral, and psychological disturbances.

Keywords: Music, music therapy, brain, cognition, behavior, emotion, dementia, neuroscience

Music and its Effects on the Brain

There is something special about being able to lose yourself in a song. I have always wondered how our minds and bodies interact with music, and how we respond to certain musical stimuli that might produce not just your typical physiological effects (that is, goosebumps and chills down the spine), but psychological -- and, in turn, behavioral -- and neurological effects as well. Music is a universal constant; it is a recurring factor in human life and is found across all cultures, expressing itself in a multitude of ways: Different instruments, melodies, genres, tempos, harmonies, voices, and dances.. It is no secret either that music has been known to facilitate and support mental and emotional well-being. It is often used to help regulate our emotions and lower stress and anxiety levels, like those who partake in music listening when they are feeling sad. Music can also promote attention and learning, as seen generally in those who listen to relaxing instrumental music, such as classical or jazz, while studying or reading -- and even in educational settings. Music will be found, too, to be a key component in assisting those with degenerative neurological disorders to recall past events and memories, such is the case with dementia patients.

The goal here is to interpret where the brain processes musical information, and how this might play into other brain regions alongside some of our cognitive processes. It is important also to consider the question of how, exactly, does music facilitate these different processes (and where) -- and what do these findings mean for music therapy? There is a reason that music can sway our mood and heighten our emotions, make us cry or make us want to dance, allow us to reminisce, and better focus on the task at hand. Music grants us the ability to not only connect with others, but better connect with ourselves and our brains, and figure out just how that organ in our skull truly responds to, and processes, musical stimuli. Researching this topic is of immense personal interest, and I sincerely hope this paper will yield an increased amount of knowledge on how music -- one of my favorite pastimes -- can significantly influence, and alter, our mind and body.

To begin, how does music work in actually affecting some of our brain functions? According to Chanda and Levitin (2013), there are many neurotransmitters in our brain that music can actively alter, including dopamine (mood and emotion regulation) and cortisol (stress and arousal), among others. With reward, motivation, and pleasure, the "appetitive" phase occurs during reward-seeking behavior, which includes learning, anticipation, and goal-directiveness. The "consummatory" phase occurs when the reward has been obtained, leading to reinforcement of whatever behavior led to reward obtainment. "Dopaminergic transmission underlies both the appetitive and consummatory phases of reward ... dopamine does not function as a 'pleasure' neurotransmitter *per se*, but rather regulates motivation and goal-directed behaviors, playing a critical role in prediction and learning related to future rewarding events" (Chanda & Levitin, 2013).

Out of three studies that used positron emission tomography (PET) to investigate regional cerebral blood flow during musical pleasure, one study found that self-selected, pleasurable music was associated with more "chill-inducing" effects and an increased level of rCBF, compared to neutral music. Regional cerebral blood flow is defined as the amount of blood flow to a specific region of the brain in a given time, which is controlled by metabolic, neural and chemical mechanisms, as well as pressure autoregulation. Regulation of rCBF is done by cerebral perfusion pressure and cerebral vascular resistance (Sharma, 2011). So this means that, at least in the aforementioned studies, regional cerebral blood flow is indicative of which areas of the brain are most active and are producing the most physiological effects during music listening -- especially when listening to pleasureable music.

This increase in regional cerebral blood flow was found in areas of the brain that are "critical to reward and reinforcement, such as the ventral striatum [including the nucleus accumbens (NAc)] and midbrain, as well as the thalamus, cerebellum, insula, anterior cingulate cortex (ACC), and orbitofrontal cortex (OFC)" (Chanda and Levitin, 2013). This tells us also about rCBF that, when listening to pleasurable music, it is more abundant in areas of the brain that help to regulate goal-seeking behaviors and motivation. It is important to note here that NAc activation was present when listening to unfamiliar, but pleasant, music as well as during singing when compared to speech. "The nucleus accumbens plays crucial roles in locomotion, learning … impulsivity, risk-taking behaviors, feeding behavior … sexual motivation … as well as incentive and reward, especially unpredictable reward" (Salgado & Kaplitt, 2015). There are quite a few brain areas, then, that play a crucial role in motivation when triggered by musical stimuli -- meaning that listening to pleasing music seems to trigger the release of dopamine and an increase in regional cerebral blood flow in important brain regions such as the ventral striatum, midbrain, anterior cingulate cortex, and nucleus accumbens (among others). These brain areas, when listening to pleasurable music, all appear to help support and regulate behaviors associated with reward, reinforcement, and drive.

One of the main reasons people partake in music listening is because it helps one to feel more centered and calm, leading to a decrease in stress levels. This is where cortisol comes into play. Cortisol, a glucocorticoid (also a product of the HPA [hypothalamic pituitary adrenal] stress axis), regulates metabolism and immune function. Other hypothalamic hormones -- such as corticotropin-releasing hormone (CRH), adrenocorticotropic hormone (ACH), serotonin, and derivatives of proopiomelanocortin (POMC) -- “initiate higher-order cognitive and behavioral responses to stress, and ... act to suppress them once the stressor has subsided” (Chandra & Levitin, 2013). It is important to note that the amygdala, too, has an abundance of cortisol receptors, alongside its key role in emotion regulation, as we will discuss later.

In one study conducted by Khalfa et. al. (2003, as cited in Chandra & Levitin, 2013) that simulated everyday stress experienced, after obtaining measurements across the span of fifteen minutes to two hours, it was discovered that there was a “more rapid lowering of cortisol levels after listening to relaxing music compared to a silent control.” Another study, conducted by Knight and Rickard (2001, as cited in Chandra & Levitin, 2013), found that listening to music decreased stress-induced heart rate and blood pressure but not cortisol levels, compared to silence. *How* does this work though? And what do these results mean? Well, it is quite simple: Relaxing music (with a slow tempo) is associated with a decrease in heart rate, respiration, and blood pressure; and upbeat music (with a fast tempo) increases these brainstem-mediated measures.

Having a little bit of background on some of the ways in which our minds (and, in turn, our bodies) tend to respond to musical stimuli, we can shift our focus to higher level processes -- more specifically, how music can alter our ability to learn. According to Hetland, Vaughn, and Butzlaff (2000, as cited in Scripp, 2002), there is a strong association between music and spatial-temporal reasoning and achievement in math and reading. More specifically, it was found that music listening actually primes the brain, in a way, to prepare for spatial-temporal reasoning -- which is the ability to conceptualize physical, three-dimensional objects in time and space. This finding supports the notion that music actively affects neural networks that one would not normally associate with passively processing musical stimuli; the brain regions that are associated with processing musical information, then, might actually overlap with other brain areas that were believed to be solely responsible for certain cognitive processes (Hetland, 2000a, as cited in Scripp, 2002).

Furthermore, it was found that the study of music -- specifically, reading and playing -- actually helps to increase understanding of mathematical concepts and problems. “Meta-analyses ... suggest not only that the effect of musical training in conjunction with mathematical study may benefit greatly from explicit attention to teaching toward this particular aspect of learning transfer, but also that associations between learning music and understanding math are strongest when authentic music instruction is integrated with mathematical instruction based on spatial-temporal or proportional aspects of learning math” (Vaughn, 2000; Graziano et. al., 1999; as cited in Scripp, 2002). According to Butzlaff (2000, as cited in Scripp, 2002), there is also a strong association between the study of music and how well students do on standardized reading and verbal tests, and successfully developing a second language “occurred with the use of music-integrated instruction infused with underlying mental processes drawn from linguistics, musical perception, and speech therapy” (Lowe, 1995, as cited in Scripp, 2002).

We now know some of the ways in which music can affect certain areas of learning (e.g., mathematics and reading), but *how* and *when*, exactly, does it work? The underlying mechanisms here are important to discuss. It appears that musical stimuli -- whether active (singing or playing) or passive (listening) -- plays a vital role in assisting with verbal learning and memory. In one study, a group of healthy older adults and those with dementia were asked to encode visual stimuli of unfamiliar children's songs accompanied by either a spoken or sung recording. According to Simmons-Stern et. al. (2010, as cited in Ferreri & Verga, 2016), "While older adult controls showed no significant difference between the two conditions, ... AD patients demonstrated better recognition accuracy for the sung lyrics over the spoken lyrics." Similarly, McElhinney and Annet (1996, as cited in Ferreri & Verga, 2016) demonstrated that the number of recalled words, alongside the chunking together of recalled material, was better when sung versus when spoken. Further supporting the notion that active musical stimuli facilitates verbal learning and word recall is a study in which English-speaking participants were given word pairs -- one in Hungarian -- in a speaking condition, rhythmic speaking condition, and singing condition. Results yielded "singing to be a more effective condition for learning than either speaking or rhythmic speaking, and concluded that the melodic component may be the most important aspect for learning and memory" (Ludke, Ferreira, & Overy, 2014, as cited in Ferreri & Verga, 2016).

Moreover, even passive musical stimuli have been known to support verbal learning and memory. In several conducted functional magnetic resonance imaging (fMRI) studies, results showed that, compared to silence, background music played during the encoding phase of verbal learning greatly improves performance in item and source memory in healthy young and older adults while simultaneously decreasing prefrontal cortex (PFC) activation (Ferreri, Aucouturier, Muthalib, Bigand, & Bugaiska, 2013; as cited in Ferreri & Verga, 2016). For some context, the prefrontal cortex "plays a cardinal role in the temporal organization of behavior and cognitive activities. It controls the execution, order and timing of sequential acts toward a goal" (Fuster, 2001). As we can see, the "when" in this case is the occurrence of both active and passive musical stimuli -- whether it is singing, playing an instrument, or listening to energizing or relaxing music -- significantly influencing our cognitive processes of not only taking in several kinds of information (encoding) but retrieving and recalling as well.

Of course, we should also look into how this process works. One theory suggests that many factors are important when encoding and retrieving information -- internal factors, such as motivation, and external factors, such as the material to be learned. (Brown & Craik, 2000, as cited in Ferreri & Verga, 2016). Music has been believed to influence both internal and external factors. For instance, studies conducted on proactive interference demonstrated how musical stimuli can be used to manipulate a participant's mood during encoding and retrieval, which is also used to elicit depressive states or increase arousal level that can affect performance (Eich, 1995, as cited in Ferreri & Verga, 2016). More specifically, "melodic and rhythmic properties of music may provide a template that drives the formation of an internal rhythm in cortical networks involved in learning and memory" (Thaut et. al., 2005, as cited in Ferreri & Verga, 2016).

This supports the Dynamic Attending Theory, which suggests that the temporal structure of an event causes swaying in attention over time, and this swinging of attention facilitates both temporal and structural integration of information (Jones, 1976; Jones & Boltz, 1989; Boltz & Jones, 1986; Jones, Summerell, & Marshburn, 1987; as cited in Ferreri & Verga, 2016). Another theory, the arousal and mood hypothesis, suggests that music's positive effect on cognitive abilities can be accredited to changes in individuals' mood or arousal (Thompson et. al., 2001; Schellenberg & Peretz, 2007; as cited in Ferreri & Verga, 2016). Supporting this are many studies that have found how variations of participants' arousal and mood can heavily influence their performance during IQ subtests and spatial tasks (Schellenberg, 2005, 2006, 2012; as cited in Ferreri & Verga, 2016).

Additionally, music with a high emotional valence was found to also support memory and learning. According to Koelsch (2014, as cited in Ferreri & Verga, 2016), many fMRI studies have shown that "music modulates activity in brain structures that crucially involved in emotions, such as the amygdala, the nucleus accumbens, hypothalamus, hippocampus, insula, cingulate cortex, and orbitofrontal cortex." Furthermore, musical stimuli helps as well to foster reward and motivation through verbal learning and memory -- so not only does music directly affect our drive for reinforcement, but it can indirectly affect, with its emotional valence, this dopaminergic system through our cognitive ability to encode and recall. As Blood & Zatorre (2001, as cited in Ferreri & Verga, 2016) states, "music is likely to activate the reward system by virtue of its powerful emotional properties, in turn facilitating a variety of verbal mnemonic tasks because of the role played by reward circuits during learning." It is important to consider, however, individual differences (i.e., genre preference or physiological response) that can affect the variability in performance on memory and learning tasks (de Groot, 2006; Mas-Herrero, Marco-Pallares, Lorenzo-Seva, Zatorre, &

Rodriguez-Fornells, 2013; Mas-Herrero, Zatorre, Rodriguez-Fornells, & Marco-Pallares, 2014; as cited in Ferreri & Verga, 2016).

Moving on from music's significant influence on different facets of learning (i.e., reading and mathematics performance and second language acquisition), we shift our focus to how music can affect patients with degenerative neurological disorders, such as dementia. Interestingly enough, "music-induced emotions and memories are often preserved even in more advanced stages of dementia, possibly owing to relative preservation of medial frontal and limbic areas in AD [Alzheimer's disease], which enables the therapeutic use of music across the dementia spectrum, from MCI [mild cognitive impairment] to severe dementia" (Cuddy, Sikka, & Vanstone, 2015; Jacobsen et. al., 2015; as cited in Särkämö, 2018). Regarding behavioral and cognitive effects, stimulating background music has been found to reduce anxiety, but only short-term. However, it also was found to enhance awareness and increase performance on tasks involving verbal fluency and episodic memory (Irish et. al., 2006; Arroyo-Anllo, Diaz, & Gil, 2013; El Haj, Fasotti, & Allain, 2012; Thompson et. al., 2005; as cited in Särkämö, 2018).

For example, several studies conducted in moderate to severe dementia care facilities, using individualized music-listening, found "short-term beneficial effects of music on anxiety, agitation, and positive social behaviours and interaction" (Gerdner, 2005; Sung, Chang, & Lee, 2010; Garland, Beer, Eppingstall, & O'Connor, 2007; Remington, 2002; Ziv, Granot, Hai, Dassa, & Haimov, 2007; Clair, 2002; Ziv et. al., 2007; as cited in Särkämö, 2018). While the effectiveness of musical activities on helping to alleviate behavioral or psychological problems in individuals with moderate to severe dementia is inconclusive, still, "the evidence seems to suggest that exposure to music may have short-term (momentary) positive emotional and cognitive effects and that songs may function as a mnemonic aid in dementia..." (Särkämö, 2018).

In addition, active musical stimuli, such as singing, has also been found to facilitate reductions in behavioral and cognitive problems in individuals with dementia. For instance, several studies have reported "reductions in wandering, disruptive vocalisations and agitation; and increased reality orientation and social interaction" (Groene, 1993; Casby & Holm, 1994; Brotons & Pickett-Cooper, 1996; Riegler, 1980; Pollack & Namazi, 1992; as cited in Foster & Valentine, 1998). Comparatively, a study conducted by Foster & Valentine (1998) including twenty participants with mild-moderate dementia found that average autobiographical recall was better with background music (either familiar or novel) versus silence (71.03% and 66.22%, respectively). Regarding the emotional aspect of how active musical stimuli can affect those with dementia, a study conducted by Pongan et. al. (2017, as cited in Särkämö & Sihvonen, 2018) "assessed the effects of 12-week choir singing and painting interventions on 59 PWDs [persons with disabilities] with mild AD. Both interventions were reported to reduce anxiety and pain and improve QoL [quality of life] ... whereas only the painting intervention reduced depression." In another study, singing was found to have a short-term effect on verbal memory and either maintained or improved general cognitive functioning, attentional and executive processes, and episodic memory (Särkämö & Sihvonen, 2018). As we can see, studies are promising that music can, at least for a short time, improve recall and memory (and mood) in patients with dementia.

It is important to discuss, too, the effect music's emotional valence has on our brain functions. According to Koelsch (2018), there are many brain regions that become active due to music-evoked emotions such as the "(anterior) hippocampal formation, the amygdala, the auditory cortex, the nucleus accumbens/ventral striatum, the dorsal striatum, the medial and lateral orbitofrontal cortex, and the anterior cingulate cortex as well as ... the anterior insula, pre-SMA [pre-supplementary motor area], rostral cingulate zone, and mediodorsal thalamus." Similarly, a study found that emotional environmental sounds triggered activity in many regions that are associated with emotional appraisal and early emotional processing -- such as the lateral and dorsomedial prefrontal cortex, and the amygdala, the thalamus, the cerebellum, and the primary auditory cortex, respectively. More specifically, Western classical music activated reward processing regions -- like the anterior cingulate cortex (ACC) -- that are associated with emotional appraisal, and regions of the default mode network (DMN) (Phillips, Ladouceur, & Drevets, 2008, as cited in Lepping et. al., 2019).

Referring to the amygdala, studies have shown that the superficial (left) amygdala is sensitive to music -- as well as faces and sounds -- that one perceives as joyful or pleasant, and joy evoked by music gives rise to stronger blood-oxygen-level-dependent (BOLD) responses (Blood & Zatorre, 2008; Mueller et. al., 2011; Koelsch et. al., 2013; Bzdok et. al., 2011; & Kumar, von Kriegstein, Friston, & Griffiths, 2012; as cited in Koelsch, 2014). Detected in fMRI, the BOLD signal "reflects changes in deoxyhemoglobin driven by localized changes in brain blood flow and blood oxygenation..." (Hillman, 2014). The laterobasal (right) amygdala was also observed to respond to joyful music in certain studies, as well as sad music in other studies. Additionally, the laterobasal amygdala "receives direct projections from the auditory cortex (in addition to projections from the auditory thalamus), and by virtue of such projections the auditory cortex modulates laterobasal amygdala activity in response to complex sounds with emotional valence" (Koelsch, 2014). Another important brain region in this context is the nucleus accumbens, as previously mentioned earlier when discussing reward and motivation. When it comes to processing musical stimuli, two studies have shown that during intense feelings of music-evoked reward or pleasure is when the nucleus accumbens is active -- leading to what are called "musical fissions" or "chills," such as goosebumps or shivers down the spine (Blood & Zatorre, 2001; Salimpoor, Benevoy, Larcher, Dagher, & Zatorre, 2011; as cited in Koelsch, 2014).

Another important brain region involved with music-evoked emotions is the hippocampus. In some studies, music-evoked tenderness, peacefulness, joy, music-evoked frissions, and sadness have all been associated with hippocampal activity -- as well as both positive and negative emotions in other studies (Blood & Zatorre, 2001; Koelsch, Fritz, Cramon, Müller, & Friederici, 2006; Mitterschiffthaler, Fu, Dalton, Andrew, & Williams, 2007; Eldar, Ganor, Admon, Bleich, & Hendler, 2007; Mueller et. al., 2011; & Trost, Ethofer, Zentner, & Vuilleumier, 2012; as cited in Koelsch, 2014). Functional connectivity between the hippocampus and the thalamus has also been shown to respond to joy that is provoked by music, which supports the notion that the hippocampus is, in fact, associated with music-evoked positive emotions that have endocrine effects similar to a reduction in stress, including lower cortisol levels (Koelsch & Skourus, 2013; Koelsch & Stegemann, 2012; Chandra & Levitin, 2013; as cited in Koelsch, 2014).

After discussing how, in a myriad of ways, music can influence and affect many brain regions, what do all of these findings mean for music therapy? Do these results facilitate the usefulness of music therapy in clinical and rehabilitation settings? Personally, I believe it to be the case. For example, the use of musical memories in therapy may actually help autobiographical recall, as well as providing a tool for musical memory training to assist in enhancing nonmusical knowledge and recall (Foster & Valentine, 2001; Irish et. al., 2006; as cited in Thaut, 2010). When it comes to inattention and neglect as a result of stroke or traumatic brain injury, music can also help overcome this visual neglect -- which might be due to the arousal effects of music, specifically in the right hemisphere where visual neglect is thought to originate due to lesions (Hommel, Peres, Pollak, & Memin, 1990; as cited in Thaut, 2010). Moreso, there is even "evidence that neuro logic music therapy can be successfully used to address psychosocial treatment issues" (Kleinstauber & Gurr, 2006; Nayak, Wheeler, Shiflett, & Agostinelli, 2000; as cited in Thaut, 2010).

According to Hillecke, Nickel, & Bolay, 2005 (as cited in Koelsch, 2009), there is a working model that contributes five different factors to the effectiveness of music therapy: Attention, emotion, cognition, behavior, and communication. Firstly, music can always catch our attention, distracting us from stimuli that might put us into a negative state, such as pain, fear, anxiety, or sadness (Sussman, 2007; Koelsch, 2009; as cited in Koelsch, 2009). This appears to account for "anxiety- and pain-reducing effects of music-listening during medical procedures, as well for beneficial effects of music therapy in the treatment of tinnitus or attention-deficit disorders" (Nelson, Hartl, Jauch, et. al., 2008; Klassen, Liang, Tjosvold, et. al., 2008; as cited in Koelsch, 2009). Secondly, fMRI studies have shown that "music can modulate activity of all major limbic- and paralimbic structures ... structures crucially involved in the initiation, generation, maintenance, termination, and modulation of emotions. This suggests that music therapy could help with affective disorders like anxiety, depression, and post-traumatic stress disorder (PTSD) due to the fact that they are somewhat related to limbic- and paralimbic structures, such as the amygdala and the orbitofrontal cortex, respectively. (Koelsch, 2009).

Cognitive modulation, which includes memory processes associated with music as well as processes related to analysis of musical syntax and meaning, might contribute to the effects of music therapy on helping Alzheimer's patients' adaptation to residing in a care facility (Gerdner & Swanson, 1993, as cited in Koelsch, 2009). Fourth, behavior modulation "accounts for the evocation and conditioning of behavior (such as movement patterns involved in walking, speaking, grasping, etc.) of music" (Koelsch, 2009). Similarly, syntactic processing of musical stimuli involves brain regions that are also involved in speech -- so, because this factor is likely to influence cognitive processes, these processes can modulated by learning novel action and behavioral patterns (Koelsch, 2005: Meyer & Jancke, 2006; as cited in Koelsch, 2009). Lastly, because music can facilitate communication, music therapy in which patients are making music can be used to help improve non-verbal communication skills (Koelsch, 2009). For example, music therapy has been used to treat selective mutism and improve interpersonal competencies (Findeisen, 2007; Hillecke, Nickel, & Bolay; as cited in Koelsch, 2009).

Wrapping up, we have discussed a multitude of ways in which music affects our brains. We learned some of the neurotransmitters (cortisol [stress] and dopamine [reward]) that are affected and/or released when listening to music, as well as having discussed how music can influence mathematical and reading performance, and verbal learning and memory. Not only that, but it was discovered that music does, in fact, have a significant effect -- regardless of its emotional valence -- on many brain regions that influence our ability to regulate our emotions. Moreover, it was found that musical stimuli, (active [singing, dancing, playing an instrument] and passive [listening to music]), whether it is relaxing or upbeat, can temporarily improve cognition and behavioral problems in dementia patients and assist them with autobiographical memory and recall. These findings all have promising implications for possibly using music therapy in rehabilitation and clinical settings for some cognitive, behavioral, and even psychological problems. As we have discovered, music is an impressive medium, one that can affect many different parts of the brain that seem to work in tandem with one another -- even ones that we may not think to associate with the processing of musical stimuli. It is no wonder that so many of us enjoy the music we partake in listening to and producing. It is exercise for the brain. While facilitating recovery, well-being, and overall plasticity, music is quite the force to be reckoned with.

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