Journal of Music Therapy, 51(3), 2014, 211–227
doi:10.1093/jmt/thu023

Exploring a Neuroplasticity Model of Music Therapy

Elizabeth L. Stegemöller, PhD, MT-BC

Iowa State University

Background: *Given that music therapists work across a wide range of disabilities, it is important that therapists have at least a fundamental understanding of the neurophysiology associated with the client/patient populations that they serve. Yet, there is a large gap of evidence regarding the neurophysiological changes associated with applying music as therapy.*

Objective: *The purpose of this article is to provide music therapists with a general background in neuroplasticity principles that can be applied to the use of music therapy with multiple populations.*

Methods: *This article will review literature on neuroplasticity and literature supporting the specific attributes of music therapy that apply to neuroplasticity. Finally, examples of how to use neuroplasticity principles to explain and support clinical music therapy will be provided.*

Results: *Using the material presented in this review, music therapists will be equipped with information to effectively communicate why music therapy works using three neuroplasticity principles; increase in dopamine, neural synchrony, and a clear signal.*

Conclusion: *Music therapy is a powerful tool to enhance neuroplasticity in the brain.*

Keywords: *music therapy; neuroplascitity principles; neurophysiology*

In clinical practice, music therapists often assess client/patient progress based upon subjective and behavioral evidence. While much information can be obtained through these methods, evidence regarding what neurophysiological changes are occurring can only be inferred. Given that music therapists work across a wide range of disabilities, a full and complete understanding of the neurophysiology associated with each client/patient's disability may be challenging. Moreover, there is a large gap of evidence regarding the neurophysiological changes associated with applying

Address correspondence concerning this article to Elizabeth L. Stegemöller, 240 Forker, Department of Kinesiology, Iowa State University, Ames IA, 50011.

music as therapy. Yet, to be effective at obtaining both financial and administrative support for music therapy services, the ability to explain why music therapy works from a neurophysiological perspective can be highly beneficial. Thus, the purpose of this article is to provide music therapists with a general background in neuroplasticity principles that can be applied to the use of music therapy with multiple populations. This article will (a) review literature that explains the concept of neuroplasticity, (b) review literature supporting the specific attributes of music therapy that apply to neuroplasticity; and (c) provide examples of how to use neuroplasticity principles to explain and support clinical music therapy.

What is Neuroplasticity?

Neuroplasticity occurs in the human brain on many levels, from an individual neuron, to a network of neurons, to an entire region of the brain. For example, at the simplest level, a neuron can make a new connection and/or prune away a connection with another neuron. Additionally, networks of neurons can change the relative weight (i.e., some stronger connections while others are weaker connections) of connections among the neurons in the network. Finally, an entire region in the brain can reorganize (i.e., remapping) such that the region is responding to a completely new set of stimuli. It is important to note, however, that neuroplasticity at all levels not only refers to emergence of new neuronal connections, but also the pruning of neuronal connections. Much like in music where it is the relative relationship between sound and silence that determines the overall perception and response to the music; in neuroplasticity the connectivity and nonconnectivity of neurons, networks, and regions also determines the perception and response to stimuli in the world around us.

Synaptic Plasticity.

A synapse is the point at which a neuronal signal is passed from one neuron to another neuron. Synapses vary across the brain. In general, neurotransmitters are released from the axon of one neuron and cross the synaptic cleft where they bind to receptors on the dendrites of another neuron. This binding changes the configuration of the channels allowing for molecules carrying a charge (i.e., sodium & potassium) to flow into and out of the dendrite (i.e.,

depolarization). Ultimately, the level of the charge reaches a particular value (i.e., threshold), and an action potential is elicited. In general, this is how neurons communication to one another. Synaptic plasticity is the process by which synapses are strengthened or weakened over time, which is dependent upon the level of activity at the synapse.

Bliss and Lømo (1973) were the first to discover that a few seconds of high-frequency stimulation enhanced the synaptic activity between two neurons and that this change persisted for weeks. Thus, this phenomenon has been labeled long-term potentiation (LTP). It was later discovered that specific receptors, N-methyl-D-aspartate (NMDA), mediate the LTP response (Nicoll, Kauer, & Malenka, 1988). At rest, the NMDA receptor is blocked by a magnesium molecule. During depolarization, magnesium is expelled from the NMDA receptor and calcium enters the neuron triggering the LTP response (Nicoll et al., 1988). The properties of the NMDA receptor allow for specificity and associativity, which are important for learning and memory. For specificity, since the NMDA receptor is on the receiving neuron and is open only during strong stimulation, LTP is specific to activated synapses rather than to all synapses on a given cell (Purves et al., 1997). For associativity, weak stimulation may not be enough to open a NMDA receptor. Strong stimulation of neighboring neurons may provide enough depolarization to remove the magnesium block of the weakly stimulated receptor. This in turn would allow for selective enhancement of neighboring synapses that are activated at the same time (Purves et al., 1997). While there is still a gap between research in synaptic plasticity and human behavior, these mechanisms provide a plausible basis for how the brain retains specific properties of an encoded memory, as well as how the brain associates one experience with another. Both of these elements are crucial for learning new behaviors or relearning previous behaviors.

Plasticity of Neuronal Networks.

While synaptic plasticity provides information about what happens at the level of an individual neuron, human behavior is not controlled by one single neuron, but rather networks of neurons that often have the same function. Thus, the strength of connections between a network of neurons, as well as the level of excitability and inhibition can also change.

While it is important to understand that LTP leads to the strengthening of synapses, the opposing process also occurs, long-term depression (LTD). LTP requires a brief high rate of stimulation. In contrast, LTD occurs during low rate stimulation for long periods of time (Mulkey & Malenka, 1992). Interestingly, both LTP and LTD involve the activation of NMDA receptors. The difference between what happens next is dependent on the amount of calcium that flows into the neuron. Short high rate stimulation results in release of large amounts of calcium, which trigger a set of mechanisms that lead to increased synaptic activity (Purves et al., 1997). Long low rate stimulation results in the release of small amounts of calcium, which trigger a set of mechanisms that lead to decreased synaptic activity (Purves et al., 1997). Thus, within a network of neurons with many synaptic connections, the processes of LTP and LTD act in a "push-pull" manner and can change the relative strength of multiple synapses within the network.

Connections between neurons can be excitatory (i.e., increases the likelihood of an action potential) or inhibitory (i.e., decreases the likelihood of an action potential). In a network of neurons with multiple synapses, it could be expected that some are excitatory and some are inhibitory. LTP could increase activity of an excitatory connection and/or inhibitory connection, while LTD could similarly decrease the activity. Therefore, the level of excitation and inhibition within a neuronal network could also be modulated in the same LTP/LTD "push-pull" manner.

Cortical Remapping.

Most of the research in LTP and LTD has focused on areas of the brain that are involved in memory and learning, such as the hippocampus and cerebellum. In clinical music therapy practice, learning new behaviors and retaining these behaviors is one focus, but there is also a focus on restoring lost behaviors or finding alternative behaviors. Thus, cortical remapping is a critical component in explaining how the brain is able to restore and/or use alternative pathways. In short, in sensory areas of the brain (e.g., somatosensory cortex, visual cortex, and auditory cortex) the arrangement of receptive fields (i.e., areas of the brain that respond to a specified stimulus) can change in response to altered circumstances (Jenkins, Merzenich, Ochs, Allard, & Guic-Robles, 1990; Gilbert & Wiesel, 1992). For example, research has shown that

hand representation in the somatosensory cortex will change after amputation of a digit, such that neighboring brain areas will take over the area of the brain that was previously devoted to the amputee (Merzenich et al., 1984). This would suggest that the brain is capable of altering pathways based on experience. However, these changes most likely reflect the strengthening and weakening of synapses already present rather than rewiring. Thus, experiences aimed at restoring behavior (i.e., strengthening previously used synapses) and/or alternating behaviors (i.e., strengthening new synapses and weakening unused synapses) may result in cortical remapping.

The Critical Period.

Neuroplasticity is not the same throughout the lifespan. There is a time in which the changes in the brain are mainly due to the formation of new connections. From birth until about the ages of 2 to 3, millions of new connections between neurons are being made. Little to no pruning is taking place (Neville & Bavelier, 2002). It is important to note that during this time the number of connections is increased, but not the number of neurons. It is during this time that children are "soaking" up the world around them. It is crucial that children are exposed to appropriate stimuli during this time (termed "critical period" to underline its importance), as these experiences set the neuronal structure for future plasticity. Research has shown that abnormal experience of any kind in humans can lead to abnormal patters of brain circuitry that cannot be overcome later in life. For example if infants are born with cataracts, and the cataracts are not removed until later in life, they will never recover normal vision. However, if adults develop cataracts that are removed, normal vision is restored (Purves et al., 1997). Likewise, persistent auditory deprivation during the critical period can lead to deficits in language that are not overcome later in life (Purves et al., 1997). While the changes described in the research are extreme, it is assumed that similar mechanisms occur across other neural systems.

From about the age of 3 to 6, the brain continues to make new connections, but now there is an increase in pruning. However, there are still substantially more new connections than pruning (Neville & Bavelier, 2002). Around the adolescent years, the rates between making new connections and pruning evens out and it

is not until the early 20s that the brain is completely "wired" for one's lifespan (Gogtay et al., 2004). In fact, different brain regions develop at different times up until the early 20s, with the motor and sensory areas being among the first regions to develop and the frontal cortex being the last area to develop (Gogtay et al., 2004). Fortunately, even though the brain is "wired" by the early 20s, neuroplasticity at all levels as discussed above continues until death. It is important for music therapists to understand that the brain is ever changing and we possess unique tools to create positive brain changes throughout the lifespan from birth to death.

Neuroplasticity Model for Music Therapy

Music and Dopamine

Dopamine is a neurotransmitter in the brain that has been shown to be involved in motivation and reward-seeking behavior (Dayan & Balleine, 2002; Morita, Morishima, Sakai, & Kawaguchi, 2013; Salamone & Correa, 2002), working memory (Sawaguchi & Goldman-Rakic, 1991) and reinforcement learning (Montague, Dayan, & Sejnowski, 1996; Wise, 2004). Most importantly, research has shown that the response of dopamine neurons is transferred to stimuli during learning (Romo & Schultz, 1990; Schultz, 1992). For example, when an auditory cue precedes a food reward for completing a new task, dopamine neurons fire in response to the food reward at first. Once the task is learned, dopamine neurons transfer firing to the auditory cue demonstrating that the dopaminergic system may be responsible for predicting with temporal precision future reward events (Montague et al., 1996). This type of reinforcement signaling has been shown to be mediated by dopaminergic neurons in the nucleus accumbens (NAc) and ventral tegmental area (VTA), which have widespread projections to the cortex (Bao, Chan, & Merzenich, 2001; Montague et al., 1996; Salamone & Correa, 2002; Wise, 2004). Thus, paired stimulation of dopaminergic neurons in the VTA and sensory stimuli has been shown to result in cortical remapping (Bao et al., 2001). Taken together with research that has demonstrated that dopamine modulates LTP (Gurden, Takita, & Jay, 2000; Otmakhova & Lisman, 1998), it is well accepted that dopamine plays a vital role in neuroplasticity.

Recently, neuroimaging studies have revealed that listening to music stimulates dopaminergic regions, including the NAc and VTA (Koelsch, Fritz, Müller, & Friederici, 2006; Menon & Levitin, 2005; Salimpoor, Benovoy, Larcher, Dagher, & Zatorre, 2011). This suggests that music listening may stimulate the same neural network as that involved in reinforcement learning and reward (Chanda & Levitin, 2013). Moreover, research has shown a strong link between these regions and cognitive subsystems, including the orbito-frontal cortex, an area of frontal cortex responsible for encoding the temporal aspects of memory (Duarte, Henson, Knight, Emery, & Graham, 2010) and emotional prosodic processing (Paulmann, Seifert, & Kotz, 2010). While the results of these studies are limited to music listening, mainly listening to pleasurable music, they demonstrate the potential of music when applied therapeutically to facilitate neuroplasticity. The goal of music therapy is not to improve music performance, but rather a functional goal to improve nonmusic performance. Music is paired with a task to be learned or relearned. Given that music stimulates activation of dopaminergic regions of the brain responsible for motivation, reward, and learning, and that dopamine release from these regions may regulate neuroplasticity mechanisms (e.g., LTP), music therapists may be providing an enhanced learning environment for nonmusic tasks/behaviors through music-stimulated dopaminergic mediated neuroplasticity mechanisms. In other words, music serves as the reward and motivation for the completion of nonmusic tasks/behaviors. As in the example above where dopaminergic firing transferred from the food award to the auditory cue, music therapists have the unique capability to potentially transfer dopaminergic firing from music (i.e., reward) to the nonmusic task/behavior. Once dopaminergic firing has been transferred to the nonmusic task, the synaptic connections may be strengthened by LTP, which is mediated by dopamine, ultimately leading to the learning of a new task/behavior from which the music reward (i.e., music therapy) can be faded.

Music and the Hebbian Principle

The cellular basis for learning has its roots in a principle first proposed by Hebb in 1949. Hebb stated that "when an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes

place." (Hebb, 1949). It has since been demonstrated that synaptic plasticity is dependent on the temporal order of the two inputs (Levy & Steward, 1983). In other words, neurons that fire together within less than tens of milliseconds wire together (Caporale & Dan, 2008), otherwise known as the Hebbian Principle. This principle has been long established in the neuroplasticity literature, but there has been no research regarding its relationship to music. Thus, the following application of the Hebbian Principle remains a theory that needs research support.

Rhythm is an inherent property of music that often leads to entrainment, defined as two oscillating agents that adapt a common phase and period (Rosenblum & Pikovsky, 2003). Research has demonstrated that movement, vocalization, breathing, and heart rate can be entrained to music (Miendlarzewska & Trost, 2013; Müller & Lindenberger, 2011). However, maybe more importantly to music therapy is that, neural populations can also be entrained by sensory stimulation (Gander, Bosnyak, & Roberts, 2010; Miendlarzewska & Trost, 2013). While most literature regarding entrainment and brain plasticity suggest that entrainment produces a facilatory effect on attentional resources (Miendlarzewska & Trost, 2013), the underlying neural mechanism of this effect remain under explored. The Hebbian principle may indeed provide a reasonable theory for neuroplasticity with music therapy. As stated above, music therapists pair nonmusic tasks/behaviors with music. Often the nonmusic function is paired with rhythm. Thus, if a nonmusic function is entrained with music, then it may be deduced that music is synchronizing neural populations involved in not only the areas of the brain involved in perceiving the music but also those areas involved in the control of the nonmusic task/behavior. Following the Habbian principle, this synchrony of neural firing would strengthen the synapses involved with the control of the nonmusic task/behavior leading to neuroplasticity and the acquisition/learning of the nonmusic task/behavior.

Music versus Noise

Recent studies have shown that noise can negatively affect neuroplasticity. Exposure to noise can increase stress, which is mediated by the limbic system, the area of the brain that controls emotion. This increase in stress then impairs both cognition and memory (Amemiya et al., 2010; Hirano et al., 2006; Kraus

& Canlon, 2012). Specifically, high stress hormone levels suppress LTP in the hippocampus, a deep structure within the brain that is involved in memory (Lynch, 2004; Maggio & Segal, 2010). Moreover, chronic exposure to noise during development can have severe implications. Changes in the auditory system (Chang & Merzenich, 2003), hippocampus (Kim et al., 2006; Kraus et al., 2010) and limbic system (Roozendaal, McEwen, & Chattarji, 2009) after exposure to noise prenatally may lead to decreased memory function and anxiety in adulthood in animal models. In contrast, exposure to music has revealed opposing affects. Long term exposure to music leads to improvements in spatial learning and enhanced learning performance, presumably due to changes in the hippocampus in animal models (Kim et al., 2006; Meng, Zhu, Li, Zeng, & Mei, 2009). This would suggest that exposure to music promotes neuroplasticity while noise suppresses neuroplasticity. Yet, there remains a need to further understand what type of music signal is best for a developing brain. Extending the results of the studies above into music complexity, a less complex music stimuli may indeed be better than a more complex music stimuli, given that the more complex music stimuli may carry more "noise" within its acoustic structure. Nonetheless, research has suggested that extensive music training and experience leads to changes in the brain (Kraus & Chandrasekaran, 2010; Zatorre & McGill, 2005).

Reasoning for why music promotes neuroplasticity in the human brain may lie in the acoustic structure of music itself. Research has suggested that the acoustic signal of song is more consonant than that of speech and that professional musicians have less "noise" in both their spoken and sung signals (Stegemöller, Skoe, Nicol, Warrier, & Kraus, 2008). Thus, music therapists, who are professionally trained musicians, may be able to minimize the amount of noise in their vocal signal by optimizing the resonating precision in the vocal and/or instrumental sound (Stegemöller et al., 2008). Taken together with the evidence that noise suppresses neuroplasticity, while music promotes neuroplasticity, this would suggest that music therapists possess a unique ability to promote neuroplasticity when working with various populations just through their vocal and/or instrumental sound alone. Sung text by a professional music therapist may be more easily processed in the brain than spoken text.

In conclusion, music therapy has the unique ability to promote neuroplasticity through the increase of dopamine production, the synchrony of neural firing, and the production of a clear signal. Much of what is taught and inherently known in music therapy has roots in neuroplasticity. Music therapists are taught to pair nonmusic tasks/behavior with music. This in itself is a basic principle of neuroplasticity, but now there is more research supporting music as a rich neuroplasticity tool. What makes music therapy work, though, is the ability of music therapists to know how to use/manipulate music to shape the neural responses that underlie client/patient behavior. Like the sculptor who meticulously adds and cuts away until a final masterpiece is revealed, music therapists are the artists that use music to prune and create new neural connections resulting in a beautifully crafted masterpiece.

Applying the Neuroplasticity Model to Clinical Practice

Given the literature that supports and suggests that music promotes brain plasticity, it is important that music therapists are able to apply this information to clinical practice, as well as convey the information to other professionals in the medical field. Music therapists are well versed as explaining "what" music therapy is, but now it is imperative for music therapists begin to explain "why" music therapy works. The following section will provide examples of how to use the neuroplasticity model of music therapy to explain why music therapy works across five domains. It is emphasized that the following are examples and are not intended to be all-inclusive. There is much more to be covered within the field of music therapy, but remains outside the scope of the current review.

Social

A common goal in music therapy is to increase interaction with peers. In this case, a music therapist may have patients/clients share instruments, play and/or sing together during a session. For example, it may be observed that in a nonmusic environment the patient/client does not exchange toys independently or upon verbal cues, and may become upset when continually prompted to do so. Therefore, the music therapist develops the goal to increase social interaction with peers through sharing and turn taking. The objective is for the patient/client to successfully pass an instrument

to a peer 3 out of 5 times for five consecutive sessions. An intervention to address this specific objective may include playing an instrument until the music stops. Once the music stops, the patient/client must trade instruments with another patient/client before the music begins. So, why does music therapy work? There may be several underlying reasons for why a patient/client has decreased interaction with peers, but the general neural mechanism for increasing interaction with peers may be the same across individuals. By using preferred music, music therapy increases dopamine in the reward centers (i.e., VTA & LC) of each individual's brain. By using preferred music, music therapy is tailored to meet the specific elements of music that each individual finds rewarding increasing the patient/client-specific neural response. By not starting the music until the patient/client has traded instruments, the music therapists is pairing (i.e., synchronizing neural activity) the reward of music (i.e., increasing dopamine) to facilitate new neural connections that wire social interaction with a positive feeling of success. With repetition, this connection will continue to grow stronger and stronger until finally the patient/client can trade instruments and/or toys on their own, without music, because a new connection in the brain has been made.

Emotional

There are many goals and objectives in music therapy that target emotional expression. An example in this domain may include the observation of a patient/client in a nonmusic environment in which the patient/client shows no emotional response to distressing events. Therefore, a goal in music therapy may be to increase appropriate emotional expression through assisted music composition with the objective of completing one composition within one month of music therapy sessions. Often times patients/clients may have the neural connections that allow them to appropriately express their emotions, but are actively inhibiting the use of the connections due to various outside environmental circumstances. In this example, music therapists would be working towards remodeling the neural networks responsible for appropriate emotional expression, potentially decreasing inhibition in some neurons and increasing excitation of other neurons within the neural network, per se. Again, pairing preferred music with appropriate emotional expression through music composition provides a synchronized

dopaminergic reward that may strengthen the connections associated with appropriate emotional expression, while suppressing connectivity associated with inappropriate emotional expression. Moreover, the clear signal of the music may potentially be encoded more efficiently than the noisier signals of the environment that may be influencing the patient/client's emotional expression.

Cognitive

Music therapists address multiple cognitive goals. Often specific songs are created to help patients/clients learn or relearn procedural skills, like brushing teeth, to declarative information, like mathematical facts. Upon interview with a patient/client, the patient/client expresses interest in learning or relearning to drive a car. Thus, a specific goal may be to learn how to drive a car. Given that driving a car involves being able to complete 2 to 3-step processes (e.g., insert a key, turn the key, put the car in drive), a specific objective may be for the patient/client to complete a 3-step process in the correct order for 3 out of 5 trials for five consecutive sessions. To accomplish this goal the music therapist may create a simulation of the 3-step process of starting a car using various instruments, as well as a song with the instruction embedded in the lyrics. As above, the same process of pairing nonmusic information with music leads to neuroplasticity (e.g., making new connections for starting a car) through dopaminergic release and neural synchrony. However, probably the most important aspect of the neuroplasticity model for music therapy in this example would be that music is a clear signal. Conveying cognitive information through speech may be more "noisy" than through song. For a patient/client that may be developmentally delayed or suffer from brain injury, the "noisy" signal may not be perceived well and would make the learning or relearning of a cognitive task very challenging. Therefore, pairing cognitive information with a song performed by a music therapist, who is professionally trained musician and has a clearer signal than nonmusicians, would promote neuroplasticity because the information conveyed would potentially be better encoded in the brain.

Speech and Communication

Improving speech and communication is another common goal in music therapy. As communication contains social, emotional,

and cognitive components, most of the information presented for previous examples in those areas would also apply to communication. However, the production of speech is a unique area where an example of applying the neuroplasticity model of music therapy may be beneficial. It is observed upon interview that the patient/client speaks very softly and the caregiver also complains that it is difficult to hear the patient/client. Thus, a proposed goal may include increasing vocal loudness with the objective to increase vocal loudness to a particular range, measured with a decibel meter, for three out of five trials for five consecutive sessions. From a speech therapist and professional musician point of view, there is a proper way to produce a healthy full (i.e., loud) sound that would limit harm to the voice. A music therapist may introduce proper breathing techniques and emphasize creating a full sound, rather than a loud sound, when singing. So then, how can neuroplasticity explain the potential positive changes in the speaking voice? Patients/clients have to first learn how to breathe properly until it becomes a more automatic way of breathing so that it may transfer to everyday life speaking situations. Once again, pairing music with proper breathing techniques strengthens the neural connections associated with breathing, until they are more automated, by stimulating the release of dopamine and through neural synchrony. Interestingly the application of a clear signal may play a slightly different role when targeting speech improvements. The music therapist is providing an auditory model of sound for which the patient/client is trying to emulate. Therefore, it is important to model sound that is not as noisy. In addition to promoting neural plasticity, eliminated noise in a signal can also increase harmonic resonance and in turn vocal loudness.

Movement

The final domain that music therapists target in their clinical work is movement. One particularly interesting effect of music is that when a patient/client has difficulty walking, they can often overcome these difficulties by walking in time with music. It is observed that when a patient/client is walking around chairs, the patient/client takes small steps and eventually freezes and is no longer able to walk. A specific goal would be to improve walking, with the objective being to increase stride length by 25% after 10 music therapy sessions. The application of the neuroplasticity

in this case involves cortical remapping. In motor control, there are many cortical brain areas, and in turn different pathways, involved in the control of movement. For example, there is a pathway for the control of self-initiated movements and a different pathway for externally initiated movements. Self-initiated movements are those of an individual's own intent to move. Externally generated movements are those movements made in response to an external cue, whether visual, auditory, or tactile. Therefore, when a patient/client walks in time with music, they are using a different pathway (i.e., externally generated) than when they walk on their own (i.e., internally generated). By pairing music with walking, a clear signal that increases dopamine and neural synchrony leads to the strengthening of an alternative nonimpaired pathway (i.e., cortical remapping). Moreover, by providing specific timing and amplitude cues within the music, specific elements of walking (e.g., such as increasing stride length) can be targeted further reinforcing a new walking pattern. Once this externally generated pathway is sufficiently strengthened, the patient/client can reduce the amount of external cueing (e.g., patient/client can sing in their head instead of aloud) needed to facilitate walking through the use of this alternative pathway.

Conclusion

In conclusion, music is a powerful tool to enhance neuroplasticity in the brain. Music therapists are especially skilled at using music to change nonmusic behavior and are aware that processes governing the change in behavior are due to changes in the brain. However, there has been limited explanation regarding exactly what neural mechanisms may underlie these changes. In this paper, a neuroplasticity model of music therapy has been proposed and examples of how to apply this model have also been provided. Three principles, increase in dopamine, neural synchrony, and a clear signal, can be used to explain why music therapy works. It is important to note that the proposed model is only a theory, and much more research is needed. In any case, it is hoped that the model will provide a method to effectively communicate the amazing potential of music therapy to change neural connectivity.

Conflicts of interest: None declared.

References

Amemiya, S., Yanagita, S., Suzuki, S., Kubota, N., Motoki, C., Otsuka, T., Nishijima, T., & Kita, I. (2010). Differential effects of background noise on various intensities on neuronal activation associated with arousal and stress response in a maze task. *Physiology & behavior*, *99*(4), 521–528.

Bao, S., Chan, V. T., & Merzenich, M. M. (2001). Cortical remodeling induced by activity of ventral tegmental dopamine neurons. *Nature*, *412*, 79–83.

Bliss, T. V., & Lømo, T. (1973). Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path. *The Journal of Physiology*, *232*(2), 331–356.

Caporale, N., & Dan, Y. (2008). Spike timing-dependent plasticity: A hebbian learning rule. *Annual Review of Neuroscience*, *31*, 25–46.

Chanda, M. L., & Levitin, D. J. (2013). The neurochemistry of music. *Trends in Cognitive Sciences*, *17*(4), 179–193.

Chang, E. F., & Merzenich, M. M. (2003). Environmental noise retards auditory cortical development. *Science*, *300*(5618), 498–502.

Dayan, P., & Balleine, B. W. (2002). Reward, motivation, and reinforcement learning. *Neuron*, *36*, 285–298.

Duarte, A., Henson, R. N., Knight, R. T., Emery, T., & Graham, K. S. (2010). Orbitofrontal cortex is necessary for temporal context memory. *Journal of Cognitive Neuroscience*, *22*(8), 1819–1831.

Gander, P. E., Bosnyak, D. J., & Roberts, L. E. (2010). Acoustic experience but not attention modifies neural population phase expressed in human primary auditory cortex. *Hearing Research*, *269*(1), 81–94.

Gilbert, C. D., & Wiesel, T. N. (1992). Receptive field dynamics in adult primary visual cortex. *Nature*, *356*(6365), 150–152.

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., … & Thompson, P. M. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(21), 8174–8179.

Gurden, H., Takita, M., & Jay, T. M. (2000). Essential role of D1 but not D2 receptors in the NMDA receptor-dependent long-term potentiation at hippocampal-prefrontal cortex synapses in vivo. *Journal of Neurosciences*, *20*, 1–5.

Hebb, D. O. (1949). *The organization of behavior; A neuropsychological theory*. New York: Wiley.

Hirano, Y., Fujita, M., Watanabe, K., Niwa, M., Takahashi, T., Kanematsu, M., …& Onozuka, M. (2006). Effect of unpleasant loud noise on hippocampal activities during picture encoding: an fMRI study. *Brain and Cognition*, *61*(3), 280–285.

Jenkins, W. M., Merzenich, M. M., Ochs, M. T., Allard, T., & Guic-Robles, E. (1990). Functional reorganization of primary somatosensory cortex in adult owl monkeys after behaviorally controlled tactile stimulation. *Journal of Neurophysiology*, *63*(1), 82–104.

Kim, H., Lee, M. H., Chang, H. K., Lee, T. H., Lee, H. H., Shin, M. C., …& Kim, C. J. (2006). Influence of prenatal noise and music on the spatial memory and neurogenesis in the hippocampus of developing rats. *Brain and Development*, *28*(2), 109–114.

Koelsch, S., Fritz, T., Müller, K., & Friederici, A. D. (2006). Investigating emotion with music: an fMRI study. *Human brain mapping*, *27*(3), 239–250.

Kraus, K. S., & Canlon, B. (2012). Neuronal connectivity and interactions between the auditory and limbic systems. Effects of noise and tinnitus. *Hearing research*, *288*(1), 34–46.

Kraus, K. S., Mitra, S., Jimenex, Z., Hinduja, S., Ding, S., Jiang, H., Gray, L., Lobarinas, E., Sun, W., & Salvi, R. J. (2010). Noise trauma impairs neurogenesis in the rat hippocampus. *Neuroscience*, *167*, 1216–1226.

Kraus, N., & Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews Neuroscience*, *11*(8), 599–605.

Levy, W. B., & Steward, O. (1983). Temporal contiguity requirements for long-term associative potentiation/depression in the hippocampus. *Neuroscience*, *8*, 791–97.

Lynch, M. A. (2004). Long-term potentiation and memory. *Physiological Reviews*, *84*(1), 87–136.

Maggio, N., & Segal, M. (2010). Corticosteroid regulation of synaptic plasticity in the hippocampus. *The Scientific World Journal*, *10*, 462–469.

Meng, B., Zhu, S., Li, S., Zeng, Q., & Mei, B. (2009). Global view of the mechanisms of improved learning and memory capability in mic with music-exposure by microarray. *Brain Research Bulletin*, *80*, 36–44.

Menon, V., & Levitin, D. J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *NeuroImage*, *28*(1), 175–184.

Merzenich, M. M., Nelson, R. J., Stryker, M. P., Cinder, M. S., Schoppmann, A., & Zook, J. M. (1984). Somatosensory cortical map changes following digit amputation in adult monkeys. *Journal of comparative neurology*, *224*(4), 591–605.

Miendlarzewska, E. A., & Trost, W. J. (2013). How musical training affects cognitive development: rhythm, reward and other modulating variables. *Frontiers in Neuroscience*, *7*.

Montague, P. R., Dayan, P., & Sejnowski, T. J. (1996). A framework for mesencephalic dopamine systems based on predictive Hebbian learning. *Journal of Neuroscience*, *16*, 1936–1947.

Morita, K., Morishima, M., Sakai, K., & Kawaguchi, Y. (2013). Dopaminergic control of motivation and reinforcement learning: a closed-circuit account for reward-oriented behavior. *Journal of Neuroscience*, *33*(20), 8866–8890.

Mulkey, R. M., & Malenka, R. C. (1992). Mechanisms underlying induction of homosynaptic long-term depression in area CA1 of the hippocampus. *Neuron*, *9*(5), 967–975.

Müller, V., & Lindenberger, U. (2011). Cardiac and respiratory patterns synchronize between persons during choir singing. *PloS one*, *6*(9), e24893.

Neville, H., & Bavelier, D. (2002). Human brain plasticity: evidence from sensory deprivation and altered language experience. *Progress in Brain Research*, *138*, 177–188.

Nicoll, R. A., Kauer, J. A., & Malenka, R. C. (1988). The current excitement in long-term potentiation. *Neuron*, *1*(2), 97–103.

Otmakhova, N. A., & Lisman, J. E. (1998). D1/D5 dopamine receptors inhibit depotentiation at CA1 synapses via cAMP-dependent mechanism. *The Journal of Neuroscience*, *18*(4), 1270–1279.

Paulmann, S., Seifert, S., & Kotz, S. A. (2010). Orbito-frontal lesions cause impairment during late but not early emotional prosodic processing. *Social Neuroscience*, *5*(1), 59–75.

Purves, D., Augustine, G. J., Fitzpatrick, D., Katz, L. C., LaMantia, A. S., & McNamara, J. O. (1997). *Neuroscience*. Sunderland MA: Sinauer Associates, Inc.

Romo, R., & Schultz, W. (1990). Dopamine neurons of the monkey midbrain: contingencies of responses to active touch during self-initiated arm movements. *Journal of Neurophysiology, 63*, 592–606.

Roozendaal, B., McEwen, B. S., & Chattarji, S. (2009). Stress, memory and the amygdala. *Nature Reviews Neuroscience, 10*(6), 423–433.

Rosenblum, M., & Pikovsky, A. (2003). Synchronization: from pendulum clocks to chaotic lasers and chemical oscillators. *Contemporary Physics, 44*(5), 401–416.

Salamone, J. D., & Correa, M. (2002). Motivation views of reinforcement: implications for understanding the behavioral function of nucleus accumbens dopamine. *Behavioural Brain Research, 137*(1), 3–25.

Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A., & Zatorre, R. J. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience, 14*(2), 257–262.

Sawaguchi, T., & Goldman-Rakic, P. S. (1991). D1 dopamine receptors in prefrontal cortex: involvement in working memory. *Science, 251*(4996), 947–50.

Schultz, W. (1992, April). Activity of dopamine neurons in the behaving primate. In *Seminars in Neuroscience* (Vol. *4*, No. 2, pp. 129–138). Academic Press.

Stegemöller, E. L., Skoe, E., Nicol, T., Warrier, C. M., & Kraus, N. (2008). Music training and vocal production of speech and song. *Musical Perception, 25*, 419–428.

Wise, R. A. (2004) Dopamine, learning and motivation. *Nature Reviews Neuroscience, 5*(6), 483–494.

Zatorre, R., & McGill, J. (2005). Music, the food of neuroscience? *Nature, 434*(7031), 312–315.