Spring 5-16-2020

Mental Associations and Music Therapy: Including the History of Associationism and the Neurology of Associations

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Capstone Thesis

Spring, 2020
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Abstract

Associations are formed in our minds based upon three elements: sensory experience, emotions, and memories. These associations, unique to each individual, dictate thoughts, beliefs, behaviors, and actions. Some are necessary and supportive, while others can be maladaptive. Established associations can be changed, and new associations can be formed, to align with a client's goals. The literature presents a strong history of associationism, as well as a body of research that demonstrates the neurological processes of how mental associations are formed. There are also studies showing how music activates the brain. However, there is a lack of research which draws direct correlations between the regions of the brain involved in forming associations and the regions of the brain activated during music engagement, resulting in a missed opportunity to use music, especially music therapy, in the context of working with a client's associations. This literature review examined the history of associationism, the neurology of associations, and the brain's response to music, followed by a strong comparison between the brain regions involved in forming associations and those activated while exposed to music. This comparison was then used to support the premise that music therapy can be an especially powerful tool in working with unsupportive mental associations or creating new associations, to support a client's therapeutic goals.

Keywords: associationism, mental associations, associative learning, associative memory, association cortex/cortices, neurology of music

Introduction

Associationism is one of the most widely held theories of thought dating back to the early Greek philosophers, Plato and Aristotle (Mandelbaum, 2017). Associationism's premise is that complex thoughts result from the interconnection with each other across domains, which then facilitate higher order mental processes (Bistricky, 2013; Tonneau, 2012). The philosophy experienced a resurgence in Europe in the 17th century that lasted into the early part of the 20th century. British philosopher John Locke introduced the concept association of ideas in his 1689 writing, *An Essay Concerning Human Understanding* (Mandelbaum, 2017). Half a century later, David Hume (1748) approached associationism as ideas of the mind always predicated by experience. Sigmund Freud used free associations in his practice to help clients unlock suppressed issues within the unconscious mind. Carl Jung (1910) worked with associations, both practically and theoretically, through dream analysis, and he saw emotions as a major influence on mental connections.

Around the time of Freud and Jung, professor Howard Warren (1921) of Princeton University published *History of Association Psychology*. In it, he referred to associationism as "a connection between experiences" (p. 3). Marc Dingman (2017), who received his doctorate in neuroscience and authored the book, *Know Your Brain, Explained*, wrote on his blog, *Neuroscientificallychallenged:*

> [Association cortices] are parts of the cerebral cortex that receive inputs from multiple areas; association areas integrated incoming sensory information, and also form connects between sensory and motor areas. Because they are involved in organizing information

> that comes from various other areas of the brain, association areas are often linked to complex functions. (p. 1)

Until early the 20th century, associationism was the foundation of western psychology, and the basic concepts can be seen within the framework of other theories, including behaviorism, narrative therapy, positive psychology, social learning theory, and cognitive behavioral therapy (CBT). Terms such as *conditioning, restructuring, reframing, referencing, correlations, social learning, implicit bias* appear in a variety of different theoretical approaches, all related to the premise of the formation of associations. Associationism's popularity faded with the embrace of CBT, yet its influence is still present (Mandelbaum, 2017). Perhaps the framework of associationism should be revisited and applied within the context of modern psychology's principles and theories.

The advancement of neuroscience was accompanied by the advancement of brain imaging technologies, including functional magnetic resonance imaging (fMRI), positron emission tomography (PET) scan, and computed tomography (CT) scan. These tools have provided deep insight into the brain's neural activity and processes, including the tracking and mapping of the association cortices (or similar nomenclature). There is debate as to exactly where these cortices reside, but the consensus is in the areas of the cerebral cortex (Bota, Sporns & Swanson, 2015). Most of the literature points to three association areas or cortices residing in the parietal, temporal, and frontal lobes. Sensory input is channeled to these association areas—as well as the motor cortex—through the thalamus, which acts like a distribution center that directs the information to the appropriate areas of the brain. Other primary regions engaged in this process include the hypothalamus, the basal ganglia, and the cerebellum (Purves, Augustine, Fitzpatrick, et al, 2001).

Neuroimaging has also provided a better insight into how humans process sound, including the discovery of the association auditory association cortex, which connects the limbic and paralimbic systems, and is involved in emotion, behavior, and long-term memory (Koelsch, Skouras, & Lohmann, 2018). This may be why a person who hears a certain piece of music may have an unplanned and unintended emotional response that may stem from a conscious or unconscious memory of a particular time, place, or experience.

For centuries and in many cultures, music has been used therapeutically for improving emotional, mental, physical, and spiritual wellbeing. The field of music therapy is a more recent development that gained a foothold in the United States as soldiers were returning from World War I with physical and emotional trauma (American Music Therapy Association, n.d.). Health clinics and hospitals recruited musicians to improve the veterans' moods, and health professionals started to observe the benefits. It soon became evident that specific training would be important, so a formal curriculum was created (American Music Therapy Association, n.d.).

Over the past several decades, there has been a rapid increase in interest in the correlations between music and the brain (Thaut & McIntosh, 2010). Improved imaging techniques in neuroscience have shown that music engagement – both passive and active – involve all areas of the brain.

The literature provides a solid history of associationism and the covert or overt references to this philosophy within the psychotherapeutic community. Neuroscience now provides data that explain the mechanisms within the brain that form associations. The concept is inferenced in the field of music therapy, but there seems to be a lack of information that directly ties together the psychological theories and association neurology with music. Making these connections could provide a valuable lens for music therapists and any mental health professional who incorporates musical elements into their practice.

Ironically, as the theory of associationism began to fade, brain science began to validate what the associationists had been conjecturing for centuries, that forming associations does have a neurological basis. There is a layer below the cerebral cortex, also known as grey matter, that is called white matter due to the myelin sheaths that cover the nerve fibers. The literature has shown that white matter is in fact partially involved in the process of forming associations, along with brain regions engaged in emotions and memory formation.

The aim of this thesis is to revisit the history of Associationism and apply its principles to modern-day psychotherapeutic theories, explore the literature on how the brain forms associations, and understand how the brain processes music stimuli. Finally, I will present a discussion on how using the optics of associations can be a powerful tool in music therapy.

Literature Review

Associationism: 365 BCE – 1920 CE.

Associationism is one of the oldest and most widely held theories of human behavior, thought, and learning (Mandelbaum, 2017). This theoretical perspective focuses on the association of mental processes and strings of sequential ideas that explain the nature of human thought and knowledge (Tonneau, 2012). The American Psychological Association (2018) defines associationism as complex mental processes, such as thinking, learning, and memory, which can be mostly explained by the associative links formed between ideas, based on certain laws (VandenBos & American Psychological Association, 2018). The concepts, principles and treatises of associationism have varied over the centuries depending on the philosopher, theorist, or psychologist, but they can be easily divided into two camps: Nativists who believe that all knowledge is innate and of Divine source, and Empiricists who feel that all knowledge comes from sensory-based experiences (Warren, 1921).

Historians have traced the birth of associationism back to the early Greek philosophers, Plato and Aristotle. In his fictional dialogue *Meno* written in 365BCE, Plato (as cited in Samet, 2019) formulated the idea of *anamnesis* which holds that all learning is recollection, everything we will ever learn is already in us before we are taught, and experience has little to do with acquiring knowledge (Gluck, Mercado & Myers, 2007, American Psychological Association Dictionary, n.d.)

Aristotle, Plato's apprentice who is credited with the formal genesis of associationism, refuted the concept of all knowledge being innate and instead believed that the human mind was a blank slate or a *tabula rasa* upon which repeated experiences become habitual and result in associated ideas and behaviors (Markie, 2017). Aristotle, in his work *de memoria et reminiscentia* written in 350 BCE, presented three laws of association: contiguity, frequency, and similarity. Some sources refer to a fourth law, contrast or the opposite of similarity, as a separate law (Dawson, 2010). The law of similarity states that associations occur when ~~a~~ thoughts or experiences are similar or dissimilar to another. For example, mom/dad, or hot/cold. The law of contiguity, a law that many theorists would embrace centuries later, asserts that associations occur between items that have close proximity both in time and in space, as in lightning and thunder. The law of frequency impacts associations by two thoughts, events, or concepts repeatedly being framed together, as in cake and ice cream.

Many centuries later, associationism would be adopted by British empiricists in the 17th century and be the foundation of early psychology through the early 20th century. Empiricism is the philosophy that all knowledge is learned through sensory experiences. Howard Warren (1921), a professor of psychology at Princeton University, wrote *A History of the Association Psychology* in which he describes members of what would later be described the Associationists School of Thought (Mandelbaum, 20017). They included Thomas Hobbes, John Locke, George Berkeley, David Hume, David Hartley, Ivan Pavlov, and William James.

In the early 1600s, British philosopher Thomas Hobbes began what some refer to as the modern chapter of associationism (Warren, 1921). Hobbes built on the empiricist platform by adding the importance of a causal relationship between ideas (Duncan, 2019). In *Human Nature* (1650) and *Leviathan* (1651), Hobbes used the term sensationistic versus associationistic, stating "though the sense be past, the image or conception remaineth" (Hobbes as cited in Warren, 1921, p. 34). To Hobbes, imagination and memory were one and the same, and expectations are the byproduct influencing our concepts for the future (1921).

English philosopher and physician John Locke was the first to use the term *association of ideas* (Warren, 1921) and in his *Essay Concerning Human Understanding* of 1690, Locke discussed the connections between experiences as ideas that "always keep in company, and the one no sooner at any time comes into the understanding, but its associate appears with it" (Locke as cited in Warren, 1921, p. 3). Like Aristotle, Locke believed the human mind starts as a blank slate upon which associations are formed based on similarity, contrast, and/or contiguity of events or concepts, and that sensations (or sensory input) play a role (1921).

Bishop George Berkeley, a contemporary of Locke's, took the extreme opposite position of associationism, harkening back to Plato's premise that not all thoughts or associations come from experiences. In his 1709 work *New Theory of Vision*, Berkeley believed that we are not born blank slates upon which experiences build associations and then knowledge. He aligned himself with the principles of nativism, namely that certain knowledge originates from a higher power.

In his 1740 writing *A Treatise in Human Nature*, David Hume stated that “there is a secret tie or union among particular ideas, which causes the mind to conjoin them more frequently, and makes the one, upon its appearance, introduce the other” (Hume in Morris & Brown, 2019, 4.3). A few years later in his 1748 publication *An Enquiry Concerning Human Understanding,* Hume asserted that reasoning is based on associations and the ability to represent, recall and predict our environment (Murray, Corlett, & Fletcher, 2010). Like Aristotle, Hume identified three principles of association: resemblance (similarity, dissimilarity), contiguity (time and space), and causation (Morris & Brown, 2019). His theories established an early understanding of associative learning (Mandelbaum, 2017).

It was David Hartley’s work *Observations of Man, his Frame, his Duty, his Expectations* of 1749 that took associationism into its next chapter by introducing physiological and neurological elements. A physician, Hartley referenced the “white medullary substance of the brain” that causes traces of a sensation as vibrations which are repeatedly linked together (King, Viney, & Woody, 2009, p. 243). Despite having minimal knowledge of neural activity, Hartley’s theories will later prove valid.

By the early 1800s, James Mill and later his son John Stuart Mill were contributing their own interpretations of associationism. The senior Mill in his writing *Analysis of the Phenomena of the Human Mind* also explored the neurological influence of forming associations (Warren, 1921). James Mill supported sensations-based associations, but qualified it by including internal sensations, namely symbolism, to evoke associations. “The name *rose* is the mark of a sensation of color, sensation of shape, sensation of touch, sensation of smell, all in conjunction” (Mill as cited in Warren, 1921, p. 89). However, it was James's son, John Stuart Mill, who would formulate the concept of *mental chemistry*, combining associationism, empiricism, and neuropsychology which later influenced modern conceptions of cognition (Bistricky, 2013). The younger Mill not only studied the British empiricists like Locke, Berkeley, and Hume, but also the ancient Greek philosophers.

On the heels of Hume's associative learning and Hartley's and Mill's neurology-based theories, Russian scientist Ivan Pavlov took the concept of associationism into the field of behavioral psychology, introducing the concept of classical conditioning as a modern version of associative learning (Mandelbaum, 2017). Pavlov's research on animal learning tested the premise that two stimuli linked together would produce a new learned response (McLeod, 2014). However, it was American psychologist Edward Thorndike's study of cats trying to escape a puzzle box by learning to move a lever that expanded Pavlov's theory. His study showed that there were more than linked stimuli involved, as the consequences of the choices impacted the behavior and choices. Thorndike's 1911 publication *Law of Effect* was the first genuine psychological law of associative learning (Mandelbaum, 2017) and embraced a new and more cognitive-based understanding of associationism, namely Connectionism (Buckner & Garson, 2019).

Crossing into the 20^{th} century, another lauded American philosopher and psychologist was making his own mark on the history of Associationism. The literature refers to William James as the father of American Psychology. James was the first educator in the United States to teach a psychology course. In chapter 16 of his acclaimed work from 1890 *Principles in Psychology*, James discussed associationism in the context of memory formation being a chain of events with one component activating others. James shifted emphasis away from an association of ideas, to an association of central nervous processes that are caused by either concurrent or immediately successive stimuli (brittanica.com, n.d.).

Associationism: 1920 BCE - present

There are echoes of associationism in contemporary psychology, especially in modern learning theory and all behaviorist approaches (American Psychological Association Dictionary, 2018). From the turn of the 20th century to the present day, psychological theories would integrate, overtly or covertly, the concept of associations into their frameworks, ranging from psychoanalysis to cognitive therapy, behaviorism to humanism, and evolutionary to narrative therapy.

Psychoanalysis

Bringing unconscious thoughts, feelings and motivations to conscious awareness is the basic premise in psychoanalytical theory. In the late 1800s, Austrian neurologist Sigmund Freud, who coined the term *psychoanalysis* (Britannica.com, n.d.), had not only an interest in neurology but also in the instinctual basis of behavior (Kottler & Shepard, 2015). Freud created the technique of using free associations, where the client, in a relaxed state, speaks the first words that come to mind after the therapist shares a word from a pre-determined list. The premise is that the client's deeper truth would emerge from their unconscious, and through the analysis of these word associations, the therapist would discover imbedded conflicts and resistances.

Freud's mentee psychiatrist Carl Jung parted ways with him over Freud's view of the unconscious and the premise that the speed of response infers the level of intelligence. Jung also believed emotions played a role in creating associations. In a speech he gave in 1906 at Clark University, he presented his own association method. "The explanation lies in the emotions…the stimulus word will as a rule always conjure up its corresponding situation. It all depends on how the test person reacts to this situation" (Jung, 1910, p. 224). According to Jung, words that cause an intense emotional response take longer to form an association (Warren, 1921), and the emotional tether to a memory strengthen its recollection. "For it is known that accentuated things are better retained in memory than indifferent things" (Jung, 1910, p. 238). It would be decades later that Jung's concept would be proven in the neuroscientific research of associations.

Developmental and Attachment Theories

In the late 1960s, British psychoanalyst John Bowlby and Canadian developmental psychologist Mary Ainsworth formulated the Attachment Theory, based on studies of early childhood connections with primary caregivers. The premise was that supportive or unsupportive connections between parent and child early in life have a lasting impact (Kottler, 2015). In the context of associations, a positive or negative early attachment could create a correlating positive or negative association, impacting the child's future relationships.

Behaviorism

By 1920s, Behaviorism became the dominant theory of learning. John Watson, founder of the movement, strongly echoed empiricism with his belief that humans learn only through observable behaviors; thus, repeated exposure to a similar stimulus would form an association. Another behaviorist, B.F. Skinner, took it a step further emphasizing the importance of consequences of one's choices. His term *operant conditioning* involves having choices impacted by whether the action results in a positive or negative experience, the former reinforcing behavior, and the latter dissuading it. Associationism naturally aligns with behaviorism, as positive or negative associations with the subject impacts not only behavior, but thoughts, beliefs, and actions.

Gestalt Therapy

Developed by Fritz Perls, the gestalt approach focuses on the client's whole being and dynamic between self and environment. Perls fashioned the empty chair technique, a role play activity where the client has a conversation with a phantom person "sitting" in an opposite chair, and the client plays both roles by moving from one chair to the other. This technique can result in the client reviewing, changing or forming new associations towards that phantom person put in that opposite chair, or the issues involving that person.

Narrative Therapy

Narrative Therapy employs associations through inner dialogues that impact attitudes and behaviors. Through the lens of cultural and of feminist psychology, associations with the dominant culture (race, gender, ethnicity, religion) can impact inner narratives. Examining these self-defeating narratives and creating ways to change the associations within them can help clients rewrite their stories. (Kottler, 2015).

Existentialism

Made popular by Viktor Frankl and Martin Buber, *existentialism* takes an empiricist view of associationism of the human mind starting as a blank slate. Additionally, this theory espouses that humans are solely driven by free will and are thus responsible for all experiences in their lives. This insight then triggers anxiety as one must constantly make decisions between right and wrong, good or bad. In the context of associationism, what is good or bad, right or wrong depends on how one associates those judgments to any particular action, thought, or belief. If someone presents a form of existential anxiety, whether it is fear of death, lack of meaning to life, or fear of isolation, the goal is to take charge of and shift these associations towards an awareness of having free will (Kottler, 2015).

Cognitive and Cognitive-Behavioral Therapy

Cognitive psychology is especially ripe for working with associations. It is a short-term, goal-oriented approach that focuses on recognizing and changing thought patterns, attitudes, and beliefs that are not supportive to the client. Generalization, distortions, and catastrophizing are common self-defeating thought patterns and mental processes that can have a negative impact on one's ability to function (apa.org, n.d.). In the framework of associationism, a cognitive therapist would help the client determine their unsupportive associations, determine if the premises are valid or not, and find ways to change the associations to be more supportive.

Over the past several decades, the most popular psychotherapeutic approach has been CBT, which focuses on both changing one's thoughts and beliefs as well as one's behavior based on those unsupportive beliefs. According to the American Psychological Association, research shows that CBT is a short-term approach that leads to a significant improvement in functioning and quality of life and is often as or more effective than other forms of therapy or psychiatric medications (apa.org, n.d.).

Adlerian Therapy

Adlerian psychology, created by Austrian doctor and psychologist Alfred Adler, focuses on the interconnectedness of humanity. This approach is a hybrid of humanism and CBT, humanist because of its emphasis on the importance of a trusting here-and-now therapeutic relationship and CBT because of its goal and action-oriented approach. The associations and judgments of oneself can lead to feelings of inferiority, resulting in feelings of isolation. The goal is to become aware of these mental associations within thoughts, drives, and emotions, changing them to improve their state of wellbeing (Kottler, 2015; Psychology Today, n.d.). However, the characteristic that most correlates with associations is the Adlerian principle of *reorientation*, helping clients adjust the perceptions of themselves and their environment in more flexible and supportive ways (Psychology Today, n.d.)

Evolutionary Psychology

Evolutionary psychology purports that most behavior can be explained by internal psychological mechanisms that have adapted over time through natural selection, helping our ancestors survive and reproduce (Downes, 2018). The cognitive functions of our brain, especially the higher-functioning prefrontal cortex, work the way they do because the human brain has evolved and with it, its cognitive processes. This aligns with associative learning and supports the premise of neurologically based associations.

The Neurology of Associations

Much of the literature about the neurology of associations aligns with theories posed by theorists and philosophers from Aristotle to William James. With the expansion of the field of neuroscience and advancing imaging technologies, scientists have been able to uncover the inner workings of the brain and how associations are formed. For the past several decades, studies have tracked, mapped, and quantified the different regions and neural pathways of the brain, and what they revealed was that many different components and regions are key participants in the creation of associations.

There are some inconsistences in the literature on two fronts: the exact locations where these associations are formed and the names of these areas. In the context of locations, some research pointed to the entire cerebral cortex or grey matter as the association cortex (Purves, Augustine & Fitzpatrick, 2001). Swenson (2006) designated secondary cortices adjacent to the primary sensory cortices. Other authors described visual, somatosensory, and auditory association cortices (Arslan, 2016; Downar et al, 2000), while others stated they were in the frontal, parietal, and temporal lobes (Jung et al, 2016), or anterior, posterior, and limbic association cortices (Wright, 1997).

In the context of nomenclature, some literature referred to the *association cortex/cortices* (Webb, 2017; Bauer, 2013; Kimura et al, 2009; Simen et al, 2009; Swenson, 2006; Purves, Augustine & Fitzpatrick, 2001). Others used the terms *association areas* (Chudler, 2017; Dingman, 2017; Wright, 1997), while some referenced *association connectomes* (Bota, Sporns & Swanson; 2015) *association fibers* (Swenson, 2006; Ackerman, 1992), or *tertiary association cortices* (Jung et al, 2016). For the purpose of this thesis, the terms *association cortex* or *cortices* will be used, and the involved regions of the brain will indicate the white matter that underlies the frontal, parietal, and temporal lobes.

Despite variations in the names and locations, there is agreement about the chain of events that produces associations. First, information is received through the primary sensory cortices: the occipital lobe processes visual information, the temporal lobe processes sound in the auditory cortex and smells in the olfactory cortex, and the parietal lobe processes touch sensations in the somatosensory cortex and taste in the gustatory cortex (Bailey, 2019). Next, the association cortices gather this sensory input, sometimes merging it with information sent from the motor areas of the brain (Dingman, 2017) then combine it with established memories augmented by emotions. The end results are associations that influence our thoughts, beliefs, behaviors, emotions, and actions.

In David Hartley's *Theory of the human mind, on the principle of the association of ideas; with essays relating to the subject of it*, he made a distinction between simple physiological reflexes and associations that were a mental phenomenon (Hilgard, 1948). He also theorized that information from the five senses trigger tiny vibrations in the "white medullary substance of the brain [and] whatever changes are made in this substance, corresponding changes are made in our ideas" (Priestly, 1775, p. 8). Nearly 270 years later, researchers at the School of Biological Sciences at the University of Manchester, England explored white-matter connectivity between the association cortices and the impact on higher brain functions (Jung, et al, 2016). They focused on the intra- and inter-lobe white matter in the frontal, temporal, and parietal association cortices. The results showed dense connections of white matter internally within each lobe, but connections between the lobes were not only longer and less dense, they were intentional and directional in their layout (Jung, et al, 2016). In addition, they were able to specify which functions were attributed to which white-matter networks: executive functions correlated to subsets of the frontoparietal area; episodic memory between the medial temporal, parietal, and frontal lobes; and an extensive network facilitating language in the prefrontal, temporal, and parietal regions, including Broca's and Wernicke's areas (Jung, et al, 2016).

In his work *Principles of Psychology* from 1890, William James believed the central nervous system played a key role in forming associations. Over this past century, the literature in fact has demonstrated that not only does the central nervous system play a role, but nerves elsewhere in the brain do as well. Mihail Bota and his colleagues at the University of Southern California mapped the nervous system connectome of rats based on the established premise that cognition "emerges from neural activity in the work of association connections between cortical regions modulated by inputs from sensory and state systems and directs voluntary behavior to outputs of the motor system" (Bota, Sporns & Swanson, 2015, p. E2093). The results revealed 73 cortical regions with unique sets of input and output association connections. In addition and similarly to Jung's research team, Bota et al found four different modules with both intra- and inter-module connections, “leading to new insights into the cellular architecture supporting cognition” (p. E2093).

Associations manifest through thoughts, beliefs, and behaviors. Neuroscientist Moshe Bar of the Harvard Medical School wrote an opinion paper published in 2007 in the journal *Integrated Psychological and Behavioral Science* discussing how sensory input activates memories and associations, impacting the mind’s assumption and predictions of future events. Bar stated that the brain constantly anticipates the future through assessing information from memory, which then influences our subjective perceptions of the present. According to Bar, anxiety disorders, phobias, post-traumatic stress disorders, and other mental issues can be impacted by negative associations that produce negative predictions. The key, therefore, in working with people with these diagnoses and in general, is to understand what those negative associations are and focus on changing them to be more supportive to the client’s wellbeing.

Bar (2007) also described three variables: associations, analogies, and predictions. Like Aristotle and the empiricists centuries later, Bar described associations as framed by either contiguity, space and time, frequency, similarity, or a combination thereof. He stated that associations are formed by first analyzing patterns and regularities in our environment; clustering them together based on frameworks of space, time, similarity, and context, and then storing them in memory. When new sensory input is matched up with those memories, analogies are formed that activate representations which quickly get translated into predictions. Furthermore, the brain is constantly revising and updating these analogies and predictions based on new inputs (Bar, 2007) that are either internally or externally generated.

Some of the literature on associations focused on associative learning, which is defined as “any learning process in which a new response becomes associated with a particular stimulus, representing nearly all learning except for habituation" (Encyclopaedia Brittannica.com, 2016, para. 1). American psychologist Edward Thorndike, the founder of the connectionism movement, presented what is now called the first law of associative learning, the *Law of Effect* (Buckner & Garson, 2019) which stated that learning is the result of associations forming between stimuli (S) and responses (R). In 1994, Molchan and her colleagues at the National Institutes of Health created a study to "map the functional neuroanatomy of simple associative learning in humans" (para. 1). The framework of their study was similar to early classical conditioning experiments, using positron emission tomography (PET) to measure changes in blood flow in areas of the brain responding to stimuli. Eight volunteers received light puffs of air directed at their right eyes, generating eye blinks. Each wore earphones that emitted a tone coinciding to when the air puff was delivered. In this experiment, the puff was the unconditioned stimulus (UCS) and the tone the conditioned stimulus (CS). Eventually, the UCS was removed and when the CS, the tone, was heard, the subjects blinked their eyes. During the conditioning, the PET tracked an increase in blood flow to the right side of the primary auditory cortex, consistent with the research showing increased activity in the right hemisphere for non-verbal stimuli (Molchan et al, 1994). Changes were also noted in the parietal cortex, the frontal lobe, and the cingulate cortex which is part of the limbic system and involved in processing emotions, learning, and memory. Significant changes in blood flow to these regions could indicate associations were being formed (Molchan et al, 1994).

Also appearing in the literature is the concept of associative memory, which refers to "the ability to learn and remember the relationship between different and previously unrelated pieces of information" (Bjekić et al, 2018, p. 114) and involves the "integration and storage of associated signals in nerve cells, whose achievement can be proved by memory retrieval (recall and representations) via behaviors" (Wang & Cui, 2018, p. 3). For example, multiple associations are made when engaging with an apple: visual (color of the apple), olfactory (the smell), auditory (name of the apple and sound it makes when bitten), and taste (flavor). After these associations with the apple are shaped, "one of these signals can induce the recall of the other signals" (p.3). The literature showed that the main brain structures involved in associative memory include the hippocampus within the temporal lobe, as well as the frontal, parietal, and temporal association cortices.

Memory allows us to record, store, and recall information and past experiences (Mastin, 2010) and is categorized as either semantic or episodic. Semantic memories involve facts, concepts, and other information about the external world, while episodic memories include personal experiences and events (Clouter, Shaprio, & Hanslmayr, 2017; Lingford-Hughes & Kalk, 2012; Mastin, 2010). Findings have reported that the medial temporal lobe which houses the hippocampus plays a key role in forming both semantic and episodic memories, and its interaction with the prefrontal cortex is instrumental in the eventual storage of these memories (Puzzo, et al, 2016).

A few other brain regions of note. The hippocampus stood out in the research as an important factor in the formation of associations (Du, et al., 2019; Suzuki, 2005), while several studies pointed to the thalamus that channels sensory data to the appropriate association cortices. Wernicke's area was also distinguished in this context. Until recently, this area was thought to only facilitate speech production, but recent studies showed that this area actually processes phonological representation, which is "a process where the pronunciation of a word is interpreted based on their tones and sound and trying to link it to a previously learned sound" (Binder, 2017). To put it another way, Wernicke's area cross-references memory and the currently presented sound, and by making associations, is able to determine what to say and how to say it.

The literature has a plentitude of research demonstrating and explaining the neurology of forming associations. Meanwhile, there is another area of study that has emerged over the past several decades which has many parallels: how the brain processes music. If creating associations and music engagement activate similar regions of the brain, it could open up possibilities for using music as a tool to either create, reinforce, and/or change associations to support therapeutic goals.

Music, the Brain, and Associations

> Music can move us to the heights or depths of emotion. It can persuade us to buy something or remind us of our first date. It can lift us out of depression when nothing else can. It can get us dancing to its beat. But the power of music goes much, much further. Indeed, music occupies more areas of our brain than language does-humans are a musical species.

— Oliver Sacks, *Musicophilia: Tales of Music and the Brain*.

Music is a biological language, based on its complex rhythmic and melodic structures, sensory traits, and expressive qualities (Thaut & Hömberg, 2016). Key areas of the brain used for processing language are also used to process musical language, including the involvement of Broca's and Wernicke's areas. The consensus is that early humans used the elements of music to communicate before formal language was created. Daniel Levitin (2011) believed that music "may have prepared our pre-human ancestors for speech communication and for the very cognitive, representational flexibility necessary to become humans" (p. 260).

For millennia, music has been embraced for its practical uses, ranging from a method of communication, to its therapeutic effects, emotionally, mentally and physically. Music is strongly culture-based, and such influences begin pre-birth. Researchers at the University of Nevada Las Vegas demonstrated that preferences for melody, timber, and rhythms of the mother's culture begin to form in-utero during the third trimester and shaped the child's musical preferences (Ullal-Gupta et al., 2013).

Many of the key areas of the brain that are involved in forming associations are also involved in processing music: the primary auditory cortex, hippocampus, limbic system, and thalamus. The primary auditory cortex not only receives auditory information, it also processes the pitch and volume of music (Hall & Plack, 2009). The hippocampus receives information from the motor cortices as well as the thalamus and the brainstem while also contributing to the formation of both semantic and episodic memories (Koelsch, 2014). The limbic system, which includes the hippocampus and amygdala and is involved in processing emotions and controlling memory (Jäncke, 2008; Singer et al, 2016), utilizes a thick band of nerve fibers that connects it with the auditory cortex (Koelsch, 2018). The thalamus plays a pivotal role in generating associations by channeling sensory input to the appropriate association cortices (Psychiatric Disorders/Psychotic Disorders/Schizophrenia, 2017; Theunissen, et al, 2001), plus it shapes and influences the perception of those sounds (Bartlett, 2013), which are key in forming associations.

Other parts of the brain involved in music processing: the anterior insula, involved in emotional awareness and empathy (He, et al, 2018; Gu, et al., 2013; Brown, Martinez & Parsons, 2006); the basal ganglia which are active in language and music processing (Theunissen, et al, 2001); the inferior frontal lobe where Broca's area resides and which becomes engaged when listening to familiar songs (Jäncke, 2008); and Wernicke's area within the auditory cortex involved in speech production and phonological representation which determines the tones and sounds to use in verbal pronunciations based on previously-learned sounds (Binder, 2017).

Within the preponderance of literature on music and the brain, three areas appear to garner the most attention: music's impact on memory, on emotions, and on movement.

Memory

> A song playing comprises a very specific and vivid set of memory cues. Because the multiple-trace memory models assume that context is encoded along with memory traces, the music that you have listened to at various times of your life is cross-coded with the events of those times. That is, the music is linked to events of the time, and those events are linked to the music.
>
> — Daniel Levitin, *This is Your Brain on Music.*

The linkages to which Levitin referred between music and memories are associations that have been formed in the brain based on at a specific time, place, and context. These associations are made by mentally connecting, directly or indirectly, the music or sound to that particular event. Different types of memory formation engage different areas of the brain. Episodic memory (experiences, events in time) activates the hippocampus, while semantic memory (facts, meaning, concepts) engages areas of the frontal and temporal cortices (Mastin, 2010). Explicit memory (intentional recall) involves hippocampus, amygdala, and neocortex, while implicit memory (unconscious, automatic recall) engages the basal ganglia and cerebellum (2010).

The aforementioned areas of the brain are activated during music engagement, and the literature shows that encoding and recall improved when music was a variable. Thaut and de l'Etoile (1993) tested 50 subjects on their ability to recall information, with or without the presence of music, and found that the "subjects who participated in the mood induction condition recalled significantly more information than those in the no-music condition" (p. 70). Jäncke (2008) referenced studies that showed a strong link between music, autobiographical memory, and forming one's view of one's self (p. 4)

In the field of music therapy, practitioners often refer to the *sweet spot*, an era in time in one's lifespan that is typically between mid-adolescence and the mid-to-late 20s, during which musically-associated memories are strongly encoded. Ayelet and Amir (2014) referred to research by Tomaino (2002) who found that people with memory issues like dementia not only recall "a song's details, such as the melody or lyrics, but also of the memories and rich associations related to the song. Thus, songs can evoke these associations and enable memories and a sense of self to emerge" (p. 133).

Jäncke (2008) reviewed and presented a body of research involving music, memory, and emotions. One study (Janata, Tomic & Rakowski, 2007) found that music from one's past evoked strong autobiographical memories. Another study (Samson & Peretz, 2005) showed that the right temporal lobe played a vital role "in the formation of melody representations that support priming and memory recognition" (p. 2) which is a form of implicit memory, while the left temporal lobe was more involved in retrieving explicit memories. Jäncke (2008) also referred to research by Eschrich, Muënte and Altenmüller (2008) that showed that emotions not only enhance memories but more specifically autobiographical memories, and several studies which showed increased blood flow to areas of the brain controlling emotions when listening to music (Baumgartner et al, 2006; Blood & Zatorre, 2001)

Emotions

Music can modulate activity in brain structures known to be crucially involved in emotion, such as the amygdala, nucleus accumbens, hypothalamus, hippocampus, insula, cingulate cortex and orbitofrontal cortex. (Koelsch, 2014, p. 170).

A number of studies have looked at how music neurologically influences emotional responses, finding a correlative relationship between the strength of the emotional response to the music and the encoding and eventual recall of the memory. In his research into music and emotional processing, Koelsch (2018 & 2014) found that processing stimuli with both sociological and affective significance such as music is associated with the release of dopamine in the limbic system, engaging the amygdala, hippocampus, and nucleus accumbens, which also make up the reward pathway (Koelsch, 2014). These brain regions also play a role in the emotional aspect of association formation.

Plato believed that music played in different modes would arouse different emotions (Trimble & Hesdorffer, 2017). The literature seems to confirm this, illustrating that up-tempo songs and/or songs played in a major key are typically associated with happy and cheerful emotions, while slower-tempo songs and/or those in a minor key are associated with feelings of sorrow. (Koelsch et al, 2018; Bravo et al, 2017; Blood et al, 1999)**.** Koelsch (2018) and his colleagues engaged 24 participants from the Free University of Berlin, to listen to music that arouses joy or fear emotions, while simultaneously tracking brain response using fMRI. Participants also filled out a ratings sheet responding to how they felt about the music, from "not at all" to "very much." The results exhibited connections between the auditory cortex and the limbic/paralimbic, visual, somatosensory, and motor systems (Koelsch, Skouras & Lohmann, 2018). The study also found that responses to fear-evoking music were greater than joy-evoking music. The orbitofrontal cortex (OFC) was stimulated by the fear-based music, and this is the same brain area that responds to negative reinforcers that impact behavior change (Koelsch, Skouras & Lohmann, 2018).

Bravo and his colleagues (2017) pointed out certain variables that could impact one's associative memory response to music as being *positive* or *negative*: culture and meaning. "Culturally-acquired connotations ascribed to consonant and dissonant intervals…along with other contextual elements are necessary to define and bring meaning" (p. 157). One's associations with a piece of music may be positive based on the unique cultural and life experiences of that individual, whereas the same piece of music might evoke a negative response in someone else for the same reasons.

Singer (2016) and her team engaged 40 participants in listening to two pieces of piano recordings, one which was often described as "tense" and the other "tender" in the responses to the post-study questionnaire. fMRI was used to monitor neurological responses. The researchers observed neurological responses mainly in the limbic system including the amygdala and hippocampus, as well as the lateralized fronto-parietal networks which correlates with literature discussing an association network between the frontal and parietal regions. Singer's study also found activation in the visual, auditory, and somato-motor regions of the brain, again paralleling the literature on association cortices. The engagement of the somato-motor regions, including the pre-motor cortex (PMC), supported other research that revealed how the temporal information in music engages the areas of the brain involved in both voluntary and involuntary movement.

Motor Response

> Music in therapy…is a stimulus that influences the neurophysiological basis of cognition and sensorimotor functions…driven by scientific data and insight into music and brain functions. (Thaut & Hömberg, 2016, p.2).

There is a direct correlation between auditory processing and the brain's motor cortex (Thaut, McIntosh & Hömberg, 2014). While a robust network of neural fibers connects the primary sensory lobes to the association cortices, a unique set of fibers connects the auditory system directly to the motor centers of the brain, usurping any association cortices (2014). This may explain why it is not unusual for a person to automatically and subconsciously move an area of their body in synchronicity with hearing music, especially if the music has a strong beat.

Temporal structures of the brain play important roles in cognitive functions such as attention, memory formation, and executive control (Thaut & Hömberg, 2016) and facilitates common limbic representations of affect in music (Singer et al, 2016). Temporal structure or temporal organization is a system of internal clocks representing the synchrony between the brain and its environment (Dawson, 2004). Music and speech "are complex sound streams with hierarchical rules of temporal organization that become elaborated over time." (Abrams et al, 2011, p.1507). Brown, Martinez and Parsons (2006) discovered that many of the same brain areas were activated when one listened to spoken words or to a melody. Those areas included the primary and supplementary motor areas, the anterior insula, Broca's area, the primary audio cortex, thalamus, basal ganglia, and cerebellum (2006). Comparatively, these areas are also involved in associative memory and associative learning.

Anticipation is a critical element in motor function, as it provides cues from the brain to plan ahead in preparation of the movement, through synchronization or entrainment with the temporal structure of the song or sound (Singer et al, 2016; Thaut, McIntosh & Hömberg, 2014), what Levitin (2009) calls *temporal expectations* (p.10). Without anticipation, there would always be a delay in attempting to synchronize with a beat. In his research on the neurology of associations, Jäncke (2008) referred to this phenomenon as *priming*, describing it as "one of the manifestations of implicit memory, in which parts of particular representation or associations in memory are activated just before carrying out an action or task" (p. 2).

Leaver and her colleagues (2009) studied how anticipation and complex associations between musical sequences are stored in the brain. Ten participants listened to segments of both familiar and unfamiliar songs. Each participant was asked to memorize seven pairs of melodies, with the goal of knowing what the second song would be based upon hearing the first. There was an embedded pause between the recording of the first and the second segments. During that pause, fMRI scans showed activity in the areas of the brain involved in anticipation. The research demonstrated that anticipation in music, consisting of cued associations, are processed mainly in the frontal and parietal regions, another venue of association cortices. Their research also pointed to the fact that these same areas are involved in motor sequence learning.

Ebbesen and Olsen (2018) reviewed the literature connecting motor intentionality, finding that a majority of the research involved associationism in some form. They referenced neuropsychologist Marc Jeannerod (1997, 2006) describing anticipation as "the intentions of actions pre-exist[ing] awareness, and as such comes in the form of a motor cognition" (Jeannerod cited in Ebbesen & Olsen, 2018, p. 567), and that the motor area of the nervous system "runs ahead of the part that is mentally manifesting movement" (p. 568).

Neuroscientist Daniel Levitin, author of the books *This Is Your Brain on Music* and *The World in Six Songs*, explored the literature on the neurological responses to temporal structure in music (Levitin, 2009). He asserted that "time, tempo, and structure in music appear to involve a neural network that links the cerebellum, parietal, frontal and temporal lobes" (Levitin, 2006 as cited in Levitin 2009, p.10). These same areas have been shown in the neuroscience literature to be the areas of associations formation. The findings of Singer et al (2016) also referred to the tempo, pulse, and beat regularity in music as triggering rhythmic entrainment, affecting predictability, and impacting emotional response.

This collection of research on music and movement may support the expression that one can be “moved” by music, both moved emotionally, and subsequently, moved physically.

DISCUSSION

> It is the inner life of music which can still make contact with their inner lives which can awaken the hidden, seemingly extinguished soul; and evoke a wholly personal response of memory, associations, feelings, images, a return of thought and sensibility, an answering identity.
>
> — Oliver Sacks, *Musicophilia: Tales of Music and the Brain*.

The purpose of this thesis was to explore the historical context of associationism and the theories of associations as mental processes, to examine the research on how and where the brain forms associations, and to ascertain how and where music activates the brain. In doing so, the goal was to draw a direct comparison between regions involved in associations and those activated in music engagement in order to support the premise that music therapy is an especially powerful tool in working with mental associations.

The literature presented a long history of associationism dating back to Plato and Aristotle, while also providing a robust body of research on the neuroscience of associations, associative learning, and associative memory. Many theoretical approaches work with associations in some context, using verbiage such as *cognitive reframing* or *restructuring*, *biases*, *social learning*, *conditioning* (*classical* and *operant*), and *social cognition*.

But psychotherapy is not the only field that understands the power of associations and the impacts on attitudes and behaviors. Exploiting the influence of mental associations has a long history, from political propaganda to targeted marketing, through the use of emotionally-charged messaging. Creating a positive association or negative association with a person, ideology, or product can motivate how someone thinks of or behaves towards that subject. Several common techniques are used in propaganda and marketing include bandwagon (*everyone buys / thinks this*), testimonials (*this celebrity uses this so it must be good*), name-calling (*other brands don't cut it*), glittering generalities (*the best choice*), repetition (banner ads at sports events), card-stacking (only positive qualities presented), transfer (*if I buy this, I am patriotic*), and plain folk (*ordinary people like me think / use this*) (Bhasin, 2019).

Cultural norms and historical context also impact mental associations. Country, ethnicity, race, religious group, gender, and one's family and friends network create the environment where our first opinions are formed. Whether it is first-hand experience or input from one's milieu, opinions and biases are shaped early in life. Even though many associations are shared within subgroups of people, each person carries their own unique set of associations. One person may associate the word "date" with a fruit, while another thinks of a calendar, and yet another frames it as a social engagement. A certain smell, sound, taste, or concept may trigger positive memories or associations to some, while the same sensory stimuli may produce negative associations in others. Some associations are supportive. The "Mr. Yuk" sticker consisting of a yellow-green face frowning and sticking its tongue out is associated with poison and used to create an association with danger on products to deter children from eating or drinking them. Meanwhile, the sticker of a smiley face can be used for encouragement or reward. Reward is a powerful motivator, and there is a system within the brain that elicits psychological and neurochemical effects that impact attitudes and behaviors, which is aptly named the reward system.

Reward System and Motivation

Changing associations can be challenging without a motivation to do so, without some form of emotional benefit or reward. The reward system is involved in motivation and reinforcing behavior and is a collection of brain structures that are activated by exposure to rewarding stimuli, including sex, food, and drugs of abuse (Dingman, 2015). These areas include the ventral tegmental area (VTA) and the nucleus accumbens (NAc), connected to each other through the mesolimbic pathway that is involved in the release of dopamine (Dingman, 2015).

Music engagement has shown to engage the same reward system structures of the brain. Blood and Zatorre (2001) studied participants listening to self-selected classical pieces of music, one geared to elicit pleasure and the other chills. The results showed that structures of the reward system, including the NAc and VTA, received increased regional cerebral blood flow (rCBF) while listening to pleasurable music. They also found that when listening to music that evoked chills, the NAc and VTA again received increased rCBF, however the amygdala and hippocampus, which are activated in the *fight/flight* response, received a diminished rCBF, inferring that the chilling music suppressed those areas and thus that response.

Menon and Levitin (2005) also tracked rCBF in the brains of participants listening to music, in this case consonant and dissonant selections of classical music presented by the researchers. They found strong correlations between music and the reward system (NAc and VTA) as well engagement of the amygdala, hypothalamus, basal ganglia, hippocampus, OFC, insula, and parts of the prefrontal cortex (2005). Their results pointed to a presumption that dopamine is released in response to listening to music and that "the enhanced functional and effective connectivity between brain regions mediating reward, autonomic, and cognitive processing provides insight into understanding why listening to music is one of the most rewarding and pleasurable human experiences" (p. 175).

There is a long history of using music to encode memories and influence behavior, including the use of mnemonics, jingles, and film scores. Mnemonics is a learning technique that helps with memory retrieval, and music-based mnemonics can help recall by putting information to music, as in the ABC song. Jäncke (2008) sites a study by Koelsch et al (2004) which showed that using "short musical pieces with particular characteristics can prime the semantic language memory system, thereby yielding faster and more efficient recognition of specific words" (p. 21). Jingles, short and catchy snippets of music that advertising companies use to help sell brands, are an example of how music and its powerful encoding abilities are used to influence behavior. Films scores are composed with the intent to augment and magnify the audience's experiences of suspense, fear, sadness, joy, and resolution.

The literature has shown that the same areas of the brain involved in forming associations are also activated when one listens to music, and that the reward system, involved in dopamine release and motivation, is also activated when one listens to music. This reiterates the argument for music therapy as an especially powerful tool when working with modulating associations.

Some associations that may emerge in therapy sessions may be more obvious: phobias, an often-negative association with a situation ("if I walk on this bridge it will collapse and I will die), and implicit or explicit biases, including those directed at subsets of individuals, and contributing to prejudicial thoughts. Other associations are more subtle and influence behavior and attitudes for unknown reasons to clients, especially for those with trauma-based diagnoses. There is also a wealth of research demonstrating that many pathologies are related to inhibitions in the association cortices, including schizophrenia, Alzheimer's, borderline personality disorder, aphasia, and Parkinson's (Bjekić, et al, 2019; Delhaye, Folville & Bastin, 2019; Trimble & Hesdorffer, 2017; Thaut & Hoemberg, 2016; Thaut, McIntosh & Hoemberg, 2014; Hegde, 2014 in Thaut, McIntosh & Hoemberg, 2014; Thaut et al, 2009). It is therefore important to thoroughly assess the client to determine the underlying cause of the maladaptive associations, whether neurological, emotional, or psychological.

Assessment

Each client comes to a session with established associations, impacted by their own life experiences. The first step is to determine what they are, possibly from where they came, and if they are supportive or not. The next step is to strategize how to disempower, shift, or create new associations to support goals and improve wellbeing. How does one ascertain a client's associations? Western-oriented psychology has employed anecdotal assessment tools for the past several centuries. Sigmund Freud utilized word associations to reveal unconscious beliefs. Carl Jung interpreted images from clients' dreams. Hermann Rorschach used his famous ink-blot test to analyze clients' perceptions of images to glean insight into their psyches. A common method used widely today is the Harvard Implicit-Based Biases Test (IBT), whose measurements focus mainly on subconscious racial prejudice. In addition to talk-based therapy, music therapy can be a powerful tool to assess associations, as it activates the entire limbic system and is involved in the processing of emotions and in controlling memory (Jäncke, 2008), two major contributors to forming associations.

Music therapy interventions include several core approaches: composition (including lyric replacement), lyric analysis, receptive listening, performance, and improvisation. They provide not only a platform for creative expression, emotional catharsis, and modes of communication, but can often unlock deeply hidden experiences, biases, and thought processes that may be below the client's awareness. The literature showed that music engagement activates the emotional and memory regions of the brain, makings this modality especially powerful in discovering, analyzing, and understanding the origins of associations. Techniques like improvisation, lyric analysis, and receptive listening can be used in a psychoanalytical framework to unearth, explore, understand, and possibly change unsupportive associations. Composition, including lyric replacement, and performance can be methods to reinforce new or modified associations. These types of interventions can not only stimulate psychological changes but neurological changes as well.

Neuroplasticity

Neuroplasticity is defined as "the brain's ability to change, remodel and reorganize for purpose of better ability to adapt to new situations [….that] neural networks are not fixed but [are] occurring and disappearing dynamically throughout our whole life, depending on experiences" (Demarin & Morovic, 2014, p. 209). The phenomenon of neuroplasticity is a recent discovery in neuroscience; however, the concept is not new. William James, who wrote about associationism 1892, two years earlier stated in his book *Principles of Psychology* (1890) that "the human brain is capable of continuous functional change" (p. 209).

This new awareness about the brain's ability to change has impacted many fields, including neurological rehabilitation, education, and geriatrics. Bar (2007) spoked of research that supports the idea that predictions and analogies are malleable and can impact the anticipatory response. Stegemöller (2014) reviewed the literature on music therapy and neuroplasticity and found that music was especially effective due to its ability to stimulate dopamine production in the brain and increase neural synchrony (entrainment). There is also a large body of research from Michael Thaut and others that supports the use of music in neurorehabilitation for those who have experienced stroke, traumatic brain injury, or seizures, or who are managing the effects of diseases like Parkinson's and Alzheimer's (Ebbsen & Olsen, 2018; Thaut, & Hömberg, 2016; Thaut, McIntosh, & Hömberg, 2014; Thaut & McIntosh 2010; Thaut, 2006).

> Music can access control processes in the brain related to control of movement, attention, speech production, learning, and memory, which can help to retrain and recover functions of the injured or diseased brain" (Thaut & Hoemberg, 2016, p. 2).

The historical framework of associations is well-established, the neuroscience clinically proven, and the knowledge of how music activates the brain ever-growing. This thesis presents a framework in which music therapy can be especially effective and powerful in working associations. The lack of research into this paradigm provides opportunity for further exploration and application of this strong potentiality.

Over two thousand years ago, Aristotle asserted that mental representations are shaped by sensory information based on associative laws of similarity (or contrast), contiguity, and frequency. He also believed that music is the phenomenon of sense perception (Kalan, 2001). Over the past several decades, neuroscience has revealed how prophetic Aristotle was, not only by discovering the mechanisms in the brain that facilitate mental associations but also by showing how it responds to music. These insights are as powerful now as they were in ancient Greece, and it is up to us to find ways to utilize them for the benefit of others.

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THESIS APPROVAL FORM

Lesley University
Graduate School of Arts & Social Sciences
Expressive Therapies Division
Master of Arts in Clinical Mental Health Counseling: Music Therapy, MA

Student's Name: Dianna Rose

Type of Project: Thesis

Title: Mental Associations and Music Therapy: Including the History of Associationism and the Neurology of Associations

Date of Graduation: ______________May 16, 2020____

In the judgment of the following signatory this thesis meets the academic standards that have been established for the above degree.

Thesis Advisor: Sarah Hamil
--Signed: Dr. Sarah Hamil