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Setting the Stage: Neurobiological Effects of Music on the Brain

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Abstract

A better understanding of how and why we are so moved by music can emerge from a closer look at how the brain functions. Music causes both structural and functional changes in the brain, both with immediate exposure and over several weeks, months and years.

By the very fact that music is processed by so many areas of the brain (ranging from the cortex, to the limbic system, to the neuroendocrine and even autonomic nervous systems), exerts an effect not only on our brain, but also on our bodies.

As our understanding of how the biological processes of the brain evolve, so, it seems, will our ability to harness the properties of our evolutionary and instinctual response to music: one that arises from, and can thereby shape, our individual brain structure and function to mitigate collective disease severity and improve wellness across populations.

Keywords

Music and Cognition; Music Listening; Music Neuroscience; Receptive Music Methods

Disciplines

Neurology

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*And men ought to know that from nothing else but thence [*from the brain*] come joys, delights, laughter and sports, and sorrows, griefs, despondency, and lamentations. And by this...we acquire wisdom and knowledge, and see and hear and know what are foul and what are fair.*
Hippocrates

I would teach children music, physics and philosophy; but most importantly music, for the patterns in music and all the arts are the keys to learning.
Plato

Music is as embedded in the human experience as our deepest emotions and most firmly held beliefs. Our consciousness and the reality that it shapes: everything that we think, feel, do or perceive, ultimately arises from, and is filtered through, a collected mass of organic gray and white matter that comprises the human brain. While the collective tapestry of humanity cannot be easily reduced to, or merely defined by, our layers of neuronal tissue, a better understanding of how and why we are so moved by music can emerge from a closer look at how the brain functions. This understanding can then, in turn, guide us in developing novel therapeutics that utilize music as a tool for brain growth and healing.

Our attempts to elucidate the mysteries and complexities of both the mind and music reach back over thousands of years. In ancient Grecian times, physicians and scholars depicted certain states of distress to arise from specific areas of the brain, and also believed the disciplines of medicine and music to be inextricably linked. They equated the study of music with the power to balance the core faculties of the brain, harmonize the soul and achieve emotional catharsis (1). While our methodology and technology have evolved since then, the core search remains the same.

Today, we know that the human brain evolved to have a much larger prefrontal cortex (the rational, decision making center of the brain) while keeping the more primitive, older limbic structures (the core emotional and memory circuitry that is preserved fairly unchanged across most mammalian species) intact. This makes the human brain capable of fascinating dichotomies: we are able to think and communicate with complex symbolic representations and metaphors due to our neocortex that allows for higher order abstract processing, while at the same time, can find ourselves succumbing to our most basic drives, impulses and urges. How these various areas of the brain interact in states of health and disease is what we are really seeking to understand.

Over the past two decades, rapid developments in imaging technology now allow us to monitor how the brain fires in real time by tracking changes in blood flow, oxygen and glucose uptake that occur across various brain regions when we perceive, envision or react to a stimuli. For the first time, we can peer inside the brain in action and figure out how various neurons come together to form a circuit, and how these circuits activate in specific ways to respond to stimuli of greater complexity that ultimately shape how we create and convey thought, and how we move, respond and interact with our environment. This is the basis for understanding all human behavior and how it changes across the spectrum of both illness and wellness.

We have also begun to apply these same imaging techniques to better understand how the brain creates, interprets and reacts to music, starting with its most basic building block: sound. To even begin to perceive music, we must be able to decode and represent sounds. Our brains do this through tonotopic mapping: different acoustic frequencies are mapped onto different parts of the neural tissue, thus allowing us to differentiate between different tones and pitch (2). The cochlea, the auditory receptor center of our inner ear, perceives the vibrations of an external auditory stimulus that is converted into an electric signal once it hits our eardrum. This electric signal then travels to the brainstem via our 8th cranial nerve (the Vestibulocochlear or auditory vestibular nerve) and activates a specific auditory cortical area of our brain allowing us to perceive that particular tone.

We can only perceive what we can represent in our brain; thus, our ability to recognize and respond to any stimuli (whether auditory, visual, gustatory, kinesthetic) can only occur if we are able to both perceive it (through a sense organ) and then map it within a particular area of our brain. Music, in particular, activates several areas of our brain including multiple cortices (auditory, visual, motor), the cerebellum (involved in rhythm, timing and fine tuning movement) along with the deeper emotional (amygdala, orbitofrontal, anterior cingulate cortex), memory (hippocampus) and mesolimbic reward structures (3). All of these areas must work in concert to integrate the various layers of sound across space and time for us to perceive a series of sounds as a musical composition. Patterns of activation across these areas change in response to the type of music that we are listening to i.e., whether the music involved consonant or dissonant elements, is asyntonic or syntonic, contains variations in temporal dynamics, or evokes an emotional response or memory (4,5,6). Patterns of brain activation also change depending on whether we are listening to music, playing rehearsed music or improvising new music (7). An improved understanding of how these areas of the brain are selectively and differentially activated by exposure to different types of music will allow us to create more potent music therapy tools. For example, if we can optimize what type of music to select to invoke a certain cognitive, motor or emotional response in a patient by activating certain circuits, this can then allow us to use music to help normalize brain function in states of disease or optimize brain function in states of wellness.

Music does not only exert an effect on our brain in the moment that we are hearing or playing it, but also it alters both brain structure and function following early and repeated exposure. The structural thickness and connectivity of certain brain regions involved in processing music increases with music training over the course of several years, and musical training has also been shown to better regulate the executive control sections of the prefrontal cortex in a non-music related task (8,9). Functional changes in the brain can also occur much more quickly; even 6 weeks of piano training in adults can alter the activation of the sensory and motor regions of the brain when music is heard, or even when simply envisioned (10).

Just as tracing the anatomical and physiologic changes that occur in normal brain development in response to music allows us to better understand how music affects the brain, delineating how functional and structural changes to the brain affect our perception of music can also deepen our understanding of the interplay between music and the brain/mind. Broadly, the temporal gyrus is the primary auditory processing center of our brain. Various structural or functional alterations to this area result in different pathologic responses to sound. Sensory amusia is a phenomenon that occurs when there is a structural lesion (i.e., loss of tissue from a stroke or tumor) in the right superior temporal gyrus. This area of the brain is responsible for integrating various aspects of tone, pitch, timing and spatial mapping of music into a coherent percept. This function is integral for us to recognize and collate a series of tones as a piece of music. Thus, when this area of the brain is altered, despite being able to hear sound without any difficulty, patients lose the ability to perceive or respond to music (11). Conversely, lesions in either hemisphere of the middle temporal gyrus, resulting from single insults or neurodegenerative disease processes, can cause musical hallucinosis, a sensory/perceptual abnormality where patients perceive music in the absence of any auditory stimulus. Reports of frequently looped religious or patriotic melodies (or earworms) appear to occur more frequently in patients with lesions resulting from neurodegenerative disease; the reason behind this remains obscure, however, frequent exposure to these genres beginning at an early age may play a role (12).

Our brains our plastic: they respond to and can change through exposures and experiences. Just as adverse or traumatic life experiences can cause certain areas of the brain to atrophy, enriching life experiences can foster brain growth. This is the neurological premise on which we build a case for the therapeutic effects of music. Music causes both structural and functional changes in the brain, both with immediate exposure and over several weeks, months and years. The changes in brain circuitry and connectivity created by music exposure may allow us to activate certain areas of the brain to promote healing. While we may not be able to revive atrophied tissue from strokes, developmental or neurodegenerative diseases, we can activate, or modulate, the signaling in certain areas of the brain involved in emotional processing, cognitive flexibility (or abstract thinking), attention, reward and motivation. Over a period of time, if the brain continues to fire in new ways, it can create new neuronal pathways. These pathways allow patients to develop compensatory mechanisms that may help reduce the symptom severity that arises from disrupted signals from anatomic lesions by allowing new pathways to carry the same signal. In addition, music, as an organized, complex series of sound, may improve functionality in patients that have functional rather than structural abnormalities in the brain due to aberrant neuron firing by creating more efficient patterns of brain activation. This may have far ranging effects for a variety of behavioral illnesses ranging from anxiety and depression, to the subjective distress experiences in chronic pain syndromes, to the reward circuitry involved in addictive disorders, to the psychomotor pathways involved in Parkinson’s disease, and even to the functional connectivity changes that occur in autism spectrum disorders.

There may be even further applications. The brain controls not just our mental states, but also our physiologic states. Our nervous systems are connected bi-directionally: physiologic processes create an emotional and cognitive response, and psychological processes create physiologic changes in both the brain and body. Therefore, music, by the very fact it is processed by so many areas of the brain (ranging from the cortex, to the limbic system, to the neuroendocrine and even autonomic nervous systems), exerts an effect not only on our brain, but also on our bodies. A growing body of research suggests that music may play a role in modulating even our most basic physiologic responses. Circadian rhythms, heart and respiratory rates, and even levels of various inflammatory markers that change in response to several neurological and chronic stress induced illnesses may respond to music therapy (13).

We are on the cusp of a transformation in both the art and science of medicine. With advances in technology allowing for more powerful brain imaging techniques to be applied to developments in deep machine learning, artificial intelligence and precision medicine, we are entering an era of highly personalized behavioral medicine. Music, in particular, occupies a place both in our universal human history as well as in our personalized medical future. As our understanding of how the biological processes of the brain evolve, so, it seems, will our ability to harness the properties of our evolutionary and instinctual response to music: one that arises from, and can thereby shape, our individual brain structure and function to mitigate collective disease severity and improve wellness across populations.

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