

The Intersection of Music Listening and Stress

By Claire Li

Author Bio

Claire Li is a senior at Arcadia High School in Arcadia, California. She is particularly fascinated by the intersection of STEM and the arts, as the subjects typically are regarded as separate. At the time of writing, she was the Student Managing Intern for Arcadia Unified School District's Digital Communications Internship, and has been playing piano for many years, invited to play at Carnegie Hall and Zipper Hall. She was also a top 20 finisher in the Southern California Section of the Chemistry Olympiad. In the future, Claire hopes to study an interdisciplinary field that combines arts and science to find new ways to solve traditional problems.

Abstract

The Covid-19 pandemic accentuated a growing concern towards mental health and stress, with reports of stress increasing since the onset of the pandemic. Long term exposure to stress may not only yield health risks but may also add costly financial burdens for society. In more recent years, music listening—especially relaxing or pleasurable music—has been shown to positively affect stress management and relaxation. In specific, classical music was found to have a great effect, and music chosen based on songs popular during a patient's adolescence or early adulthood may help identify music regarded as pleasurable. Though music listening and stress modulate common brain regions such as the amygdala and hypothalamus, they induce different responses. Stress activates the sympathetic nervous system, the body's "fight or flight" response which increases cortisol levels, while music can trigger the "rest or digest" parasympathetic nervous system which dampens the HPA axis and lowers cortisol. Music's ability to regulate the HPA axis, lowering stress biomarkers such as cortisol levels, heart rate, and blood pressure is crucial to its use as a therapy for stress. Traditional stress management or prevention measures are often rather expensive and inaccessible; however, music listening provides a cheaper, non-invasive, and accessible alternative.

Keywords: stress, music, music therapy, music listening, mental health, limbic system, HPA axis, emotion, paralimbic nervous system, amygdala, classical music

Introduction

The onset of the Covid-19 pandemic has brought mental health and stress to the forefront of discussion. American Psychological Association chief executive officer Arthur C. Evans Jr., PhD, commented that Americans are now “reaching unprecedented levels of stress that will challenge [their] ability to cope” (American Psychological Association, 2022).

Stress can be defined as a response to a bodily or environmental demand that disrupts the body’s homeostasis (Kumar et al., 2013; Jackson, 2013). Such demands may require physical, mental, or emotional adjustment (Kumar et al., 2013) and may be perceived as either threatening or benign based on whether coping resources are available to an individual (McEwen and Gianaros, 2010). Though not all stress is unhealthy and a degree of stress in everyday life is natural, excessive stress may have an adverse effect on health, behavior, and relationships (Jackson, 2013). Further, the repeated activation of stress responses (chronic stress) has long term effects on the body which may contribute to mental health problems such as anxiety, depression, or and/or addiction as well as physical health risks such as chronic pain and cardiovascular disease (Witte et al., 2019). Because prolonged exposure to stress may lead to substantial financial expenditures for society and traditional stress management measures are rather expensive, cost effective preventative and stress management measures have been sought after (Thoma et al., 2013). Music therapy, an economic, non-invasive, and accessible tool, has recently received great interest in regards to managing stress.

Both music and stress have the ability to modulate the autonomic nervous system, which can be divided into the sympathetic and parasympathetic nervous system. The sympathetic nervous system is responsible for the body’s “fight or flight” response, a state of elevated activity and attention. Blood pressure and heart rate increase as a result, and nearly all living tissue is innervated (Waxenbaum et al., 2021). Contrastly, the parasympathetic nervous system, which promotes “rest and digest,” lowers heart rate and blood pressure, and innervates only the certain parts of the body such as the head (Waxenbaum et al., 2021).

This paper explores the viability of passive

music therapy, music listening that eliminates rhythmic movement involved in active music therapy (McPherson et al., 2019), as a means of reducing stress in the post-Covid world. First, the mechanics of music listening and emotional processing are explored; second, the mechanisms of stress are identified; third, the intersection of the brain regions affected by stress and music is analyzed. Subsequently, I propose how music can be used as a therapeutic tool for stress.

Methodology

This paper is a literature review compiled using search engines such as Google Scholar and Pubmed. There was no restriction on the end date of the articles chosen. However, the initial date was restricted to January 1, 2000. Keywords used to locate sources include music, limbic system, neural basis of music perception, music and emotion, mesolimbic system, amygdala, neural basis of stress, and the parasympathetic nervous system. Findings from the articles were then categorized into five main sections: Neural Basis of Music Perception, Emotional Processing of Music, Stress, Music as a Therapy for Stress, and Choosing Music for Stress Relief Music Therapy. This study will focus on the emotional processing of music as it most pertains to the brain’s response to stress.

Neural Basis of Music Perception

The sensory system for hearing is arranged in a hierarchical manner, beginning from the neural processing stations in the ear and ascending to stages with growing complexity or abstract features (Warren, 2008). Acoustic information is first translated into neural information within the cochlea (inner ear) (Kolesch and Siebel, 2005), where complex sounds are converted into electric impulse or signals (Särkämö et al., 2013). The information is then transmitted from the auditory nerve to the auditory brainstem (Särkämö et al., 2013), allowing features such as periodicity or intensity of the sound to be processed. From the brainstem, auditory information travels to the thalamus, and is projected primarily to the primary auditory cortex (PAC) and adjacent secondary auditory fields in the temporal lobe, and also to the amygdala and medial orbitofrontal cortex (Kolesch and Siebel, 2005; Särkämö et al., 2013). Within the auditory cortex (AC), more specific information such as pitch chroma, timbre, and intensity are extracted (Kolesch

and Siebel, 2005). In subsequent stages, the cerebral cortex is involved (Warren, 2008).

Following the initial encoding, music triggers cognitive, motor, and emotion processes controlled by both cortical and subcortical areas. For instance, listening to familiar music may activate processing in the hippocampus, medial temporal, and parietal areas—regions involved in episodic memory—while music perceived as emotion may engage limbic and paralimbic areas (Särkämö et al., 2013).

Emotional Processing of Music

Analysis of functional neuroimaging studies (e.g. fMRI and PET) have shown music to modulate activity in brain structures such as the amygdala and nucleus accumbens (NAc) which are crucial to processing emotion (Schaefer, 2017). The structures documented are involved in both the limbic system, a complex network central to emotional processing (Koelsch, 2010).

Limbic System

Virtually all limbic structures are shown through functional neuroimaging and lesion studies to be affected by music-evoked emotions (Koelsch, 2010). Though there is no universal consensus on the total list of structures in the limbic system, key brain regions involved are: the limbic cortex, hippocampal formation, amygdala, septal area, and hypothalamus (RajMohan and Mohandas, 2007). Limbic brain regions communicate back and forth with other regions including the thalamus and midbrain. The limbic system induces emotional responses like fear as well as autonomic and endocrine responses (Rajmohan and Mohandas, 2007). Pleasant music is found to activate both limbic and paralimbic structures such as the posterior hippocampus, nucleus accumbens, and anterior insula (Koelsch et al., 2006). Unpleasant stimuli, based on blood-oxygen-level-dependent (BOLD) responses comparing unpleasant and pleasant stimuli, were shown to inhibit emotional activity in limbic regions. Pleasant music can therefore be favored to alter limbic activity.

The amygdala, a highly differentiated region located near the temporal pole of the cerebral hemisphere (Swanson and Petrovicha, 1998), plays a crucial role in regulating and modulating

the emotion network (Schaefer, 2017). After the amygdala receives and processes information from the central auditory system and sensory systems, signals are sent to pathways to the hypothalamus, an area integral to maintaining homeostasis and overcoming stressors (allostasis) (Saper and Lowell, 2014; Schaefer, 2017; Akimoto et al., 2018). When music is processed, projections to the hypothalamic-brainstem structures from the amygdala and hippocampus induce autonomic and endocrine responses (Li, Cheng, and Tsai, 2019). One hormone produced by the hypothalamus is oxytocin. Oxytocin responses occur during music listening after the music stimuli is transferred to the amygdaloid body and the hypothalamus receives information from the amygdaloid body circuit (Akimoto et al., 2018). Some studies suggest that pleasant stimuli increase oxytocin production (Akimoto et al., 2018); oxytocin is said to regulate the hypothalamic-pituitary-adrenal (HPA) axis (Akimoto et al., 2018; Neumann et al., 2000) by reducing the amount of cortisol (C21H30O5) released by the HPA axis (Schaefer, 2017), indicating the hypothalamus can affect the parasympathetic nervous system (Schaefer, 2017).

One pathway related to the limbic system is the mesolimbic system, a dopaminergic reward pathway originating in the ventral tegmental area (VTA) of the brain that projects to the amygdala, NAc, and hippocampus (Cox and Lee, 2016). Functional magnetic resonance imaging (fMRI) conducted by Menon and Levitin (2005), aimed to examine the role of the mesolimbic pathway involving the NAc and VTA, found important dynamic interactions mediated by the VTA to the hypothalamus, insula, and orbitofrontal cortex (OFC) (Menon and Levitin, 2005). The pathway is functionally connected to the AC; for instance, connectivity between the AC and NAc can dictate whether an individual will purchase a song (Schaefer, 2017).

The mesolimbic pathway starts first in the VTA, an area in the brainstem. Mesolimbic dopamine neuron cell bodies are found in the VTA, and are projected to the NAc, a structure involved in pleasure, reward, and addiction located in the ventral striatum (Schott et al., 2008), via the mesolimbic pathway (Menon and Levitin, 2005). VTA and NAc activations were found to be significantly correlated, indicating a link between hedonic music and dopamine release; greater feelings of reward during music listening is

attributed to increased dopamine levels in the VTA and NAc (Menon and Levitin, 2005). The release of dopamine affects pleasure (“chills” are one indication) as well as motivational drives of musical reward (desire to spend money) (Ferreri et al., 2019). Even in the absence of chills, activity changes in the amygdala, ventral striatum, and hippocampal can occur as indicated by a 2006 fMRI study (Schaefer, 2017). This emotional arousal is correlated with increased sympathetic nervous system as measured by a study that examined sympathetic nervous system markers such as heart rate and body temperature following pleasurable music listening (Zatorre and Salimpoor, 2013).

As highlighted by recent studies, key limbic regions affected by music include the amygdala, hippocampus, and hypothalamus. In addition, music is proven to modulate both the sympathetic and parasympathetic nervous systems, with the regulation of the HPA axis correlating with parasympathetic activity and the increase of dopamine associated with sympathetic activity. This indicates that different music may yield different responses, hinting that the specific genre or type of music may be important to examine to achieve the best stress mitigating effects.

Stress

The brain is the primary target for various stressors due to its sensibility to stress-induced situations (McEwen and Gianaros, 2010; Kumar et al., 2013) and is also the location where the stress response begins, as the brain can discern whether a stimulus is threatening (McEwen and Gianaros, 2010). First in the stress response is the perception of a threatening stimulus (Godoy et al., 2018). Stimuli can be generally categorized into either physical (e.g. infection or hemorrhage) or psychological stressors (e.g. failure to satisfy internal drives) (Godoy et al., 2018; Doewes et al., 2021). Different stressors—physiological or psychological—are processed in different brain circuitries, though there may be some overlap (Godoy et al., 2018; Doewes et al., 2021).

The brainstem and hypothalamic regions of the brain are the main structures involved in the processing of physical stressors (Godoy et al., 2018; Doewes et al., 2021). Short-lasting responses such as alertness occur as a result of the sympathetic adrenomedullary system (SAM), the first phase stress

processing (Godoy et al., 2018). Activation of the HPA axis occurs as the second phase, resulting in amplified and prolonged secretory reactions (long-lasting responses) (Godoy et al., 2018; Doewes et al., 2021). Apart from the brainstem and hypothalamic regions, limbic regions such as the amygdala, hippocampus, and prefrontal cortex (PFC) have been shown to participate in the stress response for physical stressors by influencing the autonomic response to stress and stimulating the HPA axis (Godoy et al., 2018; Doewes et al., 2021).

Psychological stressors tend to induce physical and cognitive stress responses. Fundamental in the regulation of the stress response for psychological stimuli are the prosencephalic nuclei and limbic regions like the PFC, amygdala, hippocampus, PVN, VTA, and NAc. PFC’s significance in the stress reaction is complicated; however, one known role of the PFC is sending major projections to the amygdala, which was initially proven to stimulate corticosteroid synthesis and secretion (Godoy et al., 2018; Doewes et al., 2021).

The HPA axis is activated by both physiological and psychological stressors, signifying that it plays an important role in stress response. Moreover, there is an anatomical overlap between brain regions affected by physiological and psychological stressors and music. For both stress and music, limbic regions were documented as critically involved. Activity within these areas, such as the amygdala and hippocampus, suggest that music has the potential to affect brain areas implicated in stress, and consequently, alter the body’s response to stress.

The stress response system is also interconnected with many hormones and neurotransmitters. The HPA axis is critically involved in hormone release, while neurotransmitters involved include serotonin and dopamine (Kumar et al., 2013).

HPA Axis

Activation of the HPA axis is among the most distinguished features of the physiological stress response (Stanwood, 2019). After a stimulus is received in the hypothalamus, the HPA axis is initiated. Corticotropin releasing factor (CRF) is released, which then initiates the release of adrenocorticotrophic hormone (ACTH) and beta-endorphin from the pituitary. Released ACTH triggers the liberation of

adrenal steroids such as cortisol and testosterone (Schaefer, 2017; Kumar et al., 2013). High cortisol levels are associated with greater stress, regardless of psychological or physiological stressors (Schaefer, 2017). Once the threat subsides, cortisol levels decrease, and the parasympathetic nervous system lowers the stress response (Weissman and Mendes, 2021).

Understanding the role of the HPA axis in stress and music listening responses is crucial towards understanding the effect of music therapy on stress. Significantly, music and stress alter the HPA axis in opposite ways: stress activates the axis while music can regulate it, inducing the parasympathetic nervous system which lowers the stress response.

Serotonin

Long-standing stress has been evidenced by previous studies to reduce serotonin levels (Kumar et al., 2013). Within the endocrine system, serotonin has a complex effect on the stress pathway as it helps to regulate the HPA axis at many levels (Berger et al., 2009). It was found that oxytocin triggers serotonin release (Lefevre et al., 2017).

Because oxytocin and the serotonin produced regulates the HPA axis, it likely may be an important chemical in the stress coping response. Thus, higher levels of serotonin or oxytocin may be associated with lower levels of stress and may be an indicator towards whether music therapy is beneficial or not.

Dopamine

Preclinical studies have suggested varying dopamine responses to different stimuli. More acute, controllable, or escapable physical stressors were found to increase dopamine release in the ventral striatum, while chronic, inescapable stressors reduced dopamine levels (Kumar et al., 2013). Further, dopamine facilitates the stress response by coregulating chemical transmitters (Stanwood, 2019).

Interestingly, both stress and music can induce the dopaminergic system. Though dopamine contributes to the stress response, it may also affect the stress coping response (Stanwood, 2019). For instance, midbrain dopamine neurons were found to be capable of regulating the HPA axis as dopamine

decreases reduced stress-induced corticosterone secretion (Stanwood, 2019), suggesting music's ability to increase dopamine levels may not necessarily signal an increase in stress, but rather, may help reduce stress.

Music as a Therapy for Stress

In general, music that is considered pleasurable or relaxing is correlated with decreasing stress. The ventral striatum, part of the mesolimbic "reward" pathway, is activated during pleasurable music listening; for instance, music that is found pleasurable because of its familiarity (Chanda and Levitin, 2013). "Relaxing music" (generally including slow tempo, consonant, low pitch, and no lyrics) was demonstrated to decrease stress and anxiety in healthy subjects, pediatric patients undergoing medical procedures, patients undergoing invasive medical procedures (e.g. surgery, dental procedures), and those with coronary heart disease (Koelsch et al., 2006; Chanda and Levitin, 2013). Secretory immunoglobulin A (sIgA) is an antibody involved in immune exclusion, the process of limiting access of microorganisms, bacterial, or antigens (Schaefer, 2017; Corthésy, 2013); high levels of sIgA are associated with positive effects, while low levels may relate to chronic stress (Schaefer, 2017). Relaxing music or musak were observed to significantly increase sIgA concentrations (Schaefer, 2017; Kreutz et al., 2004). A 2004 study found no significant changes in sIgA, but did note a decrease in cortisol levels (Kreutz et al., 2004). Though many studies reaffirmed the benefit of music therapy towards stress, not all studies found a significant change likely because music is very subjective. Taken together, the findings generally indicate that relaxing music can reduce stress. Since the 2004 study did not find significant changes but also did not discover adverse effects of relaxing music, it signals that relaxing music for music therapy may be a good strategy to potentially help patients suffering from stress without the risk of inducing much harm.

Various characteristics of the music presented often impacts the effects of music therapy. Classical choral, meditative, and folk music have been found to greatly lower cortisol levels, while techno music has been correlated with increased cortisol levels (Schaefer, 2017; Chanda and Levitin, 2013). The increase in cortisol level triggered by techno music highlights how certain types of music may actually increase stress levels as opposed to decreasing levels,

thus underscoring the importance of choosing the right music for stress therapy. Unlike the more relaxing music types such as classical, choral, or meditative, techno music is characterized by its heavy bass drum on each beat, snare of clap on the second and fourth beats, and hi-hat on the sixteenth beat. Likely, this strong drumming pattern impairs the relaxing qualities of music. Slow-tempo music has also been shown to increase salivary oxytocin compared with fast-tempo music (Akimoto et al., 2018). Because brainstem neurons generally fire synchronously with tempo, slow music and musical pauses often correlate with lower heart rate, respiration, and blood pressure, whereas faster music increases such parameters (Chanda and Levitin, 2013). Another study compared three pieces of music selected due to their different rhythmic properties: a Strauss waltz (regular rhythm), a modern piece by H.W. Henze (irregular rhythm), and a meditative piece by Ravi Shankar (non-rhythmic).

Though the meditative piece was shown to significantly reduce plasma levels of cortisol and norepinephrine, no effect was concluded for the other two pieces (Chanda and Levitin, 2013). Results from this study indicate non-rhythmic music may be best used as a stress therapy. Additional study explored the effects of 528 Hz music, which has more recently been regarded as “healing” music, and 440 Hz music, music based on the reference tone of tuning. Exposure to 528 Hz soothing piano music significantly reduced mean cortisol levels and increased mean oxytocin levels after 30 minutes, while exposure to 440 Hz music showed slightly decreased mean cortisol levels after 30 minutes. No stress mitigation effect could be confirmed from the 440 Hz condition because there were no significant differences in the mean oxytocin levels or mean levels of cortisol (Akimoto et al., 2018). Taken together, results from these experiments suggest that music is beneficial to treating stress and may share characteristics such as an absence of a strong bass (i.e. classical choral, meditative, and folk music), slow tempo, and pitch based on the 528 Hz tone.

When using music as a therapy for stress, regard for individual music preferences and context factors appear to be significant in mediating the effects of music (Kreutz et al., 2004). Further, some researchers noted that music preferences may vary depending on the listener’s mental state (Akimoto et al., 2018). These two factors underscore how music

therapy not only varies from person to person, but may even differ in an individual from time to time. Because of this, there may be some disparities in the studies presented, as the music chosen may now have been the most pleasurable or relaxing to all participants. In addition, it highlights the need to carefully examine the individual to find his/her preferences when selecting music used to alleviate stress.

Based on the studies outlined above, I propose that certain types of music, the most optimal generalized as music that people find pleasant and relaxing, which may typically feature characteristics such as familiarity, slow tempo, absence of strong drumming, and non-rhythmic patterns, can be used to activate the parasympathetic nervous system to reduce cortisol and relieve stress. This is especially useful in the post-Covid world where stress has increased and music streaming platforms have made music more accessible than ever. For the best results, individual preference and mood should be taken into consideration as music is highly subjective.

Choosing Music for Stress Relief Music Therapy

Preferential relaxing music best suited for stress relief music therapy often possesses characteristics such as familiarity, slow tempo, and non-rhythmic patterns. Though people’s music preferences are shaped by factors such as ethnicity, personality, and/or social class, the most determining factor has been identified as age and nostalgia (Davies et al., 2022). This indicates that finding music released during a person’s late adolescence or early adulthood may help when selecting music for music therapy. For instance, for the Baby Boomer generation, one might choose more music under the rock and roll genre, while pop or hip hop might be used more for Generation Z. While familiar, self-selected songs have shown to reduce stress (Labbé et al., 2007), other studies revealed that classical music has a greater benefit (Chennafi et al., 2018). Likely, both the popular, familiar music and classical music can induce oxytocin stimulation, associated with positive, happy feelings; however, the genres most popular amongst generations tend to have a faster, upbeat tempo which is involved more in emotional excitation (Ooishi et al., 2017), contrasting with the physiological relaxation associated with slower tempo music.

In regards to classical music, music from the Impressionist Period may be best suited for passive music therapy when treating stress. Pieces from this period are known for evoking more surreal impressions or feelings, less confined to a traditional harmony or structure. Further, the music often lacks a steady, defined rhythm, unlike music from other periods. Choosing slower tempo Impressionist music can thus fulfill characteristics of relaxing music such as a slow tempo and non-rhythmic pattern known to activate the parasympathetic nervous system.

Conclusion

Of the total respondents in the United States 2022 Pandemic Anniversary Survey conducted online by The Harris Poll on behalf of the American Psychological Association, 56% noted that they could have benefitted from more emotional support since the onset of the pandemic. Music, which can lower stress and stimulate pleasure, may be an effective tool to help address such needs. Stress activates the sympathetic nervous system, stimulating the HPA axis and producing cortisol, while music listening triggers the parasympathetic nervous system which regulates the HPA axis and lowers cortisol production. Before using music as a therapy for stress, though, individual preferences regarding relaxing and pleasant music must be considered to ensure music will alleviate, not magnify stress. Music selections can be made by taking in factors such as the person's age to choose music popular during their adolescence. Classical music was also shown to be amongst the most effective genres to use, and music specifically from the Impressionist Period may be a good selection, fitting characteristics of stress relieving music such as a non-rhythmic pattern. Future studies may analyze music preferences amongst certain age groups or cultural groups to identify genres or songs that are viewed as most pleasurable or relaxing to each category. More research can also be conducted to assess the impact of music therapy in conjunction with other tasks such as exercise as a means of reducing stress.

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