2023

A theoretical basis for understanding and researching the relationship between music, stress, and biofeedback

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A THEORETICAL BASIS FOR UNDERSTANDING AND RESEARCHING THE RELATIONSHIP BETWEEN MUSIC, STRESS, AND BIOFEEDBACK

A Dissertation

Presented to the Faculty of

Antioch University Seattle

In partial fulfillment for the degree of

DOCTOR OF PSYCHOLOGY

by

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June 2023

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Antioch University Seattle
in partial fulfillment of requirements for the degree of

DOCTOR OF PSYCHOLOGY

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ABSTRACT

A THEORETICAL BASIS FOR UNDERSTANDING AND RESEARCHING THE RELATIONSHIP BETWEEN MUSIC, STRESS, AND BIOFEEDBACK

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Music's ability to influence emotional states and physical arousal has become an increasingly popular area of study. The wealth of literature around music and stress suggests a significant amount of interest in leveraging music to manage stress. However, as attention increases, the robustness of research becomes an increasing concern. This study investigates the current literature and proposes recommendations for the future studying of the psychological and physiological impacts of music as it relates to stress reduction. Existing literature was reviewed with a focus on the operationalization of key concepts of music and stress. The analysis showed considerable discrepancies in research design, operationalization of music, operationalization of the psychological aspects of stress, and operationalization of the physiological aspects of stress. The findings of this study have implications for future research design. This dissertation is available in open access at AURA (https://aura.antioch.edu) and OhioLINK ETD Center (https://etd.ohiolink.edu).

Keywords: music, stress, biofeedback, psychophysiology, research design

Dedication

I dedicate my dissertation work to my family and many friends. I dedicate this to my grandparents, who believed that I would become a doctor one day and for providing an example of persistence even in the face of great struggle. I dedicate this to my parents, who have always shown unwavering love and nurtured my curiosity. I dedicate this to my brother, who has been my physical and mental sparring partner since his arrival on this earth. To my cats, Summer and Luna, for ensuring I maintain a routine and providing warmth and comfort on the coldest of nights. Lastly, I dedicate this to my loving partner, Amy, who has shown a startling amount of patience and unending support throughout the entire doctoral program.

Acknowledgements

I am deeply indebted to the members of my dissertation committee for their unwavering support, flexibility in the face of the COVID-19 pandemic, and patience guiding me through this process. I am grateful to my chair, Dr. Michael Toohey for his encouragement to succeed and for the inspiration to blend two loves—music and psychology—within this research. I appreciate Dr. Michael Sakuma for his calm and passionate presence that has always felt like a lighthouse in choppy waters. I am thankful for Dr. Brad Lichtenstein for being the first to inspire me to look beyond just the science of the mind-body connection but to engage with it through a lens of creativity and playfulness.

I also want to acknowledge Drs. Jeff Houck, Daniel Kang, Julie Oyemaja, Kathleen Gathercoal, and Sally Gildehaus for fostering a greater love for research. Finally, I want to recognize the faculty and my peers at Antioch University Seattle for their friendship and support throughout the doctoral program.

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CHAPTER I: INTRODUCTION

Stress and its effects have increasingly been researched regarding its effects on physiological and mental health. The American Psychological Association (2019) defined stress as a reaction to a situation that is either short-lived or chronic and can interfere with daily living over a period of time. The relationship between increased stress and worsening mental health has been well documented (Langner & Michael, 1963), and prolonged exposure to stress has been correlated with poor individual health (McEwan, 1998). Stress and mental health concerns were identified as a growing concern amongst individuals between the ages of 15 and 21, and 27% reported fair or poor mental health (American Psychological Association, 2018).

Selye (1978) wrote that "although stress itself cannot be perceived, we can appraise it by the objectively measurable structural and chemical changes which it produces in the body" (p. 363). Most people experience stressors as mentally and physically exhausting. Stressors reflexively evoke a primitive behavior of rising on to the balls of the feet and hunching forward (McGuigan & Lehrer, 2007). While this is an adaptive response to an acute stressor and helpful for survival, it is often prolonged beyond the immediate emergency. This results in chronic, excessive tension and continued activation of the nervous system.

Herman (1985) synthesized four elements of relaxation from dictionary definitions: state of being of an individual, decrease in tension, physiological dimensions, and psychological dimensions. Within the psychological dimensions, relaxation may be considered an emotional state of low arousal (English & English, 1958). While significant overlap exists between the definitions of stress reduction and relaxation, the two concepts are better understood as related but different. Whereas relaxation may encompass the four elements as defined by Herman (1985), stress reduction omits the state of being within its technical definition. Relaxation techniques, then, will often focus on alleviating excessive psychological and physiological tension. In contrast, stress reduction techniques may encourage actively or passively engaging with the initial stressor in order to overcome and confront a perceived threat (Salleh, 2008).

The concept of relaxation for psychological stress was first explored by Jacobson (1938), who proposed that, to reverse the harm that comes from chronic tension, a person needs to learn to relax skeletal muscle. To do so, Jacobson (1938) suggested that systematic and practiced relaxation of the skeletal muscle could improve overall health outcomes; his practice became known as progressive relaxation or progressive muscle relaxation (PMR). Similarly, other practices evolved to address the psychophysiological reactions to stressors, including autogenic training (Schultz & Luthe, 1959) and biofeedback (Strobel, 1985).

Music is present in daily life for many people. Technological advances have played a major part in enabling listeners to produce a soundtrack in their everyday life and carry music into different situations. Beyond the scope of simply entertainment, the use of music to treat health problems can be traced to ancient cultures (Boxberger, 1962). In more recent years, interest has grown in how it can facilitate relaxation (Scartelli, 1984, 1989; Thaut, 1989). Research suggests that music as well as formalized music therapy can elicit physiological, psychological, cognitive, social, and spiritual responses (Dileo & Bradt, 2005).

In his book, *The Anthropology of Music*, Merriam (1964) describes the function of music as that which “concerns the reasons for its employment and particularly the broader purpose which it serves” (p. 210). In comparison, Merriam (1964) proposes that the use of music, or the “situation in which music is employed by human action” (p. 210), contains an infinite number of specific behaviors; functions, then, provide a more thematic framework upon which to understand music. He describes 10 principal functions of music, including:

1. Emotional expression.
2. Aesthetic enjoyment.
3. Entertainment.
4. Communication.
5. Symbolic representation.
6. Physical response.
7. Enforcing conformity to social norms.
8. Validation of social institutions and religious rituals.
9. Contribution to the continuity and stability of culture.
10. Contribution to the integration of society (Merriam, 1964, pp. 219–227).

In their literature review, Sloboda, Lamont, and Greasley (2016) identified four recurring functions of music within everyday life: distraction, energizing, entrainment, and meaning enhancement. Distraction engages otherwise-unfocused attention and reduces boredom. Energizing is a means to increase arousal and task-oriented attention. Entrainment describes the natural synchronization with music of physical movements, such as dance, or physiological function, such as heartbeat. Finally, meaning enhancement illustrates the use of music in drawing out or augmenting the emotional significance of a task or activity. From these four functions, Sloboda, Lamont, and Greasley (2016) further identified five main areas of daily living where music is often incorporated into: travel, brain work, body work, emotional work, and attendance of live music performance.

Neuroimaging studies on music and emotion has demonstrated that music may influence the amygdala, a part of the limbic system, which is thought to be responsible for regulation and experience of emotion (Koelsch, 2014; Koelsch et al., 2013; Lehne et al., 2014). Consequently, damage to the amygdala may also inhibit the emotion-related experiences of music; scary music may appear less arousing and peaceful music less relaxing (Gosselin et al., 2007). A systematic review by Moore (2013) indicated that music listening and musical improvisation could reduce activity of the amygdala, which, in turn decreases the intensity of stress-reactions and psychophysiological arousal.

Statement of the Problem

Research has found mixed findings in terms of the efficacy of music in combination with relaxation training (Reynolds, 1984; Robb, 2000). Furthermore, it is unclear whether the perception of relaxation is related to the psychophysiology of relaxation in the context of music-assisted exercises. In past studies, physiological changes associated with music listening were not always statistically significant. Thaut (1989) argued that an individual's physiological response to music is influenced by their idiosyncratic physiological makeup as well as their individual psychological experience of a music experience. Personal choice and interest in different styles of music may also affect outcomes of music and relaxation (Thaut & Davis, 1993). This suggests that psychological and physiological measures of stress and music may be independent of one another. Robb (2000) studied the psychological effects of music-assisted progressive muscle relaxation, progressive muscle relaxation alone, music alone, and silence and concluded that each method was equally effective in producing changes in anxiety and perceived relaxation; however, he did not examine the correlates between perception and psychophysiological markers.

The limited statistical power in existing literature may be due to the significant variability in research design or with unclear constructs used in the research. While there is considerable research suggesting the effects of music and music-augmentation in therapeutic outcomes, the specific mechanisms remain unclear with often mixed results in outcomes. Additionally, given the prevalence of music-listening in daily life, the need to better construct research around music is warranted.

Research Questions

This study attempted to answer the following research question and sub-questions:

1. What are the recommendations for the future studying of the psychological and physiological impacts of music as it relates to stress reduction?
    a. What is the current construct of music in research and what are the existing limitations?
    b. What is the current construct of stress in research and what are the existing limitations?
    c. What is the current construct of biofeedback and psychophysiological measurement in research and what are the existing limitations?

Purpose of the Study

The purpose of the present study is to investigate the validity and measurements commonly used in examining the role of music in relaxation studies and formulate an underlying theory as a foundation of action for future study. This study will attempt to better understand how researchers organize and understand music-related stress reduction and examine the psychological and physiological constructs of music and relaxation.

Significance and Clinical Implications of the Study

This study’s clinical implications are twofold: First, it establishes the significant variability in research design and outcome measures in music and music-augmented interventions. Second, it proposes suggestions for future research surrounding music, stress, and relaxation.

CHAPTER II: MUSIC IN CURRENT LITERATURE

The operationalization of music in research will be discussed to understand the current strengths and limitations in existing literature. While it is generally accepted that music can induce emotional changes (Lundqvist et al., 2009), the specific mechanisms are somewhat unclear. Few studies specifically tested the underlying processes that explain how music induces emotional responses (Juslin & Väsfjäll, 2008). The preexisting literature on music interventions for stress focus mainly on two modalities: (a) music medicine, the passive listening of music, or (b) music therapy, where individualized treatment was provided by a music therapist (Bradt, Dileo, & Potvin, 2013). Much of the current research suggests usage of music labeled as soothing or relaxing when discussing stress reduction; however, many studies failed to define these terms. A review of studies surrounding music, stress, and relaxation revealed a picture that is overall unclear. There are many studies that suggest that music can reduce stress; however, there is no comprehensive explanation as to the mechanisms by which music influences stress. A literature review by Nilsson (2008) looked at 42 randomized control studies on reduction of stress and anxiety by music intervention with individuals with pain symptoms. Of the 42 studies, the music presented was reported as soothing when tempo was between 60 and 80 beats per minute. Twenty-nine of the 42 studies asked participants to select their own music; this included using the participant's own favorite music or one chosen from a selected list (Nilsson, 2008). Familiarity and preference in music will be discussed further.

Tempo

Tempo or musical rhythm may promote relaxation or arousal through the process of entrainment. Entrainment is a term borrowed from physics to describe the phenomena that rhythmic psychological or behavioral events will match an external rhythm, such as in the case of the circadian rhythm modulating to match the rising and setting of the sun. Through the process of entrainment, tempo and musical rhythm can influence changes in heartbeat, respiration, and blood pressure, which are often correlated with a stress and relaxation response (Thaut, 2003). This suggests that slower, consistent tempo could be utilized to aid or induce a relaxation response.

Harmony and Musical Mode

While tempo is most strongly utilized in this research, other factors in music may also be relevant to change in mood and stress states. A study by Nater et al. (2006) compared the differences of a classical music piece (*Miserere* by Allegri) and three heavy metal songs by the band Marduk in effecting an arousal response. In their study, while tempo was largely consistent between the three pieces selected, participants had significantly higher physiological arousal levels to the heavy metal music compared to the classical piece (Nater et al., 2006), suggesting that tempo may not be the only contributor to music’s effectiveness in inducing mood and relaxation. Other studies have corroborated this finding that tempo is not solely responsible for changes in arousal and emotion (Roy, Mathieu, et al., 2009; Roy, Peretz, & Rainville, 2008).

To understand this, a distinction in terms must be made between a musical scale and a musical mode. A musical scale is a series of pre-determined pitches in a distinct order that highlight the typical notes that may be available for use in a work of music. Prior to the adoption of named keys (i.e., A major, a minor, C# major, etc.), musical modes were utilized to organize and determine the theme of the musical piece. A musical mode incorporates the notes on a musical scale and adds a framework of melody type, and thus defines the expected evocation of experience from the organization of the musical pitches.

Harmonically pleasant or unpleasant chord patterns are also implicated in changes in activity in the limbic and paralimbic structures in the nervous system (Koelsch, 2005). Music that is played in major keys reduced self-perception of stress and cortisol levels more than music played in minor keys (Suda et al., 2008), suggesting that musical mode likely plays a role in the effect of music and relaxation.

Amplitude and Volume

Peak volume of the music-based interventions is also sometimes suggested in other research designs. Most commonly, studies kept peak volume of 70 decibels for the music (Gerra, et al., 1998; Knight & Rickard, 2001). The reasons for choosing this volume were not explicitly stated by the authors of these studies. Ayres and Hughes (1986) codified normal recreational listening levels as follows: 70 decibels was considered normal listening levels, 100 decibels was normal listening levels in bars, and 107 decibels was typically encountered at amplified concert levels. In one study on music volume and relaxation, participants were exposed to music playing at volumes between 60 and 90 decibels; participants psychophysiological stress responses were most reduced when listening to music between 60-70 decibels on average (Staum & Brotons, 2000). Other studies have established that environmental noise levels that exceed 85 decibels can induce a stress response after 25 minutes (Westman & Walters, 1981). A study by Mehta et al. (2012) noted improvements in cognitive performance and creativity when in the presence of moderate noise of about 70 decibels compared to both lower and higher levels of noise. The physiological effects of music volume have been studied as well. Wilson and Aiken (1977) compared the effects of loud and soft rock music on three psychophysiological indicators of stress: skin conductance level, heart rate, and respiration rate as well as the subjective responses of the participants. While their findings suggested no clear difference in physiological arousal due to differences in volume, there was a statistically significant preference for the softer music.

Music Frequency

The effects of different noise or music frequency may also effect the stress and relaxation process. Much of the research on frequency and stress, however, has been focused on environmental noise rather than music. Low frequency noise, defined as the frequency range from about 10Hz to 200Hz, is associated with increased stress and perceived annoyance (Leventhall, 2004). Low frequency noises have been correlated with increased salivary cortisol response (Waye et al., 2002). In one study by Walker et al. (2016), short-term exposure to both low frequency (31.5–125 Hz) and high frequency (500–2000 Hz) noises was associated with reduction in heart rate variability, with greater reduction in heart rate variability associated with the low frequency noise. By comparison, the lowest frequency on a full-sized, 88-key piano, is 27.5 Hz while the highest key is generally tuned to 4186 Hz (White & White, 2014).

While modern day tuning for instruments have the A above middle C (A_4) tuned to 440 Hz, tuning of orchestral instruments prior to 1955 was often set at 435 Hz for A_4 (Beyer, 1998). This meant that music played and recorded prior to 1955 may have been played at a slightly lower frequency overall. A study by Halbert et al. (2018) established that a lower frequency tuning of music had more pronounced relaxation effects compared to modern, standard tuning. Halbert et al. (2018) argued that, consequently, modern music tuning frequencies may have less effectiveness compared to older music tuning frequency. Music that skews towards lower frequencies with no extreme changes tends to be associated with greater outcomes for relaxation (Pelletier, 2004).

Familiarity and Preference

Familiarity has also been demonstrated to play a role in the relaxation effects of music. In one study, Tan et al. (2012) noted that music preference was highly correlated with listener's perception of relaxation. A meta-analysis by Pelletier (2004) corroborates the importance of music preference. The meta-analysis suggested that in music-listening interventions, music preference tended to predict better outcomes than research-based music selections. However, research-based selection tended to prompt better effects than individual preference when music was an augmentative part of the intervention rather than the sole intervention (Pelletier, 2004).

CHAPTER III: DISCUSSION OF CURRENT MUSIC LITERATURE

Dillman Carpentier and Potter (2007), Pelletier (2004), Robb et al. (1995), and Yehuda (2011) summarized the research-based selection of music for relaxation. They noted that music should have a tempo at or below a resting heart rate (<80 beats per minute), regular rhythm with no sudden changes in tempo, predictable dynamics with no sudden changes in volume, pleasing harmonies, lower frequencies, music with no lyrics, and preferably acoustic tonality. An example of this may be found in research by Robb et al. (1995), which determined that Daniel Kobialka's *Going Home Medley*, based on Antonin Dvorak's *New World Symphony*, included ideal components for relaxation based on tempo (72 beats per minute or less), predictable dynamics, fluid melodies, pleasing harmonies, regular rhythm, and acoustic tonality.

A contradictory view suggests that there may be no universally accepted operational definition of soothing music (Hanser, 1988). This is exemplified in a study by Roy, Peretz, and Rainville (2008) on pain modulation using music which used a preliminary survey in which participants were asked to rate different musical excerpts on dimensions of pleasant-to-unpleasant and relaxing-to-stimulating. While they established that unpleasant excerpts were universally more arousing, it also demonstrates the subjective nature of how studies have operationalized music (Roy, Peretz, & Rainville, 2008). A recent meta-analysis by Bradt, Dileo, and Potvin (2013) seems to corroborate this argument. They examined 26 randomized control studies on the effects of music for stress and anxiety reduction in coronary heart disease patients. They noted that, while there was some noted benefit from music interventions for stress, few studies provided detailed information about how music was chosen, and that only one of the 26 studies provide composition title, composer, and tempo information (Bradt, Dileo, & Potvin, 2013).

Music is often intentionally designed to communicate and inspire emotion, using any means available. While some existing literature proposed musical pieces that may encourage a relaxation response based on research-based characteristics (i.e., Daniel Kobialka's *Going Home Medley*, based on Antonin Dvorak's *New World Symphony*), there is significantly less research that explores how longer pieces of music, which commonly involve more complex shifts in dynamics, harmony, and musical theme may interact with the perception of stress and emotion. One possible explanation may involve "the law of affective equilibrium" as defined by Beebe-Center (1932), which postulates that emotional shifts towards pleasantness and unpleasantness exist are amplified by exposure to a contrasting emotional state; pleasant sensations feel enhanced when they immediately follow an unpleasant sensation. However, due to the relatively limited research constructs on music, these specific nuances remain unclear.

Cross-Cultural Considerations

While research depicts the common trends associated with music utilized for relaxation, including tempo, amplitude, and frequency, the importance of harmony and individual preference suggests that there may be an importance in considering cultural norms and differences. Much of the existing research has been sampled from participants in Western countries using music samples from Western music. Juslin (2012) suggests that evocation of emotion may apply cross-culturally based on the underlying mechanisms of music and sound; however, existing literature does not sufficiently account for the impact of cultural differences in tonality of music.

What may be tonally pleasing in one culture may be tonally discordant in another. The scales of western music are organized with 12 unique semitones per octave, and therefore, harmony and musical mode are defined by combinations made possible by having 12 semitones.

A common scale in western music utilizes a heptatonic (seven-note) scale comprised of different combinations of the 12 semitones and is commonly identified with the solfège naming conventions of do-re-mi-fa-sol-la-ti-do. Because of the widespread influence of this musical scale, modern popular music across cultures has adopted similar tonality.

While the widespread adoption of the 12 semitones may suggest a universality in music, this disregards the historical context in which musical pieces were written, played, and enjoyed. By contrast, traditional Chinese music utilizes a pentatonic (five-note) scale which roughly aligns to the solfédge of do-re-mi-sol-la-do, thus changing the possible combinations of tones utilized for music. Like the western scales, the Indian musical scale utilizes 12 semitones but can be subdivided further into 22 different notes per octave. Consequently, differences in number of unique notes per octave may evoke a sense of being tuned incorrectly or harmonically confusing to a listener that is unaccustomed to these differences in organization of music.

Role of Preference and Individual Differences

The effect size of music in evoking a relaxation reaction varied significantly between studies, suggesting limitation in generalizability of the results. However, this diversity of results may not be due to an overarching inadequacy of research design, but due to the individual differences that may account for the efficacy of music for relaxation. Research has suggested that emotional reactions to music may be affected by multiple identifying characteristics, such as the listener’s age, gender, music training, and music education (Abeles & Chung, 1996). This corroborates the study by Davis and Thaut (1989) and the meta-analysis by Pelletier (2004) who identified that preference significantly impacted the effectiveness of music to induce a relaxation response. The role of preference in music should not be overlooked in future research design.

Gregory and Varney (1996) established that cultural tradition impacted the affective response to music more so than the inherent, technical qualities of the music.

Research has also suggested that there may be gender differences in musical processing and preferences (Koelsch et al., 2003) between cisgender individuals who are assigned male or female at birth. Women typically score higher on scales that measure emotional connection to music (Kreutz et al., 2008), and are more likely to emphasize the emotional-related functions in identifying preference to different music (Chamorro-Premuzic et al., 2012).

Engagement with music also tends to diminish with age (Chamorro-Premuzic et al., 2012; Schäfer & Sedlmeier, 2009). Preference, too, may be related to differences in cohorts; North and Hargreaves (2008) identified that older individuals identified greater preference for classical, sixties pop, musicals, and opera while younger individuals preferred styles such as hip hop, rap, dance/house music, R&B, indie, and current chart pop. In a longitudinal study of music preference, Delsing et al. (2008) identified that music preference was already fairly stable by early adolescence and become increasingly stable into older adolescence.

A study of age-related differences in music preference by Bonneville-Roussy et al. (2013) utilized the MUSIC model to identify preferences for music that was classified as mellow, unpretentious, sophisticated, intense, and contemporary. Their results suggested that preference mellow music remained stable with age, preference for unpretentious and sophisticated dimensions increased with age, and preference for intense and contemporary styles of music tended to fade with age. This led Bonneville-Roussy et al. (2013) to suggest two possible explanations for this trend; the first that adolescents and younger adults may prefer music with more rebellious themes as they make movement towards independence, while another explanation may be that as hearing changes with age, there may be a decreased tolerance for loud noises.

CHAPTER IV: STRESS IN CURRENT LITERATURE

An overview of operationalization of stress induction and stress measurement in current literature will be discussed. Stress is a natural response to changes in circumstance or in managing difficult situations. While there is no clear consensus about the definition of stress, researchers tend to examine stress through the relationship between one or more events and induction of change. Hans Selye (1978) is generally credited with the adoption of this term to discuss how irregularities in body functions resulted in a non-specific strain on the body. Selye's (1978) General Adaptation Syndrome (GAS) suggested that physical stressors would produce similar psychological reactions as a defense as a stress reaction that was organized through the nervous system through the adrenal cortex. A similar reaction was noted with presentation of psychological stressors (Mason et al., 1976).

Lazarus (1993) explained that organisms respond to physical and psychological stress with behavioral and physiological defenses. However, physical and psychological stressors differ in presentation. Whereas physical stressors assert a noxious stimulus to biological tissue, psychological stressors are simultaneously more and less unified in its understanding. Psychological stressors, then, are mediated by personal meaning associated with the perception of a task or demand, a concept which Lazarus (1993) terms as cognitive appraisal.

Consequently, in research, stress reactions are often defined using psychological screeners, physiological measurements, or a combination of the two (Crosswell & Lockwood, 2020; Kirschbaum et al., 1993; Linares et al., 2020). Consequently, because stress itself cannot be adequately measured, the combination of psychological and physiological measures provides a more robust approximation of the stress reaction for laboratory research. The physiological response to stress includes an endocrinological response and cascading activation of the sympathetic nervous system. The resulting physiological adaptations may include, but are not limited to, increased cortisol volume within the saliva, increases in heart rate, decreases in heart rate variability, increased sweating response, changes in core and peripheral body temperature, and changes in breathing. Psychological responses may manifest as changes in emotion and cognitive appraisal of the situation, which may be estimated through the use of a variety of psychological screeners and assessments.

Induction of Stress

To fully explore the effects of a relaxation or stress reduction modality, stress must be adequately and appropriately induced in the experimental design. To appropriately measure the dynamic relationship between stressor and stress reactions, research must employ stressor challenges that are reliable and repeatable. While physical stressors have more pronounced effects than cognitive or emotional stressors when measured on physiological stress response markers (Wasmund et al., 2002), they inherently carry greater risk of confounding data collection. Nevertheless, research has also suggested that not all negative experiences trigger a uniform or repeatable cortisol response (Mason, 1968), making the need to better understand which stress induction tasks most reliable paramount to research design.

The Stroop color word test has been utilized as a stress induction technique due to its ability to increase physiological and emotional stress responses in a relatively short amount of time (Renaud & Blondin, 1997; Silva & Leite, 2000; Tulen et al., 1989). The Stroop was first described by John Ridley Stroop in 1935 (Stroop, 1935) and has been extensively researched in the realm of experimental psychology (MacLeod, 1991). The Stroop color word test asks the individual to inhibit overlearned verbal responses (reading printed words) and instead name the dissonant ink colors in which the words are printed. Notably, however, the specific interactions between the Stroop color word test and stress reactions are less well-defined. One study by Booth and Sharma (2009) noted that increased stress responses reduced attention to irrelevant information, therefore increasing performance overall with the Stroop task and reducing performance-based stress reactions. Thackray and Jones (1971) noted that presentation of the stimulus material in the Stroop task were not strongly associated with increased autonomic nervous system arousal, but that increasing stimulus presentation rate did increase overall arousal.

Arithmetic tasks are often cited as mental stress induction tasks (Jiang et al., 2013). Tasks including arithmetic have been suggested as increasing subjective distress and increasing psychophysiological arousal (Atchley et al., 2017; Ushiyama et al., 1991). In considering research design, Linden (1991) reported that in comparing oral versus written delivery of responses by participants, that oral responses demonstrated the most consistency in augmenting subjective distress, lowering overall performance, and increasing physiological responses.

One study by Absi et al. (1997) examined the effect size of arithmetic-based stress and the anticipatory stress of preparing for public speaking. They concluded that, while both increased cardiovascular, neuroendocrine, and psychological stress, the anticipatory stress to public speaking produced greater changes. Public speaking events also more closely resemble stresses of daily life than cognitive or physical stressors, suggesting greater validity in their utility (Matthews et al., 1992). The effects of public speaking stress reactions, however, may vary more widely due to differences in levels of speech anxiety amongst individuals (Feldman et al., 2004; Jaremko, 1980).

The Trier Social Stress Test (Kirschbaum et al., 1993) was developed as a stress induction technique for use in laboratory and research settings that incorporates both a 5-minute public speaking task and a subsequent 5-minute mental arithmetic task. Their original protocol was designed to induce a reliable stress response in a majority of healthy individuals (Kirschbaum et al., 1993). The Trier Social Stress Test, therefore, incorporates both elements of uncontrollable and socio-evaluative elements of stress induction that has been suggested to increase reliability as a stress induction technique (Dickerson & Kemeny, 2004). Additionally, the Trier Social Stress Test also allows researchers to compare changes between treatment groups (Kudielka et al., 2007).

Measurement of Stress Using Psychological Screeners

The use of psychological measurements has often been used in the literature on stress and music. In research, stress is often represented as either anxiety or stress, with little explanation for the difference. Endler and Parker (1990) highlight this issue and note that there is significant disagreement regarding the difference and similarity between anxiety and stress. One study by Ventura et al. (2012) noted a parallel decrease in reported anxiety levels and cortisol levels when listening to relaxing music, suggesting some correlation between psychological constructs of anxiety and neuroendocrinological markers of stress.

The concept of anticipation is crucial in understanding the relationship between anxiety and stress (Daviu et al., 2019). Stress reactions can be defined as an emergency state in response to a perceived threat. Anticipation is a response to psychological stressors (Koolhaas et al., 2011), and may or may not be concurrent with actual safety concerns.

State-Trait Anxiety Inventory

Originally developed by Spielberger (1983), the State-Trait Anxiety Inventory (STAI) is designed to measure and differentiate between temporary state anxiety and more long-standing trait anxiety. State anxiety can be defined as fear, nervousness, discomfort, and can be marked by arousal in the autonomic nervous system (Spielberger & Sydeman, 1994), and is measured across 20 statements that ask people to describe how they feel at a particular moment in time on a four-point Likert scale ranging from *not at all* to *very much so*. Trait anxiety, by comparison, defines how individuals feel across typical situations that arise daily; the STAI trait scale consists of 20 statements describing how people generally feel using the same Likert scale from *not at all* to *very much so*.

The State-Trait Anxiety Inventory (STAI) is also commonly utilized measurement of negative affect (Bados et al., 2010), and is also often used in research of distress amongst caregivers (Greene et al., 2017), university students (Deckro et al., 2002; Franzoi et al., 2020), and cancer and pain (Li et al., 2017; White, Nielson, et al., 2002), amongst others. A review of the State-Trait Anxiety Inventory by Novy et al. (1993) suggested that the STAI demonstrated appropriate validity across the most dominant ethnic groups in the United States: White, Black, and Latino populations. Further study suggests its validity in use with Asian/Pacific-Islander individuals with some caution surrounding certain items (Hishinuma et al., 2000). Nilsson (2008) conducted a meta-analysis on 42 studies of music and stress and identified that the most utilized assessment was the State-Trait Anxiety Inventory.

Despite its widespread use, the utilization of the STAI in research is not without concern. Barnes et al. (2002) conducted a meta-analysis of 816 research articles that utilized the STAI. They noted that 73% of their surveyed research ignored or did not mention reliability of the STAI at all, 21% of the research articles mentioned reliability or reported reliability coefficients from another source, and 6% computed and reported reliability for their own data (Barnes et al., 2002).

Subjective Units of Distress

Subjective units of distress scale (SUDs) were first described by Joseph Wolpe in 1969 (Wolpe, 1969). SUDs ask an individual to estimate their distress using a numerical, ordinal scale, and are often used clinically for the purposes of behavioral or exposure therapy (Wolpe, 1969) as well as in research on anxiety disorders (Milosevic & McCabe, 2015) and general stress (Kiyimba & O'Reilly, 2020; Morgan et al., 2002).

Of the studies reviewed, SUDs were the second most utilized measurement of stress. Many of the studies did not clearly state their reasoning for choosing a SUDs. In one study utilizing both a SUDs and the State-Trait Anxiety Inventory, Barnason et al. (1995) identified that there were no significant differences between the two measurements.

Beck Inventories

The Beck inventories are self-report measurements developed by Aaron Beck as a measurement of depression, anxiety, hopelessness. While these instruments have been established as valid for measuring constructs of depression (Wang & Gorenstein, 2013) and anxiety (Fydrich et al., 1992; Piotrowski, 1999), their utility in stress studies is not as well established. However, one study by Borden et al. (1991) identified that higher scores on the Beck Anxiety Inventory are positively correlated with greater subjective distress, suggesting that it may retain some utility when examining overall stress.

The Beck inventories are relatively easy to administer and take little time to complete them. Per the test-publisher for these scales, Pearson, the Beck Depression Inventory (BDI Beck Depression Inventory, n.d.) is estimated to take 5 minutes while the Beck Anxiety Inventory (BAI Beck Anxiety Inventory, n.d.) is estimated to take 5–10 minutes to complete. However, their ease-of-use may also be their greatest liability for research. While commonly utilized in both research and clinical applications, the Beck Anxiety Inventory tends to overidentify anxiety in females, underidentify them in males, and may be confounded by cultural diversity (Bardhoshi et al., 2016).

CHAPTER V: DISCUSSION OF CURRENT STRESS LITERATURE

The complexity of the stress response has resulted in numerous models of stress measurements. Within the literature reviewed, different outcome measures have been utilized to approximate the effects of stress within experimental conditions, including physiological, psychological, neurochemical, and endocrine changes.

Additionally, this literature review identified that many studies measured state-based anxiety as an estimate for an immediate stress reaction. State anxiety and stress are often used interchangeably in literature; however, different outcome measures are used. While some studies have attempted to establish the connection between stress and anxiety (Daviu et al., 2019; Ventura et al., 2012), there is still significant disagreement regarding the relationship between the two constructs. This conflation of the two constructs is not a new criticism, as evidenced by the article published by Endler and Parker (1990) noting a tendency in research to connect anxiety and stress despite a lack of agreement in the degree to which the concepts overlap. Based on current literature, it is likely that anxiety often induces a stress response, but that not all stressors are estimated appropriately through measures of anxiety.

Stress Induction

The multivariate aspect of stress suggests applicability of multiple methods of stress induction. While many different stress induction methods have been utilized in the context of stress studies, the Trier Social Stress Test (Kirschbaum et al., 1993) represented a methodology that was repeatable and cited across different studies (Linares et al., 2020). However, one notable challenge in this time it takes to induce stress using this method, taking 10 minutes for both the public speaking and the arithmetic tasks. While the Trier Social Stress Test has been positively correlated with the activation of the associated physiological and endocrine reactions of the hypothalamic-pituitary-adrenal axis (HPA), the psychological measurements of stress vary significantly and thus, the effect size is diminished. This seemingly corroborates the meta-analysis by Campbell and Ehlert (2012) on the Trier Social Stress Test, which suggested that the emotional reactivity, as measured by many of their reviewed studies, and the physiological reactivity to the tasks may be too weakly correlated in some individuals for it to be a consistently reliable stress induction technique.

Measurement of Stress Using Physiological Information

In one meta-analysis on music and stress, Nilsson (2008) identified that 24 of the 42 studies evaluated vital signs associated with stress reactions, including heart rate, blood pressure, respiratory rate, as well as various blood indicators. Of basic vital signs, blood pressure and heart rate were the most measured, whereas of the blood indicators, cortisol was the most measured stress indicator (Nilsson, 2008). Notably, of the studies reviewed by Nilsson (2008), seven studies utilized more than one physiological measurement of stress while the remaining 17 that evaluated vitals only included one measurement of stress. This reduction of stress measurements to a single physiological variable is noted in other similar studies. Pelletier (2004) provided a meta-analytic review of research using music to decrease arousal associated with stress. Out of 22 studies used for the meta-analysis, seven out of 21 studies used a physiological indicator of stress, all of which were reported as changes in heart rate (Pelletier, 2004).

Skin conductance measurements are also a frequent measurement of stress response in research. Khazan (2013) noted that skin conductance is generally a good predictor of emotional arousal because of its sensitivity to autonomic nervous system activity and not typically under voluntary control. This is aligned with a study by Jacobs et al. (1994) that identified that skin conductance increased in response to cognitive stressors and was not significantly affected by medications, such as beta blockers that may affect heart rate and blood pressure.

Yehuda (2011) identified that the physiological response to stress includes an increase in heart rate and blood pressure, an endocrinological response surrounding stress hormone, the resulting sympathetic nervous system response, and an immunological system reaction to stress. This largely corresponds with other research that suggests that heart rate and blood pressure increase during periods of stress reactivity (Hjortskov et al., 2004; Taelman et al., 2009).

Cortisol, a hormone released by the adrenal cortex, is an indicator of hypothalamic-pituitary-adrenal (HPA) activity, therefore salivary cortisol is often utilized as a physiological marker of endocrinological expression of stress. Hellhammer et al. (2009) note that salivary cortisol levels are considered a reliable measure of hypothalamus-pituitary-adrenal (HPA) axis adaptation to stress. However, the subtleties of salivary cortisol responses may lead to misinterpretation when used as a sole indicator of stress (Clow & Smyth, 2020). Collection of salivary cortisol is relatively simple and non-invasive. The saliva sample may be collected through drooling into a tube or using absorbent swabs that are inserted into the mouth until fully saturated. The samples can then be examined within a laboratory environment using sampling equipment.

Measurements associated with biofeedback are often used to provide real-time information about the stress response. A literature review conducted by Yu et al. (2018) identified that heart rate variability (HRV), multimodal biofeedback, respiration, heart rate, and skin conductance level (SCL) appear to be the most utilized methods of biofeedback for stress reduction. Models of biofeedback will be explored further in this review.

CHAPTER VI: BIOFEEDBACK IN CURRENT LITERATURE

For the purposes of this study, literature was reviewed for the purposes of determining best practices in psychophysiological measurements of stress rather than the utility of biofeedback alone as intervention. The term, biofeedback, was first used in 1969 to describe a "real-time physiological mirror" (Strobel, 1985). Biofeedback is an applied psychophysiological training that enables individuals to learn how to regulate their reactions to restore autonomic balance. Practices in biofeedback are intended to address the peripheral psychophysiological changes that are more easily observed because of a stress reaction. As described by Khazan (2013), the purpose of biofeedback is to raise and train awareness of cognitive, emotional, and physiological processes and increase efficacy of self-regulation of these processes.

Models of Biofeedback

Two primary models of biofeedback exist to explain the benefits of biofeedback as intervention: (a) operant conditioning and (b) mindfulness and relaxation practices. As participants engage in biofeedback practices, they first become more consciously aware of their physiological shifts. Through training, they are then expected to learn overt skills to modulate and regulate their physiology. As the participant becomes more familiar with these skills, the ability to shift physiology becomes more intuitive and takes less conscious effort.

Operant Conditioning

Operant conditioning is a model of learning that leverages reinforcement and punishment to modify voluntary behavior. In a typical biofeedback intervention, an individual is placed in front of a computer screen which displays feedback about their physiological state to build awareness. However, simply providing information is often insufficient to improve self-regulation; individuals must be taught using operant conditioning how to change their physiological reactions by providing real-time reinforcement while regulation attempts happen (McKee, 2008). As the individual increases appropriate activity or decreases inappropriate activity, feedback may be provided visually on the screen, verbally by the clinician, or through other pleasant responses to foster learning.

Mindfulness and Relaxation Practices

In addition to operant learning, biofeedback training often integrates self-regulation techniques of mindfulness practices or relaxation practices. Mindfulness and relaxation practices differ in their handling of stressors and discomfort, however, have similar efficacy for improving psychological and physical health outcomes (Astin et al., 2003). Mindfulness practices teach acceptance of present moment experiences while relaxation techniques teach strategies to change current experiences.

A meta-analysis by Sedlmeier et al. (2012) compared the effects of mindfulness and relaxation. They concluded that, while mindfulness and relaxation share common traits, their practices and effects are different; mindfulness was associated with larger effect sizes for most psychological outcomes while relaxation techniques were associated with greater physiological changes.

Biofeedback and Applied Psychophysiological Measurements

Psychophysiological stress reactions may commonly include one or some combination of heart rate (HR), heart rate variability (HRV), electromyography (EMG), skin conductance level (SCL), respiratory, and thermal measurements. Instrumentation used for biofeedback and applied psychophysiological practices are designed to provide precise and rapid feedback of changes in order to build awareness and support changes through the use of behavioral techniques.

When engaged, the sympathetic nervous system has an initial response delay of up to 5 seconds, with a maximum response typically observed after 20 to 30 seconds (Von Borell et al., 2007). The latency between presentation of a stressor and a sympathetic nervous system reaction may impact the utility of certain modalities to different sorts of stressors. Skin conductance reactions onset typically occur after 1,599 to 2,225 milliseconds, with tactile stimuli eliciting the quickest reaction, followed by auditory stimuli, with visual stimuli prompting the highest latency response (Sjouwerman & Lonsdorf, 2019). Changes in heart rate due to sympathetic nervous system activity tend to be slower, with peak effect observed after about 4 seconds; however, parasympathetic regulation typically have a short latency, with peak effect at about 0.5 seconds (Bernston et al., 1997). This suggests that HR and HRV may be better immediate measurements of a relaxation response than a stress reaction, unless taken within an appropriate context.

Heart Rate Variability and Heart Rate

The relationship between heart rate variability and stress is well-established in research. A search on November 11, 2021, of the terms “heart rate variability” and “stress” amongst peer-reviewed articles on the database, APA PsycInfo returned 1,522 articles published between 2011 and 2021 after accounting for duplicate articles. A meta-analysis by Castaldoet al. (2015) identified that heart rate variability was significantly restricted during times of acute, mental stress.

While much of the existing research examines the effects of stress on HRV (Boonnithi & Phongsuphap, 2011; Kim et al., 2018) or the effects of HRV biofeedback on stress (Goessl et al., 2017), fewer studies examine nuances of HRV measurement as it pertains to research design. One study by Pereira et al. (2017) established that HRV measurements of 50-second intervals were a reliable metric of varying stress levels.

Heart rate is measured as average beats per minute (bpm), and therefore provides an aggregated number rather than detailed information about heartbeat patterns. As a result, data from heart rate measurements may misrepresent the actual effects of nervous system arousal if averaged over too wide of a timeframe. Heart rate data is insufficient on its own to indicate and measure the stress response and is incorporated within measurements of HRV. HRV provides information on both heart rate and its variability across time. The impact of heart rate on HRV's predictive quality for stress reactions is less clear; one study by Sacha (2014) established that the removal of heart rate in HRV analyses makes HRV more predictive of non-cardiovascular health while including heart rate in the analysis improved predictability of cardiovascular health concerns. Consequently, biofeedback interventions that focus on reducing heart rate tend to focus more on stress inoculation tasks (Larkin et al., 1992).

Electromyography

Electromyography (EMG) is the recording and representation of electrical activity running along muscle tissue. Its utility in detecting changes in psychophysiological stress has been well-established, with cardiovascular arousal positively correlating with EMG activity (Lundberg et al., 1994).

The process by which muscle contraction is achieved starts with the motor units, which Shaffer and Neblett (2010) defined as the building blocks of skeletal muscle fibers. Each motor unit consists of three parts: a motor neuron in the spinal cord, the muscle fiber that it innervates or energizes, and an axon on the motor neuron that transmits electrical signals to the muscle fibers. Once the neuron sends the electrical signal down the axon, acetylcholine is released which stimulates muscle contraction. This process is achieved through generation of a muscle action potential (MAP).

A muscle action potential (MAP) occurs when there is a change in muscle cell membrane voltage from about -70mV to 30mV and then back to -70mV. At rest, the inside of the muscle cell is more negatively charged than the outside of the cell. Depolarization, where the voltage changes from -70mV to 30mV, is the first step of the action potential. This occurs as soon as the neuron receives an electrical signal to initiate a certain action, such as muscle contraction. If the initial electrical signal is not strong enough, the MAP will not be reached, and the muscle will not contract. If the signal is strong enough, the MAP is generated and moves down through the axon. Shaffer and Neblett (2010) noted that, therefore, sEMG recording sensors should be placed in the direction of the muscle fibers.

Surface electromyography measures the MAP as it occurs. Because the muscle action potential is either triggered or not triggered, it is the quantity of action potentials triggered rather than the strength of action potential that is measured through sEMG (Khazan, 2013). Therefore, muscles with larger amounts of muscle fiber, such as the muscles in the calf, will have larger amplitude of sEMG reading than muscles with smaller amounts of fibers, such as in the face. Because of this, sEMG readings can only be compared when using the same muscle group (Peek, 2016).

A review was conducted of peer-reviewed literature utilizing the keywords of stress, EMG. Studies were excluded if the purpose of EMG measurement was to treat a definitive medical concern or if findings were inconclusive to better generalize studies to overall stress reactions. Furthermore, studies were also excluded if they did not have a true experimental design or did not include a control group against which to compare. A total of 11 studies was reviewed that met the inclusion and exclusion criteria (Table 1).

While the frontalis muscle is often suggested as a good indicator of overall stress (Carlson, 1977; Freedman & Papsdorf, 1976), the upper trapezius muscles have generated more interest in stress studies in more recent years. The interest in the frontalis muscle stems from the assumption that increase and reduction in tension in the frontalis muscles generalizes to other muscle groups throughout the body (Alexander, 1975). However, muscle tension related stress reactions appear to have considerable individual variability (Wærsted et al., 1991; Westgaard & Bjørklund, 1987).

Table 1

Placement of EMG Electrodes

Author/Year	Number of participants	Age of participants	Muscle placement of EMG electrodes
Pourmohammadi & Maleki, 2020	34	20–37	Upper trapezius & erector spinae
Luijcks et al., 2014	70	18–65	Upper trapezius
Wijsman et al., 2013	30	19–53	Upper trapezius
Nilsen et al., 2007	44	21–61	Upper trapezius
Van Galen et al., 2002	20	Undergraduates	Biceps, Triceps, Flexor Carpi Ulnaris, & Extensor Carpi Radialis Longus
Lundberg et al., 1994	62	18–64	Upper trapezius
Pritchard & Wood, 1983	30	25–52	Frontalis
Passchier & Helm-Hylkema, 1981	20	17–62	Frontalis
Burish & Schwartz, 1980	56	Undergraduates	Frontalis
Carlson, 1977	48	Undergraduates	Frontalis
Alexander, 1975	28	Did not disclose	Frontalis, Forearm Extensor Muscles, & Leg Extensor Muscles

Skin Conductance

Skin conductance level (SCL) has also been defined as galvanic skin response (GSR) or electrodermal activity (EDA); the term skin conductance level will be used as a unified term for the purposes of this review. To measure skin conductance, sensors are used to measure the small variance in electrical conductivity within the skin as a measurement of arousal of the autonomic nervous system. SCL is generally considered the best predictor of emotional arousal because it is sensitive to autonomic nervous system activity and not generally under voluntary control (Khazan, 2013; Krumhansl, 1997; Rickard, 2004). Khazan (2013) noted that skin conductance is highly responsive to emotional and cognitive stressors.

Skin conductance is intimately tied with activation of the sympathetic nervous system. With increased sympathetic nervous system activity, eccrine sweat glands produce more moisture and salts, consequently, increasing conductivity of the skin. Sweat production by the eccrine glands is associated with the release of stress hormones (adrenaline and cortisol). Sweat gland activity, however, cannot be directly measured, and measurements of conductivity help to approximate amount of activation.

Skin conductance reactivity has been correlated with perioperative stress (Storm et al., 2002), pain (Harrison et al., 2006), depression (Lin et al., 2011), post-traumatic stress disorder (Hinrichs et al., 2017), and cognitive load (Nourbakhsh et al., 2012), suggesting that SCL is an appropriate measurement for cognitive and emotional stress reactions. Crucially, skin conductance responses appear in reaction to activation of the amygdala-driven, visceral experience of stress but not in the hippocampus-driven, declarative processing of stressful stimuli (Williams et al., 2001). This distinction suggests that immediate stressors are more likely to elicit a skin conductance response compared to more organized and declarative stressors, such as retelling a stressful experience.

Respiratory Biofeedback

Respiratory biofeedback measures breathing-related information, such as depth, frequency, and timing to help identify and learn specific breathing skills for relaxation and stress relief. Respiratory biofeedback measures may be completed using measurements of end-tidal carbon dioxide or through measurement of abdominal expansion and contraction, both of which provide different measures of breathing. End-tidal CO_2, the level of carbon dioxide released at the end of an exhaled breath, reflects the effectiveness of gas exchange during each breath. Breathing rate or volume may be estimated by measuring the pace of expansion and contraction of the abdomen. Pertaining to psychophysiological stress, lowered end-tidal CO_2 is often associated with the occurrence of hyperventilation, which may be seen as excess breathing rate or breathing volume. While breathing rate and volume may be easier to estimate, they may be insufficient in measuring respiratory reactivity to psychological stressors (Suess et al., 1980).

Breathing practices are one of the most common practices for stress management, with deep, controlled breathing techniques typically associated with stress reduction (Perciavalle et al., 2017). However, breathing practices that were shorter in length often fail to see noticeable changes in end-tidal CO_2 and its concurrent cardiovascular benefits (Conrad et al., 2007). The variability in predictive quality for breathing as a stress measurement aligns with findings by Tiwari et al. (2019), who suggested that the transferability of laboratory stress measurements to natural settings lacks in statistical power when not utilizing a more complex measurement of breathing.

Thermal Biofeedback

Thermal biofeedback is suggested to measure peripheral stress responses associated with changes in blood pressure, dilation and constriction of blood vessels, and its resulting changes in skin temperature. Thermal changes in stress tend to be more pronounced in body peripheries than in core temperature, with decreases at distal skin locations, such as at the hands and relatively unchanged skin temperature close to the heart (Vinkers et al., 2013). Thermal biofeedback readings are often accomplished using temperature probes or thermometers at the hands or fingers.

CHAPTER VII: DISCUSSION OF CURRENT BIOFEEDBACK LITERATURE

Yucha and Gilbert's (2004) review of efficacy of biofeedback for utilized a five-level stratification of treatment efficacy based on research available at the time, ranging from level one (not empirically supported) to level five (efficacious and specific). Conditions for which biofeedback was researched were rated based on the extensiveness, robustness, and specificity of research that had been done at that time.

Relating Yucha and Gilbert's (2004) review to the purpose of this conceptual-analytic study, the conditions most commonly associated with a stress reaction ranged from level two (possibly efficacious) to level four (efficacious). Of conditions commonly associated with stress; anxiety, headache in adults, hypertension, and temporomandibular disorders were rated as efficacious. Chronic pain, pediatric headaches, and insomnia were rated as probably efficacious (level three). Depressive disorders and post-traumatic stress disorder were rated as level two (possibly efficacious). Notably, more chronic conditions that are associated with long-term exposure to stress were also more likely to be rated within the possibly efficacious range, and include diabetes and Raynaud's disease.

This variance in efficacy levels may be explained simply by a lack of robust literature rather than truly being a measurement of treatment efficacy. Yucha and Gilbert (2004) also provide the distinction between biofeedback as treatment versus biofeedback as training, with the implicit difference being the level of participation. When utilized as intervention, biofeedback is often said to require active participation and practice between training sessions (Frank et al., 2010). Garnefksi and Kraaij (2006) stress the use of biofeedback as an approach to bring into awareness physiological reactions, validate beneficial use of strategies, and identify dysfunctional coping strategies. However, other researchers, such as Birbaumer et al. (2013)

suggest that changes may still occur through more passive participation. Thus, the specific mechanisms of biofeedback remain somewhat unclear.

Experimental research of stress requires a clear definition of the research objectives to best select which factors of stress are measured. Measurements of salivary cortisol are frequently used as a biomarker of stress due to the relative ease of collection. However, this method has certain limitations. In stress studies, saliva is often collected once pre-stressor and again post-stressor, allowing for direct comparison of cortisol levels in a controlled, repeatable fashion. However, due to the necessity of laboratory equipment to reliably measure levels of salivary cortisol, it is often prohibitive when taking real-time measurements. This may lead to an oversimplification of the stress induction and relaxation processes as well as miss valuable information about trends in the stress response.

A recurring limitation of all psychophysiological stress measurements is that they measure peripheral activity in the HPA axis. Whereas salivary cortisol is a measurement of adrenal cortex activity, the concurrent physiological measurements are estimates of the body's responses to the increase in cortisol and other neurotransmitters. Additionally, Rees (1989) suggested that stress is not simply a mechanical reaction, but a complex interaction of individual characteristics and affected by whether the individual has adequate support or skills to cope with the demands of a situation. This aligns with research indicating that correlations between autonomic nervous system biomarkers tends to be small (Lazarus et al., 1963), which suggests that limiting the number of biomarkers used in research may increase tendency to underrecognize or overgeneralize concepts of stress reactivity.

CHAPTER VIII: MUSIC, STRESS, AND BIOFEEDBACK LITERATURE

One study by Lundqvist et al. (2009) highlighted the physiological responses to music in facial muscle activity, changes in skin conductance, changes in finger temperature, and changes in heart rate. Facial muscle activity was measured using bipolar EMG readings. Heart rate was measured using a photo-plethysmograph probe to a finger. Skin conductance was recorded using two electrodes placed on the first and second finger. Finger temperature was measured using a temperature probe attached to the distal phalanx of the second finger of the left hand.

Burns et al. (2002) conducted a study into the effects of different types of music on perceived and physiological measures of stress. In their study, participants were asked to complete a Likert-type relaxation rating scall with 1 being “not relaxed at all” to 7 being “totally relaxed.” They were additionally administered the State-Trait Anxiety Inventory (STAI) as measurement of both transient and more chronic anxiety that may amplify the experience of stress. Physiological readings included measurement of skin temperature, frontalis muscle activity, and heart rate as an estimate of physiological arousal associated with a stress reaction. For their study, a stress reaction was induced using a cognitive stress task with the assumption that both the mental stressor and the anticipation of the stress would induce a significant enough stress reaction. Notably, results from their study revealed that the perceived experience of stress decreased, as evidenced by lowered scores on the STAI and self-report, across all music genres studied (hard rock, classical, and self-selected). In contrast, classical and self-selected music both generated a decrease in physiological arousal measurements, whereas listening to hard rock resulted in no significant change.

A meta-analysis by de Witte et al. (2020) concluded that music not only reduces physiological arousal, but also affects emotional states. Regarding research design, they identified that the type of psychological outcome measures (stress or state anxiety) was not a confounding variable across 104 randomized controlled trials of music interventions. In their review of literature, de Witte et al. (2020) also noted that physiological outcome measures did influence the effect size of research into music and stress reduction. Significantly stronger effects were found in research utilizing heart rate and heart rate variability measurements rather than blood pressure or salivary cortisol. De Witte et al. (2020) posited that this may be due to the more immediate changes that are observed in heart rate rather than the slower changes in blood pressure or salivary cortisol.

CHAPTER IX: OVERALL IMPRESSIONS OF MUSIC, STRESS, AND BIOFEEDBACK LITERATURE

There has been growing interest in understanding how music and stress in the past two decades. However, much of the research has followed a specific experimental design that focused on one music genre, utilized either group or individual interventions, or focused on a narrow age range (Hillecke et al., 2005). While many of the studies reviewed on music and stress utilized a quantitative research design, many of them did not meet criteria as a true experimental design. Many of the studies utilized measures that were designed primarily for single-instance stress and did not provide opportunities for pre-intervention and post-intervention data collection. Research that did provide pre- and post-intervention data often did not leverage a control group to provide comparison data.

The inconsistency of research design often makes it difficult to understand whether constructs are directly comparable between studies. An example of this is in the constructs of music-as-intervention compared to music therapy interventions. Notably, meta-analyses identified that music therapy, as provided by a music therapist, did not have greater effect sizes than music-as-intervention alone (Bradt, 2012; Bradt et al., 2013). However, another meta-analysis by Dileo and Bradt (2005) suggested that music therapy was more effective and suggested that this was due to the individually tailored nature of music therapy interventions. One possible explanation of this may be due to the increased number of studies reviewed between the 2005 meta-analysis and the more recent ones conducted partially by the same authors.

Results of the literature reviewed suggested that self-selected music tended to have the best outcomes in music-as-intervention. However, other research suggests no clear difference and that research-selected music has better outcomes than self-selected music when music was used as an adjunct for another intervention. A possible explanation for this discrepancy may be that the term “self-selected” is used differently between studies exploring these possibilities. While some studies allowed the participants to self-select from any music, others provided a limited sample of music from which selections were made. Additionally, because of the existing research-base suggesting certain features of relaxing music (i.e., music with a tempo of 60–80 bpm, sound volume between 60–80 dB, acoustic tonality, etc.), the selection of music that is made available on research-provided choices is often more limited.

A recurring theme in the literature surrounding stress, music, and biofeedback is the uncertainty of mechanisms and constructs within the research. Current applications of music to stress presume an effectiveness of music to evoke emotional and physical responses, but the literature on how music evokes those changes is still emerging. Indeed, some of this ambiguity exists because of the colossal task in understanding the specific facets of how stress and emotion are related.

Mechanisms of Stress, Music, and Relaxation

Existing research has rarely proposed a specific etiology of the interaction of music and stress. Music not only impacts physiological arousal and endocrine response, but also affects emotional states. There is no unifying understanding of how these processes interact, however, it may be that music impacts activation of certain brain regions, such as the amygdala, which is believed to manage emotional processes. Another theory may be that the emotional valence of listening to music interpreted as pleasing music impacts the cognitive appraisal of the situation and therefore impacts the physiological responses aligned with the Cannon-Bard theory of emotion.

Another possibly explanation for the mechanism of music-based stress reduction may be that music provides a sense of distraction from situations and thoughts that might otherwise be stress-inducing. While research tends to be inconsistent around the effectiveness of music as a tool for stress-inoculation (Thoma et al., 2013), the distractive effects of music interventions on acute stress reductions has been established in research (Linneman et al., 2015).

CHAPTER X: RECOMMENDATIONS FOR EXAMINING MUSIC, STRESS, AND BIOFEEDBACK

This study highlights some challenges which may hinder or introduce confounding factors into the interactive effects of music and stress reduction. Given the breadth of research designs and findings, it is premature to suggest a unified understanding of the psychological, psychophysiological, and neurological mechanisms as they relate to music. Not all studies face similar challenges in research design, however, a new model for research design may aid future research by addressing potential methodological problems.

Defining Variables and Constructs

For effective future research to take place, studies would benefit from providing more specific details of the variables involved regarding both the mode of music interventions, selection of music, and measurement of stress response.

Literature reviewed highlighted the ambiguous constructs of music, and specific key details should be made clear in the research design. Information about tempo, tonality and harmony, instrumentation, and frequency ranges should be identified more transparently in the music selection. Music-interventions should also be more clearly delineated between more passive interventions, such as music listening, or more active, such as playing an instrument or singing. Music therapy interventions, led by a music therapist, should be demarcated from other music interventions, as these are often more personalized to the individual and are likely to be influenced by the relationship between the music therapist and the participant.

Participant controlled factors should also be clearly considered. Personal responses by participants, including whether they were familiar or enjoyed the music selection, should be a part of research design and analysis. Future research design should also account for the differences in self-selected music versus research-selected music; music that is self-selected tends to predict better outcomes when used as a standalone intervention whereas research-selected music tends towards more significant differences when music is an augmentative factor rather than the primary intervention.

Current literature reviewed also tended towards single markers of stress, with fewer studies utilizing multiple biomarkers or psychological measurements. Because of the multifaceted nature of stress, it is understandably difficult to propose a unified construct of stress for the purposes of research. Additionally, real-time measurement of stress constructs tends to estimate neurological activation through peripheral changes. Few papers in this review examined which neurological pathways caused these biomarkers to be altered or explained why one biomarker was chosen over another. Heart rate and heart rate variability have been extensively covered in existing research, and future research should work to increase conversation about other biomarkers of stress reactivity.

For future research, skin conductance may also be a better research measurement for studies examining the relationship between stress and music. Skin conductance measures tend to be less sensitive, and therefore more consistent, to medications or other potential confounds that may impact some other biomarkers. Notably, habituation and normalization to cognitive stressors has also been associated with a decrease in SCL (Nourbakhsh et al., 2012), which may present an inherent challenge in research design that utilizes repeated tasks to induce stress. However, relying on singular biomarkers would be ignoring the complexity of the stress reactions and the individual differences between people. Future research would benefit from incorporating multiple biomarkers of stress to improve overall generalizability of results.

Many existing psychological measures of stress also have limitations in construct validity towards immediate stress reaction measurement. While measures, such as the State-Trait Anxiety

Inventory (STAXI), the Beck Depression Inventory (BDI) and Beck Anxiety Inventory (BAI) measure are commonly used in research, their utility is often more targeted at specific correlates of a stress reaction—anxiety and depression—at best, they estimate the immediate impact of stress on an individual. While this may suggest a call for development of new measures, the imprecision of current measures towards associated stress reactions may consequently provide a nuance towards understanding the practical applications of music-based or music-assisted interventions.

Accounting for Individual Preferences in Musical Taste

Generally, research on stress and music tends to be reductionistic and assumes that people's perception and preference for music and styles of music to be generalizable. Schäfer and Sedlmeier (2009) provide one approach to address this research limitation by asking participants to rate their preference for specific styles of music on Likert scales using four evaluative questions: "I like this music," "I couldn't live without this music," "I regularly visit clubs or concerts," "I just need this music," "I'm a passionate listener of this music," and "I usually spend a lot of money to purchase this music" (p. 285). A scale like this would allow for personal preference to be a core component in understanding the psychophysiological impact of music by first accounting for the level of preference an individual may have towards the chosen piece.

Recommendations for Researchers

Two specific research designs are proposed from this study. The first focuses on measuring the effectiveness of music-as-medicine. Another research design focuses on understanding real-time interactive mechanisms of music and psychophysiology.

Research Design for Music-as-Medicine

One research question that may be explored using the guidelines proposed by this study may be in identifying the differences between music-as-medicine, treatment as usual, and music-as-augmentation. Specifically, what differences in stress reduction are there between music-listening, progressive muscle relaxation, and music-assisted progressive muscle relaxation. While Robb (2000) completed a similar study examining the differences in perceived stress and relaxation following music-assisted progressive muscle relaxation, progressive muscle relaxation, music listening, and silence. However, there were certain limitations in the research design, including limitations in sample size (n = 60), no stress induction technique utilized, and measuring stress and relaxation through self-report without corroborating data.

To expand on the design, a future study should try to increase sample size to increase statistical power. Limitations of sample size in music research are discussed by Bradt (2012), and noted the difficulty in creating music intervention protocols, limiting effects studied to only music, and sampling and allocation based on convenience as reasons for the typically smaller sample sizes seen in music-intervention research. Specifically, Bradt (2012) also identified that the relationship between the participant and researcher may confound the data; warmth by the researcher may increase individual effects whereas researchers that appear more detached may negatively impact the effects of the intervention. In keeping with stage models for research, studies that have demonstrated adequate statistical power with smaller sample sizes may benefit from expanding the scope of sampling by reducing strictness of inclusion criteria, and therefore increasing potential for generalizability of the research. Consequently, Robb's (2000) study recruited participants from "an undergraduate health sciences class, a graduate counseling class, and the School of Law" at a "large midwestern university" (pp. 6–7). Therefore, an increase in recruitment is warranted in future research, potentially from other universities and healthcare centers. The primary control variable in the research by Robb (2000) was a period of silence; however, this may have also made it more difficult for recruitment or allocation of participants to different experimental groups. While unclear in the written research article, if participants knew that they may not receive an active intervention, there may have been greater increase in stress due to dissatisfaction within the control group compared to the experimental groups. Consequently, Robb's article did not mentioned any possible participant attrition as a result. Future, non-deception research design could make an effort to address this by using a comparison to a treatment-as-usual so that all participants understand that they are receiving some sort of intervention.

To expand on Robb's (2000) study, physiological measurements should also be utilized pre-stress induction, post-stress induction, during the interventional, and following the intervention. A similar research design by Scartelli (1984) comparing EMG biofeedback with music, EMG biofeedback alone, and music alone, suggests real-time measurement of physiological arousal through EMG measurement of the frontalis muscles. Given the number of studies suggesting the frontalis muscles as estimates of overall stress reactions, incorporating EMG readings into Robb's (2000) design is strongly suggested. Augmenting this information with other psychophysiological measures, such as HRV and SCL are also suggested, given the rate of response of SCL to stress induction and the rate of response of HRV to stress reduction.

Methodology. Following the recruitment period, participants will be randomly allocated to one of three groups: Progress muscle relaxation (PMR), progressive muscle relaxation with music (PMR+M), and music listening. Given the difficulties with blinding the direct researchers and participants, instructions for the studied techniques will be provided by an audio recording and the data interpretation will be done by blinded statisticians and other researchers. For purposes of this study, the PMR group will act as a treatment-as-usual comparison approach given its greater breadth of literature suggesting efficacy for stress reduction. Participants will be tested individually by randomly assigned researchers. Following a 10-minute interval that allows for participants to transition and adapt to the testing environment, participants will be connected primarily to three common biofeedback sensors, measuring electromyography at the frontalis muscles, HRV through the finger using a photoplethysmography sensor, and skin conductance using electrodes placed on the fingertips of the second (index) and fourth (ring) fingers. Obtaining this data pre-stress induction would allow for later analysis on the effectiveness of the stress induction technique and provide a homeostatic baseline to understand if the specific intervention was able to aid a person in returning to that baseline.

The Trier Social Stress Test (TSST) will be utilized as the stress-induction technique. Given the limited physiological stressors involved in the TSST, real-time EMG, HRV, and SCL measurements are not likely to be confounded by active physical movement. Immediately following the stress induction, participants will briefly rate their current stress levels using a subjective units of distress scale (SUDs) ranging from 1–10, with 10 being very stressed. participants will be instructed to perform their instructed intervention technique (PMR, PMR+M, and music listening). For the interventional groups, Daniel Kobialka's *Going Home Medley* will be played, as it meets many of the research-based criteria for ideal stress reduction. Additionally, given its length of 15 minutes, 34 seconds, the *Going Home Medley* aligns with common progressive muscle relaxation script length. Real-time psychophysiological measurements will be taken throughout the intervention to provide greater information about the trends of the stress reduction response. Following the completion of the research interventions, participants will be asked to sit quietly for another two minutes to establish a post-intervention baseline for their psychophysiological measurements. After the two minutes, participants will also be asked to complete a post-intervention SUDs, again ranging from 1–10.

Research Design for Understanding Relationship Between Music and Psychophysiology

A second study design based on the findings of this current research addresses the mechanistic relationships between music and psychophysiology. This research design may serve to provide information about the order of psychophysiological entrainment to tempo of music and understand if urges to move or sing along with music may evoke the entrainment response of heart rate or if heart rate entrainment occurs independently. This study may be best conducted as a mixed-methods, deception study to blind participants from intentionally skewing the data. As such, the hypotheses explored would include:

- Hypothesis 1: Moving along with music occurs before heart rate entrainment.
- Hypothesis 2: Singing along with music occurs before heart rate entrainment.
- Hypothesis 3: Heart rate entrainment occurs before an individual sings or moves along with music.
- Null hypothesis: There is no relationship between singing or moving along with music and entrainment effect observed in heart rate.

Methodology. Participants will be informed that this study is examining the effect of music and their physiological responses, and testing will be administered individually. At the outset of data collection, participants will be connected to commonly utilized biofeedback instruments measuring heart rate/heart rate variability (HR/HRV), electromyography (EMG), and breathing rate; sensors for heart rate and heart rate variability will be measured using a photoplethysmography sensor. One pair of EMG sensors will be placed on the abdomen and to measure movement commonly associated with dancing, singing, or humming; another pair of EMG sensors will be placed on the upper trapezius as an indicator of head nodding that is commonly associated with listening to music. Breathing rate will be assessed using a breathing belt measuring increase in abdominal circumference, which may also detect presence of singing or humming. Sensors will be placed prior to initial interview questions being asked to provide participants opportunities to normalize the sensations of the sensors. Following placement of sensors, individuals will be asked to name their favorite piece of music. They will then listen to that piece of music without additional instruction. Following their selected piece, Daniel Kolbialka's *Going Home Medley* will be played for them. They will then be asked to rate how much the *Going Home Medley* aligns with their musical preference or familiarity. The purpose of using both participant-selected and research-selected music is to have some ability to compare the intensity of the entrainment effect across multiple conditions. Following data collection, analysis of data will include comparison between EMG readings, breathing rate measurements, heart rate, and rhythm of all the pieces chosen.

Recommendations for Clinicians

While significant literature exists on the use of music therapy techniques, where selection of the musical intervention is done with the guidance of a music therapist, music-as-medicine techniques are less defined. Given the findings of this research, clinicians seeking to use music-as-medicine may benefit from completing a semi-structured questionnaire prior to selection and recommendation of music (see Appendix A). This questionnaire serves to provide insight into individual identification of present concern, pleasantness of emotional experience, emotional and physiological arousal, music preference, and feasibility and capacity to integrate music-as-medicine practices into their daily experience.

Pre- and post-measurement of stress within clinical work provides not only a way of measuring changes in levels of stress, but also in building motivation and engagement. Real-time feedback of psychophysiological signals within biofeedback serves not only to build insight, but also self-efficacy as an individual better learns to recognize, adapt to, and decrease psychophysiological arousal. Consequently, clinicians seeking to utilize music-as-medicine approaches would benefit from incorporating HRV and SCL measurements before, during, and following music-listening interventions. While most clients and patients may not have access to these instruments at home, providing them with the initial feedback may help provide confidence and motivation in using music-as-medicine throughout their daily routines.

Given the effect of preference in music-listening interventions, the clinician should work with the client or patient to identify music that satisfies research-backed criteria of relaxing music that is within their preferred style or genre. In particular, the clinician should collaboratively identify preferred music that maintains tempo like the human heartbeat at rest, has pleasing harmonies based on listener preference, maintains consistent volume at around 70db, and limits extreme variability in pitch. Once music has been identified, clinicians should help the client or patient identify ways to strategically integrate this into their daily routine, whether as specific music-listening time or as adjunctive to other activities, such as driving.

Additionally, the role of clinician warmth should not be dismissed to meet the research-supported music-as-medicine interventions. The relationship developed between the clinician and the person they treat also accounts for outcomes in reducing psychophysiological arousal. The *person-factor* or *person-effect* in biofeedback training, first described by Taub and School (1978), identified the importance of interpersonal dynamics and described that biofeedback training is itself a social situation. Similar phenomena were documented by Norcross (2002) where meta-analysis of psychotherapy factors identified that a predominant predictor of positive outcomes was in the therapeutic relationship. The importance of provider warmth has also been observed in medical practices (Burgoon et al., 1987; Howe et al., 2019). The preponderance of the clinician warmth in impacting outcomes across different disciplines suggests that ensuring a positive and collaborative relationship is important in considering implementation of intervention. Much like the role of music preference influencing potential outcomes, ensuring that the client or patient experiences a sense of warmth in the relationship should maximize efficacy of the chosen interventions.

CHAPTER XI: CONCLUSION

The purpose of research is to contribute to knowledge by both offering new conceptual information, to expand upon existing research, and encourage new paradigms of thought. This current conceptual-analytic study attempted to summarize and expand upon existing literature around music and stress and propose a more robust model for future research. This study focused on answering two primary questions: (a) what are the essential constructs in current research design exploring the affective properties of music, and (b) how should future research be constructed to study the psychological and physiological impacts of music as it relates to stress reduction?

The research questions of this current study can be framed within the ongoing discussion of the impact of nature versus nurture. What aspects of music engagement are generalizable at a species-level to all humans and what aspects are informed by the culture in which a person is raised and develops? An answer to this question would advance the understanding of the significance of music, and warrants an integration of cognitive, behavioral, neuroscientific, psychophysiological, and ethnographic research.

Prior literature has demonstrated that music is used by listeners to regulate mood and reduce stress (Boxberger, 1962; Tsai, 2007). In turn, there appears to be an increasing interest in understanding how music may affect physical health and emotional wellbeing. However, future research would benefit from greater understanding of the underlying mechanisms of music, stress, and wellness.

It is, perhaps, best to consider that the effect of music on stress is a consequence of multiple, intersecting mechanisms of action. Music may induce shifts in emotional and physical state in many ways. Juslin (2016) writes “more often than not, music is intentionally designed to stir our emotions, exploiting whatever means available" (p. 209). It is less a question about if music can affect the stress reaction, but more of a question on how to benefit most from music.

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APPENDIX A: MUSIC-AS-MEDICINE QUESTIONNAIRE

NAME: ______________________________________

DATE: ______________________________________

What specific concerns are you currently facing?

Please rate from 1-10 how pleasant of an emotional reaction you have with this concern:									
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9	☐ 10
Very unpleasant									Very pleasant

Please rate from 1-10 how intense of an emotional reaction you have with this concern:									
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	☐ 8	☐ 9	☐ 10
Very low intensity									Very high intensity

How does this concern affect you physically (i.e heart rate, breathing, sweating, muscle tension, body temperature, blood pressure, etc.)?

What types of music do you prefer to listen to?

What are some of your favorite songs, musical pieces, or musical artists?

How much time can you devote to listening to music?