THESIS

# DIFFERENCES IN CORTICAL ACTIVATION WITH LIVE MUSIC COMPARED TO RECORDED MUSIC: AN fNIRS STUDY

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ABSTRACT

DIFFERENCES IN CORTICAL ACTIVATION WITH LIVE MUSIC COMPARED TO RECORDED MUSIC: AN fNIRS STUDY

The purpose of this study was to compare and assess the neural activations during live music and recorded music engagement in neurotypical adults aged eighteen to sixty years old within a social context. The research questions sought to answer if cortical activations in areas of the brain involved with social interaction would be different in the live music conditions compared to the recorded music conditions and if blood oxygenation levels across the entire cortical surface would be different in any area across the four conditions.

This study was a within-subjects quasi-experimental design where each of the 32 recruited participants were exposed to all four conditions while mirroring the CR (clinician-researcher) in a tapping task. The four conditions were: recorded sung, recorded spoken, live sung, and live spoken. Participants were exposed to the four conditions as well as a rest condition in pseudo-randomized order. Each participant underwent five trials of each condition using a block design. Cortical activation was measured using functional near-infrared spectroscopy (fNIRS).

A total of 27 participants were included in the analyses. Imaging results revealed significant differences in inferred cortical activation during live stimuli compared to recorded stimuli, live music compared to recorded music, music stimuli compared to non-music stimuli, live music compared to all other conditions, and live spoken stimuli compared to recorded spoken stimuli in brain regions of interest and globally. Results support the possibility that live

music may have a greater effect than recorded music in regions of the brain that process social responses. Future research could better illuminate the comparisons of neural activations between live and recorded auditory stimuli.

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# CHAPTER ONE: INTRODUCTION

The comparison of live and recorded music delivery methods is a common topic in music research. Researchers have examined the differences between live and recorded music exposure using many different measures including physiological (Garunkstiene et al., 2013; Bush, 2018), behavioral (Holmes et al., 2006; Walworth, 2010), and psychological (Földes et al., 2017; Bieleninik et al., 2016; Horne-Thompson & Bolger, 2010). Although there is a foundation of behavioral, psychological, and physiological research comparing live and recorded music, there is no known neuroscience research examining differences in cortical activations between live music and recorded music. In the current study, functional near-infrared spectroscopy (fNIRS) will be used to detect differences of cortical blood flow when participants are exposed to speech, recorded music, and live music within a social context.

Understanding how music is processed in the brain is important to inform the profession of music therapy and other music-based healthcare professions. Music is a fundamental part of human existence and is part of our lives from birth until death, present at almost all milestones and events such as graduation, marriage, and funerals (Levitin, 2006). Music has both aesthetic and functional uses, including music for enjoyment purposes or music played as part of a ceremony. Furthermore, music has been used in music therapy to promote changes in motor, communication, and socioemotional outcomes in healthcare settings (de l'Etoile & LaGasse, 2013). In the United States, music therapy was established with a professional organization in 1950 (Davis et al., 2018), and the profession has grown due to advances in technology in neuroscience and neuroimaging (de l'Etoile & LaGasse, 2013). Through the neuroscience research that has been made possible with emerging technologies, music therapists have increased their understanding of how music can impact the brain and facilitate functional outcomes.

Although the neuroscience research on music and the brain continues to grow, there are no known studies investigating differences in brain activation when a person is exposed to live and recorded music. Exploring cortical responses to live and recorded music will elucidate the processes that occur with changes in the type of music delivery. This information will increase our understanding of how the brain responds to different methods of music delivery, which could inform music therapy clinical practice. This information may aid music therapists in clinical decision making on the type of music that could help a client reach their outcomes.

There are several different technologies that are used in the cognitive neurosciences for the purposes of measuring brain responses including functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), and Electroencephalography (EEG). fNIRS is used to measure cortical activations in the brain through cerebral blood flow changes, with the capability to create real-time maps of the hemodynamic responses (Pinti et al., 2018; Quaresima & Ferrari, 2019). fNIRS is one of the newer technologies, becoming more popular as a tool for research in the field of cognitive neuroscience over the past few decades (Pinti et al., 2018). One aspect that differentiates fNIRS from other technologies is the ability for the participant to engage in some movements, allowing researchers flexibility to mimic interventions that have an active engagement component (Hunt & Legge, 2015).

Although fNIRS could be a helpful tool to contribute towards neuroscience and music research, there are few studies using this technology to study music perception (Hunt & Legge, 2015). fNIRS allows for the measurement of brain tissue concentration changes of oxygenated ($HbO_2$) and deoxygenated (HbR) hemoglobin following neuronal activation in response to present, ongoing stimuli such as music (Pinti et al., 2018). Measurement of neuronal activity is possible through the use of near-infrared light shined into the head which can penetrate through the skull and into brain tissue. By using fNIRS to record activation in response to music stimuli, researchers can determine which areas of the brain are active during different presentations of musical stimuli.

There are specific aspects of fNIRS, that makes this technology potentially useful for music researchers. fNIRS caps are portable and have strong movement tolerability (Ferrari & Quaresima, 2012), an attribute which is necessary when researching active music making. Additionally, fNIRS is very safe and non-invasive, potentially meaning fNIRS could be used with diverse populations of varying ages, capabilities, and needs. Lastly, fNIRS is silent as opposed to a comparable cognitive neuroscience method, fMRI. Having silent technology helps to reduce the potential for extraneous variables due to environmental noise, creating a stronger tie from auditory stimulus to resulting cortical activation.

The purpose of this study is to assess neural activations during live music and recorded music engagement in neurotypical adults aged eighteen to sixty years old. Two additional conditions will be presented with live and recorded speech stimuli to ascertain if there is a significant difference in cortical activation when music is present. The experiment will involve a social experience where the clinician-researcher (CR) and participant are engaging in synchronous rhythmic tapping during either live or recorded musical stimuli.  The following research questions will be addressed:

1. Will cortical activations in the frontopolar area, orbitofrontal area, and the right pre-frontal cortex be different in the live music condition compared to the recorded music conditions?

2. Will blood oxygenation levels across the entire cortical surface yield significant differences in any area across the four conditions?

# CHAPTER TWO: LITERATURE REVIEW

This literature review will begin with an overview of cognitive neuroscience and go on to explore branches of cognitive neuroscience and music with considerations from the field of music therapy. To contextualize this experiment, it is necessary to understand the field of study that has made this research possible. The background and history of neuroscience will be shared along with specific information about functional Near-Infrared Spectroscopy (fNIRS), the measurement method that will be employed. From there, music and cognition will be dissected. Following basic information about how music is perceived and processed in the brain, there will be a transition to other areas of research to explore the difference between live and recorded music. Clinical relevance to music therapy will then be discussed with a focus on therapeutic interaction, and neuroscience-informed music therapy. To provide a frame of reference for interpreting the human interaction component of this study, the relationship between social processes and music will be explored.

## Cognitive Neuroscience

Cognitive neuroscience is a branch of neuroscience (Caramazza & Coltheart, 2006) in which scientists attempt to understand how the "brain represents mental events" (Albright et al., 2000, p. 612). One of the first papers written with the main theme of cognitive neuroscience was published in 1982 and titled "Cognitive Neuroscience: Developments Toward a Science of Synthesis." The authors posited that a merging of cognitive science and neuroscience would serve to create a field where researchers could further understand the relationship between mind and brain processes (Posner, Pea, & Volpe, 1982). A more comprehensive definition of the field is articulated by Raichle (1998): "Cognitive neuroscience combines the experimental strategies of cognitive psychology with various techniques to actually examine how brain function supports mental activities. Leading this research in normal humans are the techniques of functional brain imaging" (p. 765).

*Basic Principles of Cognitive Neuroscience*

Cognitive neuroscientists typically use brain-imaging technology to determine which brain regions are associated with a given perception or behavior (Raichle, 2010). An experimenter can manipulate the mental state or brain processes of a participant through presenting different conditions and then comparing the changes in neural activity through their chosen measurement method (Dijkstra & de Bruin, 2016). The strength of temporal and spatial resolution varies depending on the technology. Temporal resolution indicates when a cognitive process happens and spatial resolution indicates where the activity is occurring (Varvatsoulias, 2013). Choosing the right set of conditions is a key component of cognitive neuroscience research, as the independent variable must be able to be isolated while the dependent variables must be controlled. One of the strategies used to determine that a task is associated with an increase of activation in a brain area is called cognitive subtraction. Cognitive subtraction is the process of examining the differences between control and experimental conditions that are intended to differ in only the independent variable (Harrison & Pantelis, 2010). For example, a researcher may present visual stimuli of famous faces followed by visual stimuli of non-famous faces. Through cognitive subtraction, the researcher can take the data from both conditions and note the differences. Although cognitive subtraction has limitations which can lead to incorrect interpretations of data (Jun & Yoo, 2018), the strategy remains a part of the foundation of cognitive neuroscience.

Another critical point of understanding in modern cognitive neuroscience is the perception that cognition stems from the "integrated activity of large-scale distributed networks of brain regions" (Meehan & Bressler, 2012, p. 2231), as opposed to previous ideas that cognitive functions could be mapped and localized on separate, individual brain regions (Meehan & Bressler, 2012). Cognitive neuroscience has moved from a modular paradigm into an emerging paradigm where more recent evidence is aligning with the idea that cognitive functions surface from interactions within and between brain systems (Bressler & Menon, 2010). Interpreting data from brain imaging studies is complex and it can be difficult for researchers to draw clear conclusions. Findings are contextual dependent on the conditions in the experiment as well as the inner-workings of brains at any given moment.

A misconception regarding the interpretation of cortical activation that has persisted despite numerous findings indicating otherwise is that brain areas are only activated during a given behavior when needed for a particular task (Raichle, 2010). However, there is constant activity happening in the human brain-even when a person is at rest. The brain system that operates when the mind is at rest is known as the default mode network (Raichle, 2010). The discovery of the default mode network has helped to create understanding of data interpretation in cognitive neuroscience research. Some areas of the brain may be more active for one task than another, but researchers cannot necessarily show that a brain area is needed for a task.

*Technologies used in Cognitive Neuroscience Research*

There are several different technologies that cognitive neuroscientists have utilized to study the relationship between mind and brain. These include, but are not limited to, Positron Emission Tomography (PET), functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), Magnetoencephalography (MEG), Computerized Tomography (CT) and functional Near-Infrared Spectroscopy (fNIRS). The method a researcher chooses is dependent on the research questions at hand as well as availability of the required technology.

There are advantages and disadvantages of each method. Considerations must include needed spatial and/or temporal resolution, cost, ecological validity concerns, invasiveness, experiment conditions (e.g. movement requirements for participants may result in choosing a method that can account for movement artifacts) and more.

**functional Near-Infrared Spectroscopy**

Functional near-infrared spectroscopy is a neuroimaging technology begun in 1992 and is based on principles founded by Jöbsis (1977) who reported that the transparency of brain tissue in the NIR reach (how deep NIR light can travel) allows for non-invasive detection and recording of hemoglobin oxygenation through transillumination spectroscopy. The first fNIRS study was conducted in 1992 by Hoshi and Tamura (1993). The researchers used a single channel continuous wave system to observe bilateral prefrontal cortex oxygenation changes (Ferrari & Quaresima, 2012). More recent systems can have as many as 128 channels, there are wireless and portable systems, and applications for fNIRS continue to grow (Ferrari & Quaresima, 2012).

fNIRS detects and measures the changes that occur in blood oxygenation (Strait & Scheutz, 2014). fNIRS works by distributing light through the skull and cerebral spinal fluid to the brain. The NIR light is "either absorbed by pigmented compounds (chromophores) or scattered through the tissues" (Ferrari & Quaresima, 2012, p. 923). The blood vessels absorb the light which is relayed depending on hemoglobin which allows for information gathering in terms of oxygenation changes (Ferrari & Quaresima, 2012).

fNIRS is developing into a viable method for neuroimaging methods; however, there are benefits and limitations. This neuroimaging technique is non-invasive, portable, and cost-effective. fNIRS allows for head and body movements, allowing for the participant to engage in limited mobile activity during neuroimaging. fNIRS is capable of providing both spatial and temporal resolution, although the spatial coverage and spatial resolution is limited (Sun et al., 2018). fNIRS has a "higher sampling rate than PET/fMRI" (Zhang et al., 2010, p. 1151) although "NIRS provides lower spatial resolution compared to PET and MRI neuroimaging systems" (Moghimi et al., 2012, p. 8). However, fNIRS provides better or more refined spatial resolution than EEG or MEG (Zhang et al., 2010). Additionally, scientists using fNIRS can only obtain information on cortical structures, as the light cannot extend to subcortical areas (Wilcox and Biondi, 2015). Benefits of using fNIRS over other functional neuroimaging methods include lower cost, less constraints induced or created by the scanning environment, and a more comfortable environment (Ferrari & Quaresima, 2012) resulting in less potential for harm overall. fNIRS researchers use light that does not cause any harm or discomfort. There are few risks associated with fNIRS. The strongest risk in using fNIRS is minimal at best, which is potential discomfort for the participant as the cap can become tight, creating pressure on the scalp over lengthy experiments.

Although fNIRS may not be a feasible method for studying structures deep in the brain, there is evidence that it is a viable technique for investigating many areas involved with social cognition. Sun et al. (2018) endeavored to discover the feasibility of fNIRS to investigate the mirror neuron system which is reported to occupy four major regions of the brain. Their research question was if fNIRS could detect the Mirror Neuron System (a possible neural mechanism of social interaction) in these four areas, which are related to the social cognitive neurosciences. The four regions are the pre-motor cortex, inferior frontal gyrus, superior parietal lobule, and rostral inferior parietal lobule. Sun and colleagues (2018) found that it was feasible and the four brain areas were involved in both conditions meant to engaged the MNS.

*fNIRS and Music*

There are currently few fNIRS studies involving music, primarily based in passive music listening. Bigliassi, Barreto-Silva, Kantahck, and Altimari conducted a study (2014) where fNIRS was used to investigate cortical phenomena influenced by musical stimuli while accounting for gender differences. This study examined the activation in the pre-frontal cortex (PFC), as the PFC plays a role in control of feelings and interpretation of feelings (Bigliassi et al., 2014). One area examined was the difference in PFC oxygenation in men and women when listening to different music genres. The results indicated that there was a difference between genders as women had lower PFC blood flow values for most of the genres. Another notable result from the Bigliassi study is that the songs chosen by the participants changed blood flow in the PFC in both hemispheres in greater amounts that other song/genre conditions indicating preferential music may result in different activation in the brain than therapist-selected music. Researchers examining the PFC's response to music have also used fNIRS to investigate the effect of emotionally-laden music on the PFC activation (Moghimi et al., 2012). In addition to the previous studies, researchers using fNIRS found that music can lessen the demand of the PFC while simultaneously enhancing short-term memory in healthy young adults (Ferreri et al., 2013).

**Music Cognition**

Music is a complex stimulus comprised of many elements that vary greatly from one auditory pattern to the next. Tones can vary in "pitch, duration, amplitude, and timbre" (Stalinski and Schellenberg, 2012, p. 486) and yet young listeners can perceive and remember pieces of music (Stalinksi and Schellenberg, 2012). Even more fascinating is the great extent to which music can elicit strong emotion, capture and regulate attention, shift mood states, and contribute overall to our well-being (Pearce & Rohrmeier, 2012). Music cognition research draws from multiple disciplines including experimental psychology, music theory, musicology, computer science, biology, psychophysics, neuroscience, and more to better understand how the brain processes and perceives music and how that manifests in our lives (Tirovolas and Levitin, 2011).

Pearce and Rohrmeir (2012) proposed three possible answers to the question of why music cognition should be of interest to those in the cognitive sciences: Music is a core human trait, music played a role in human evolution and development, and the cornucopia of basic cognitive mechanisms involved in musical behaviors. Early developments of music cognition focused on cognitive processing of musical structure and in later years have shifted to the study of how we perceive music through the lens that music is a uniquely human trait (Pearce and Rohrmeier, 2012). In short, music cognition research helps us to understand human history, physiology, and ourselves as individuals and as members of society and community.

*Cortical Activation and Music*

The brain responds to music stimuli in varied and dynamic ways. Our neural responses to merely hearing a musical composition are complex due to interactions between areas of the brain working together to result in our perception of the musical piece (Stegemöller, 2018**)**. In one musical composition, there are several singular elements or attributes of music that can be manipulated and activate the brain. Processing music involves many areas of the brain including networks involved in cognitive, auditory, motor, visual, and sensory areas (Stegemöller, 2018). Levitin and Tirovolas wrote that "music is characterized by eight perceptual attributes, or dimensions, each of which can be varied independently: pitch, rhythm, timbre, tempo, meter, contour, loudness, and spatial location" (2009, p. 213). For example, when rhythmic patterns are perceived, active areas in the neurotypical brain include the cerebellum, basal ganglia, the premotor cortex, and the supplementary motor area (Levitin & Tirovolas, 2009).

Many different aspects of music have been studied in the neuroscience literature. Researchers have been able to separate out the parts of music and how they influence the brain. For example, when pleasant/consonant music is perceived, "music activates orbitofrontal, subcallosal cingulate, and frontal polar cortical areas" (Levitin and Tirovolas, 2009, p. 219). In an early neuroimaging study, researchers using PET examined cerebral blood flow changes when listening to pleasurable music (or "chill-inducing" music) self-selected by the participants. Blood and Zatorre (2001) found that activation was strong in the same areas that of the brain such as the orbitofrontal cortex and the amygdala that are linked to pleasure and reward, setting the stage for many research studies to follow. Music engages areas all over the brain, bilaterally, and shares networks with many non-musical networks. This factor supports the profession of music therapy. If music gives the clinician access to different parts of the brain, then change is possible where music and functional skills occupy the same space. For example, Zatorre & Peretz (2005), wrote "some of these regions might not only overlap but might also share processing components with other functions, such as those involved in language" (p. 105).

There is still much to learn about the interaction of music in the brain and researchers are continually gaining new insight. In just the past few years, researchers have indicated that there is the potential for neural networks that are specific to the processing of music (Armony et al., 2015) located within the anterior superior temporal gyrus. While there are numerous resources delineating areas of music and neuroscience, further progress will bring a greater understanding of the value that music holds within and outside of therapeutic settings. One of the areas needed to explore is the brain's interaction with live music as compared to recorded music. We know that listening to music promotes pleasure responses and that brain imaging studies show that music listening stimulates brain regions that are involved in reward/motivation, emotion, and arousal (Lamont, 2011), but there is a dearth of literature that examines the differences between listening to live and recorded music.

**Live and Recorded Music: Comparison Studies**

We experience music in many different settings, places, and situations. One situational aspect of music listening is whether the method of delivery is live or recorded. There are inherent differences between live and recorded music, including possible psychoacoustic and social factors. For example, when listening to recorded music you may be alone or listening with others; however, the music is produced through a device with no instrumentation or performer present. With live music listening, there is an individual listening and an individual performing, which adds a potential social context to the experience. The properties of music may also be different in these two methods of delivery including volume, vibrations from the instrument(s), and sound quality. Other factors that may influence responses to music include additional people listening (group listening) and the location (Balteș & Miu, 2014). In this way, live and recorded music experience may differ in many aspects that could change the response to the music.

The different aspects of live and recorded music have been linked to emotional experiences within music. For example, Lamont (2011) analyzed 46 university students' free reports on music-listening experiences and found that students reported that they were most likely to have strong positive experiences of music listening if they were in a live music situation (2011). Aligning with this perspective, Swarbrick et al. posited that people both enjoy the social elements present when experiencing music with other people and the feeling of being connected with the performers (2019). Although these factors may indicate that live music have greater potential advantages than recorded music, there is a need for research to establish stronger understanding of the ways or reasons that humans may be more inclined towards live music listening.

Researchers have investigated the impact of different methods of music delivery in music-based interventions in many different settings and with many different populations. In a meta-analysis of music therapy with preterm infants and their parents, researchers chose to analyze the intervention that used live music when there was greater than one treatment condition with music included so as to compare the means and standard deviations of one experimental condition (music) and one control condition (non-music). They noted that this preference for live music was "consistent with active [music therapy] approaches that are individually tailored to infant and infant/parent dyadic responses" (Bieleninik et al., 2016, p.3). In another study with infants, Researchers compared the physiologic effects of live music, recorded music, and a control condition was completed with 35 stable preterm infants. The infants' heart rate decreased significantly for both music groups, no significant difference was observed in oxygen saturation levels (Garunkstiene et al., 2014). In the live music condition, deeper sleep was reported than the remaining two conditions (Garunkstiene et al., 2014).

Researchers have compared live and recorded music interventions in the pediatric setting. Bush (2018) measured the effect of live music therapy interventions on heart rate, blood pressure, and respiratory rate in critically ill pediatric patients aged birth to two years of age using live, preferred music and compared the experimental group to a control group which received recorded, preferred music. Bush reported that live music therapy interventions reduced heart rate, respiratory rate, and mean arterial pressure, although of those three, only heart rate showed significant results. The recorded music interventions did not produce significant results and showed a slight increase in respiratory rate and heart rate. A limitation of this study was a small sample size of n=10.

There has been research comparing live and recorded music interventions with adults. In 2010, Walworth conducted a study to determine the effect of live music therapy versus recorded music on patients undergoing MRI scans. The researchers were interested in determining the most effective intervention for anxiety during scans in an effort to reduce movement artifacts resulting from anxiety as well as decreasing discomfort and anxiety during the experience. Walworth reported that patients receiving live music therapy “had fewer scans repeated due to movement” and also requested fewer breaks during the scans (p. 344). Walworth concluded that there is preliminary evidence of the possible benefits of live music therapy and furthermore stated that this evidence looks promising for protocol changes in the future. A similar study looked at anxiety levels of patients undergoing MRI imaging procedures but measured self-reported anxiety levels and used no live music condition. Of the three conditions, nonmusic (control), recorded music synchronized to the pulsation of the MRI device, and recorded music with random consistent tempo, participants in the music groups reported that the experience was significantly more pleasant which highlights the value of recorded music in this setting (Földes, et al., 2017). Participants noting that the recorded music conditions elicited a more positive experience indicates that the presence of music alone could influence data in a neuroscience study where researchers are examining cortical activation differences between live and recorded music.

Live and recorded music has also been studied for adults with amyotrophic lateral sclerosis with interest in anxiety levels. Patients with amyotrophic lateral sclerosis were given pretests and posttests to determine perceived anxiety levels after taking part in either a recorded music therapy session, a live music therapy session, and a control condition with an activity, like reading or watching a television show (Horne-Thompson & Bolger, 2010). The researchers of this study found no significant differences between any of the groups, although the authors noted that 81% of the participants reported little or no anxiety prior to the interventions as a possible limitation.

Within the research base of older adults, researchers have published papers on live versus recorded music as well. Holems (2006) investigated 32 patients with dementia by comparing live interactive music with passive pre-recorded music to a baseline of silence for thirty-minutes. In this study, it was determined that positive behaviors, indicating increased engagement (as reported by raters), were more prevalent in the group with live music than the recorded music group. Both of the music groups had more positive behavioral interactions than the control group of no music (Holmes et al., 2006). This research indicates that music is useful tool within the population of patients with dementia overall, but that live music may be more advantageous for stimulating positive pro-social behaviors. However, a clean comparison between live and recorded music cannot be made as this study included the confound of interactivity and passivity.

**Relevant Neurophysiologic Research**

There is currently no known neuroscience research investigating cortical activations present during live and recorded music. However, researchers have created studies that look at neurologic responses to varied auditory stimuli in the form of spoken communication that are presented either live or recorded. These studies provide insights into whether there may be an expected difference in neural processing when presented with live or recorded stimuli and where increased activation between conditions may be expected by researchers comparing live and recorded music. For example, Shimada and Hiraki (2006) sought to discover whether human infants perceived live stimuli in the same way as infants perceive televised stimuli. Using fNIRS technology, the researchers specified their region of interest (ROI) as the sensorimotor area and monitored activation of the ROI while infants observed live movement stimuli and while the infants observed televised movement stimuli. Both of these conditions were compared to a control condition where the infants were themselves performing actions. In the live movement condition, the infant's motor areas were significantly activated, while the recorded movement condition did not produce significant activation. The authors suggested that the human brain responds differently to the real world and the virtual world. Similar to the previous study, researchers have "examined brain responses during both social and non-social movies (Movie format), and during a naturalistic live interaction (Live Action format) in which infants could pay attention to either social or nonsocial features" (Jones et al., 2015, p. 844) using EEG. Researchers in this study saw a greater difference in EEG activity in the live, naturalistic setting. McDonald and Perdue cited both these studies as support for using live and naturalistic stimuli in fNIRS studies to examine social responses stating that these studies "suggest that the use of live social stimuli may prove to be a more powerful elicitor of social brain responses" (McDonald & Perdue, 2018, p. 44).

Sulpizio and colleagues (2018) compared neural activations in infants when exposed to recorded adult directed speech and infant directed speech. Varied auditory stimuli were expected to produce different effects, specifically that greater variations in pitch may cause greater activation in the right pre-frontal cortex. Infant directed speech typically exhibits greater variation in pitch and timbre than adult directed speech and that greater variation in pitch may cause greater activation in the right pre-frontal cortex as the "right prefrontal cortex has a role in judging variations in pitch of speech in adults" (Sulpizio et al., 2018, p. 91). This indicates that this area of the brain may also be active when listening to music with melody, which inherently has pitch variations. The prefrontal cortex is also tied to complex social behavior (Grossman, 2013). Another region of the brain that may be affected by changes in pitch is the orbitofrontal cortex, an area involved in emotional regulation (Sulpizio et al., 2018). Therefore, comparing music to non-music conditions where pitch is naturally varied, may elicit greater activation in the right pre-frontal cortex as well as the orbitofrontal cortex. Additionally, the frontopolar area is of interest in a study utilizing a social lens as mature brains' frontopolar area is "connected to the superior temporal sulcus and gyrus which are associated with the interpretation of social signals, including emotions of others" (Sulpizio et al., 2018, p.91). Therefore, changing the levels of social stimuli in the presentation of music could contribute towards differences in cortical activation in the frontopolar area, superior temporal sulcus and gyrus.

**Relevance to Clinical Music Therapy**

Music therapists use a clinical process to determine many aspects of the session including what type of musical interaction would most benefit the client and how different components of music facilitation may positively impact the client's goals (Hanson-Abromeit, 2015). These choices made about the music are informed by years of musical training, clinical experience, and interpretation of best available research (Kern, 2010). Although there are studies comparing live and recorded music, many music therapy researchers have noted that more research is needed on method of music delivery, including live and recorded music (Yinger, 2018).

According to Robb, Carpenter & Burns (2011), the type of music delivery can impact the clinical treatment and therefore, clearly identifying aspects of music, including music delivery method, is important for music therapy clinical relevance. In a systematic review of music-based interventions in the medical setting that included 187 papers, 12% of the single music component interventions reviewed used live music and 88% used recorded music (Robb et al., 2018, p.30). Although many music therapy clinical papers supported the use of live music, this systematic review seems to highlight a trend for using recorded music interventions in the healthcare setting. Further research is needed to understand if there are differences in music processing in order to inform clinicians how to select the type of music delivery.

Music therapy clinical research has highlighted a need for further research of music delivery methods and the consistency with which they are reported. Researchers have indicated that variations in music delivery may influence results. Silverman (2009) stated that live music may have more favorable components than recorded music; however, this has yet to be documented for the mental health setting. Ghetti (2012) suggested that live or recorded music can be used in procedural support, but determined that the majority of the authors in her analysis recommended live music for the adaptability potential when working with a patient. Bradt and Dileo (2014) stated that live music delivery can provide humanizing and validating experiences for the patient (Bradt and Dileo, 2014), an aspect that may not be present in recorded music delivery. Although these researchers indicate that there may be differences in music therapy treatment based on music delivery method, there are no data indicating how the client responds on a neurophysiological level to different methods of music delivery.

Music therapists practicing from a neuroscience-approach based their clinical decisions on the science of music perception and production (Sena Moore & LaGasse, 2018). In this approach, music therapists attempt to understand how music impacts the brain and, based on this information, how music can be use in a therapeutic context. In other words, best practice involves knowing the mechanisms of the interventions that facilitate change (Michie et al., 2009). For instance, the increased understanding of how rhythm impacts motor movement has helped with the establishment of clinical techniques facilitating motor rehabilitation (LaGasse & Thaut, 2013). Establishing initial information about how music impacts the brain can help inform music therapy research and treatment. Researchers have indicated that more research is needed in the neuroscience of music perception and production, an idea that is clear in the 2017-2019 NIH Sound Health initiative, where neuroscientists, musicians, and music therapists worked collaboratively in an effort to better understand the neuroscience of music and how this information can impact practice (About Sound Health, n.d.).

As indicated by Bradt and Dileo (2015), social connection is also an aspect of music therapy intervention. Magee & Stewart (2015) posit "Music can be a useful medium to work on interpersonal issues for a number of reasons. Within a musical interaction, you can sing "with" a person, not simply sing "at" or "to" one another; you improvise, listen, attune and respond using imitation or reflection" (p. 3). Therefore, the music therapy experience is inherently tied to a social interaction. However, most neurophysiological research on music perception has lacked any social aspect (Hunt, 2015). Therefore, introducing the social aspect will serve to function as creating a naturalistic setting for which to interpret data collected from stimulus input.

**Social Responses to Music**

All humans are equipped with the ability to participate in music and to interact with others through music. Starting in the fetus, spontaneous movement to music in the final stages of gestation has been observed (Novembre et al., 2015). This [the human predisposition to physically react to music and to engage with others through music] "develops through infancy into more complex forms of action and interactions such as dance and collaborative music making" (Novembre et al., 2015, p. 2). In infancy, imitation is one of the foundational social skills that infants use to learn about themselves, and the world around them. Imitation is a distinctive tool for early human learning while also promoting bonding and interpersonal affiliation (Meltzoff & Marshall, 2018). Many social functions including imitation are embedded in music making between two or more individuals, at the core of which is social contact with another human (Koelsch, 2015).  Koelsch stated that: "The ability and the need to engage in these social functions are part of what makes us human, and the emotional effects of engaging in these functions include experiences of reward, fun, joy, and happiness" (2015, p. 198).

Music on its own is inherently a social activity. Music facilitates social bonding through important events from weddings to funerals, connects people through lyrics and shared emotional reactions, and brings people together in group music making experiences, dances, and religion. In an article discussing the interplay between the psychology of music and the psychology of well-being, Croom provides support that music can influence our emotional states which affect our relationships, facilitate joint action, interpersonal coordination, social bonding, and engagement (2012). Music can serve to promote positive social behaviors in therapeutic settings as well. In music therapy settings, the client is actively learning through engagement with music in a social context of working with the music therapist. Having the opportunity to practice social skills within a musical context is a way to "strengthen social skills generally" (Spiro & Himberg, 2016, p. 4).

Additionally, when two people are making music together there is the opportunity for synchronicity allowing for further development of a trusting relationship, or prosocial behavior. Kokal, Engle, Kirschner & Keysers (2011) found that participants were more likely to pick up a pencil dropped by the experimenter when they had just drummed in synchrony than when they were drumming in asynchrony. Furthermore, moving together, or performing a joint action can be facilitated with music. Due to the "temporal predictability" of music, two or more people are able to synchronize their movements and engage in a shared experience (Chang et al., 2017). This shared experience can serve to promote social bonding. Rhythm itself is a main function of human behavior. Breathing, walking, and heartbeat, all are natural parts of human behavior that are inherently rhythmical. These endogenous behaviors can "become aligned in phase and frequency within an individual and between individuals" and "the temporal patterns of an individual or a group of individuals can become entrained to an external timekeeper" (Stupacher et al., 2017, p. 159). With music creating a structure for synchronization, there are increased possibilities for social connection within rhythmic organization. For example, the caudate is an area of the brain that is linked to "synchronizing, reward and prosocial behavior" (Kokal et al., 2011, p. 9) and in a synchronous drumming study utilizing fMRI methods, Kokal and colleagues found that participants who were proficient in the target rhythm exhibited an increase of activity in the bilateral caudate when their drumming partner played in synchrony with them. The researchers also noted that the amount of "activity in the right caudate during synchronous drumming predicted the level of prosocial commitment" (Kokal et al., 2011, p. 11).

**Purpose of Research**

There are no studies that examine the differences in cortical activation between live and recorded music stimuli. The present study may be the first to record and measure cortical activations in the brain between live and recorded music presented in a social context involving the clinician/researcher and participant. This information will provide initial information about the level of activation in cortical areas of the brain during social interactions when exposed to varied auditory stimuli which will increase the neuroscience of music literature. In this effort, the purpose of this study is to determine if there is a difference in cortical activation across the four conditions and answer the following questions:

1). Will cortical activation in the frontopolar area, orbitofrontal area, and the right pre-frontal cortex be different in the live condition when compared to the recorded conditions?

2). Will blood oxygenation levels across the entire cortical surface yield significant differences in any area across the four conditions?

# CHAPTER THREE: METHOD

## Study Design

This study was a within-subjects quasi-experimental design where each participant was exposed to all four conditions in pseudo-randomized order. Pseudo randomization was achieved by randomizing conditions on a spreadsheet and then manually editing the document if pre-specified undesirable sequences occurred. The primary example of an undesirable sequence was if rest conditions were all occurring consecutively. There were four conditions: recorded sung, recorded spoken, live sung, and live spoken. Each participant underwent five trials of each condition using a block design. This was to help ascertain differences in cortical activation among conditions presented to each participant. In order to have a live condition, the clinician-researcher (CR) and the participant were in an interactive setting.

## Participants

Thirty-two (*N*=32) neurotypical, right-handed participants, ages 18-39 were recruited for this study through online advertising, e-mail to students taking collegiate classes when given permission by professors, and word-of-mouth. The CR also asked university professors for permission to e-mail students in non-music core courses to participate in the study. Participants completed an online survey prior to the experiment to determine if they were eligible and fit the criteria. The researcher recruited non-musicians, defined as not having played or studied an instrument in private instruction for longer than one year over the past 5 years. Additional screening questions were administered to provide researcher with background information pertaining to additional music experience and any past or existing neurologic disorder or variation. Participants were excluded if they had any interaction with the CR outside of the study, as that could affect social responses in the brain. This study was approved by the

Colorado State University Institutional Review Board, and informed consent was obtained from all participants.

**Procedures**

Participants were informed of the procedures, given an approximate amount of time to be expected, and completed consent procedures. Participants verbally answered questions pertaining to recent drug and alcohol use and were informed of the experiment procedure. There were four conditions, repeated five times each in randomized order with fifteen-second breaks interspersed throughout. Interaction was achieved through synchronous tapping on legs in that interventionist and participant were both be performing the same action at the same pace. There was a cue to start tapping legs and when to stop. The participant was shown how to tap their legs to the beat, and told to play along with the interventionist as best as they could, matching the beat as accurately as possible. They practiced tapping synchronously for a fifteen second period with the CR. Right before each thirty second block, the participant was given an auditory cue to begin. When the participants were ready, an fNIRS cap was positioned and fitted on participants' heads. A swimming cap was placed over the cap to block out interfering light sources in a well-lit room that was needed to present a more realistic environment for human interaction and to increase the strength of ecological validity.

Participants engaged in tapping synchronously with the CR while listening to a pre-composed melody using solfege syllables in both live and recorded formats or while listening to spoken solfege syllables in both live and recorded formats occurring at all times except the start and stop cues. Each thirty second block consisted of the independent variable manipulations with the exception of four seconds at the beginning to state "one, two, ready, and start" and the last remaining four seconds to provide an ending cue: "3…2…1 and stop". Each participant's blood oxygenation levels in the brain were measured during each condition using fNIRS.

The pre-composed melody consisted of solfege syllables (e.g.: do, re mi). The musical excerpt (Figure 8) began and ended on the tonic 'do'. No words were used to remove the possibility of the participant having associations with words or lyrics that may affect the data. Consonance was featured predominantly over dissonance and pitches selected were in predictable and common patterns akin to well-known folk songs. Unconscious familiarity with the tonal elements of the musical excerpt was intended to remove any cortical activation differences that may arise from unpredictable or unfamiliar tonal shifts. The melody was intended to be familiar, but not known. The tempo chosen was approximately 75 beats per minute. The spoken conditions used the same solfege syllable but were spoken instead of sung (Figure 9).

**Interventions**

Recorded Spoken: Participants were exposed to a thirty second block trial of tapping their own legs as CR was simultaneously tapping their legs and hearing a recorded excerpt of interventionist's voice speaking solfege syllables at approximately 70 decibels.

Live Spoken: Participant were exposed to a thirty second block trial of tapping their own legs as CR was simultaneously tapping their own legs while CR spoke the same solfege syllables that were present in the recorded spoken condition at approximately 70 decibels.

Recorded Sung: This condition is akin to "recorded spoken" except the CR was singing instead of speaking on the recording. In this condition, the participant heard thirty seconds of a recorded melody with solfege by the CR.

Live Sung: Participant was again tapping their legs to the beat with CR as in the first three conditions, but this time the CR sung the melody live when cued by E-Prime program, the program used to computerize the experiment design. CR sung the same melody as the recorded intervention.

Rest Condition: Participant rested for fifteen seconds with no interaction with CR. This condition was pseudorandomized as well.

Tapping Task: In order to mimic interactive music therapy sessions, participants interacted with the CR in each condition through the medium of rhythm. CR was sitting across from the participant. Each condition consisted of a recorded audio start cue stating "1…2..ready and start," followed by 25 seconds of the CR providing a steady beat on legs ending with a recorded stop cue of "3..2..1..and stop". The participant was instructed to imitate CR. The CR used decibel reader during live conditions to remain in close proximity to the decibel level of recorded conditions. Additionally, the CR attempted to keep personal facial affect (overall demeanor) constant.

**Data Collection**

The CR conducting this study used the neuroimaging technique of fNIRS which detects and quantifies the changes that occur in blood oxygenation" (Strait & Scheutz, 2014). Each participant wore a lightweight and tight fitting cap equipped with probes functioning as photo emitters and detectors. The NIRScoutX (NIRScout; NIRx Medical Technologies, Los Angeles, CA, USA) cap was formulated with 48 light-emitters and 32 detectors (Figure 1). The light-emitting diodes (LEDs) emitted wavelengths of 760 and 850 nanometers at a sampling rate of 3.67 Hz. 136 channels were formed between sources and detectors.

Placement of the cap was standardized between subjects by using the international 10-20 system. The location of the Fpz (frontal polar zone) site was set at 10% of the total distance between nasion (area of the face superior to the bridge of the nose) and inion (projection located at the posterioinferior part of the skull) for each participant (Kentopp, 2017). A large swimming cap was placed over the probes to cover the emitters and block possible light interference as the room remained well-lit throughout the experiment to more closely replicate a music therapy session.


*Figure 1*. Side view, frontal view, and posterior view of EasyCap (cap montage M15) specialized recording cap (Easycap GmbH, Germany) without NIRx spring-loaded grommets

**Data Analysis**

Neuroimaging data were analyzed through SPM (statistical parametric mapping) for fNIRS toolbox, software that utilizes statistical parameter mapping (Ye et al., 2009). Data was collected from the entire cortical surface of the brain with the cap arranged to incorporate the full selection of sensors. Using the modified Beer Lambert-Law for “the calculation of oxygenation from the light intensity values” (Wang et al., 2017, p. 69), changes in oxyhemoglobin and deoxyhemolgobin concentrations were detected and calculated (Quaresima & Ferrari, 2019). Motion artifacts were removed from the data through SPM software. Five contrasts were formed in the SPM fNIRS toolbox to statistically compare: 1) live music to recorded music, 2) live auditory stimuli to recorded auditory stimuli, 3) music stimuli to speaking stimuli, 4) live music to all other conditions, and 5) live speaking to recorded speaking stimuli. To test for statistical significance, one sample *t*-tests were used to compare averaged contrast estimates in each condition to determine if there was a significant difference among any of the conditions.

1. Will cortical activations in the frontopolar area, orbitofrontal area, and the right pre-frontal cortex be different in the live music condition compared to the recorded music conditions?
2. Will a blood oxygenation levels across the entire cortical surface yield significant differences in any area across the four conditions?

# CHAPTER FOUR: RESULTS

## Participants

Thirty-two participants were recruited for this study aged between eighteen and thirty-nine years. There were a total of twenty-seven females and five males (Table 1). All participants were right-handed, neurotypical, non-musicians with no social connection with the clinician researcher (CR). A total of five participants were excluded from data analysis, with four removed due to poor quality of data and one due to incomplete background surveys/paperwork. A total of 27 participants were included in the analyses. Participants reported no more than 2 years total of private lessons on an instrument and no experience in private lessons in the last five years (*n* = 24), negative report of neurologic disorders (*n* = 24.), and negative report of illegal drug use in the 24 hours preceding testing (*n* = 26).

**Table 1**. *Participant Demographics*

| Participant Total | *n* = 27 |
|---|---|
| Biological Sex | Female: *n* = 22, 81% |
| | Male: *n* = 5, 19% |
| Age: (Avg., Min., Max., SD) | 22.74, 18, 39, 4.7 |

## fNIRS Data

For each of the 136 channels (formed from connections between sensors and detectors in the optode array), the researcher examined five different contrasts: 1) live auditory stimuli compared to recorded auditory stimuli, 2) live music to recorded music, 3) music stimuli to speaking stimuli, 4) live music to all other conditions, and 5) live speaking to recorded speaking stimuli. Contrast comparisons were assessed using dependent *t*-tests, to determine changes in the region of brain activations. Anatomical brain areas were then determined using fOLD, a

MATLAB application. Due to the lack of certainty in identifying the exact brain region from fNIRS data stemming from the fact that the optodes are placed on the exterior skull making it difficult to ascertain absolute location information from below the cortical surface, specific location information was reported as broad regions. For example, if fOLD reported that activity was in the right superior gyrus of the occipital lobe, the region was reported was "occipital lobe (right)". fOLD does provide percentages of specificity or likelihood that the specific region being reported is correct. The specificity percentage was reported when specific location names were used.

**Activations in the Frontal Area**

In research question one, the researcher investigated differences in cortical activations in the frontopolar area, orbitofrontal area, and the right pre-frontal cortex in the live music condition compared to the recorded music condition (contrast two). Statistical analysis comparing changes in blood oxygenation across the brain indicated significance between the live and recorded music condition in the left middle frontal gyrus (48.5% specificity) of the orbitofrontal area/prefrontal cortex (channel 4), with a stronger signal for the live music condition compared to the recorded music condition (Figure 3). There were no other significant differences found for blood oxygenation at the different channel locations for the live and recorded music condition in the frontopolar area, orbitofrontal area, and the right pre-frontal cortex (Table 2).

**Table 2.** *Live Music vs. Recorded Music*

| Brain Area | NIRS Channel | S-D Pair | Channel Location X | Y | Z | *t* value | *p* |
|---|---|---|---|---|---|---|---|
| **Live Music vs Recorded Music (Contrast 2)** | | | | | | | |
| Frontal Lobe (Left) | 4 | AF7-AFF5h | -52.82 | 66.31 | 6.25 | 3.11 | .0044 |
| Temporal Lobe (Right) | 32 | F4-FFT8h | 78.11 | 28.22 | -50.50 | 2.29 | .0303 |
| Supplementary Motor Area | 94 | Cz-FCz | .39 | 9.11 | 94.46 | 2.68 | .0124 |
| Precentral Gyrus (Right) | 72 | FC6-FC4 | 70.91 | 21.83 | 40.03 | -2.08 | .0475 |
| Precentral Gyrus (Left) | 55 | TP9-FC3 | -62.77 | 5.54 | 60.00 | -2.84 | .0084 |
| Precentral Gyrus (Right) | 96 | FCC4h-FC4 | 57.09 | 15.76 | 64.57 | -3.03 | .0054 |
| Postcentral Gyrus (Left) | 119 | CCP3h-C1 | -44.54 | -19.44 | 85.03 | -2.36 | .0256 |
| Precentral Gyrus (Right) | 72 | FC6-FC4 | 70.91 | 21.83 | 40.03 | -2.08 | .0475 |

*Notes:Channels with significant changes in HbO levels. Listed for each channel are MNI coordinates, and 10-05 labels are given for source-detector pairs. AAL2 brain areas were determined using the fOLD application for Matlab 2017a.*

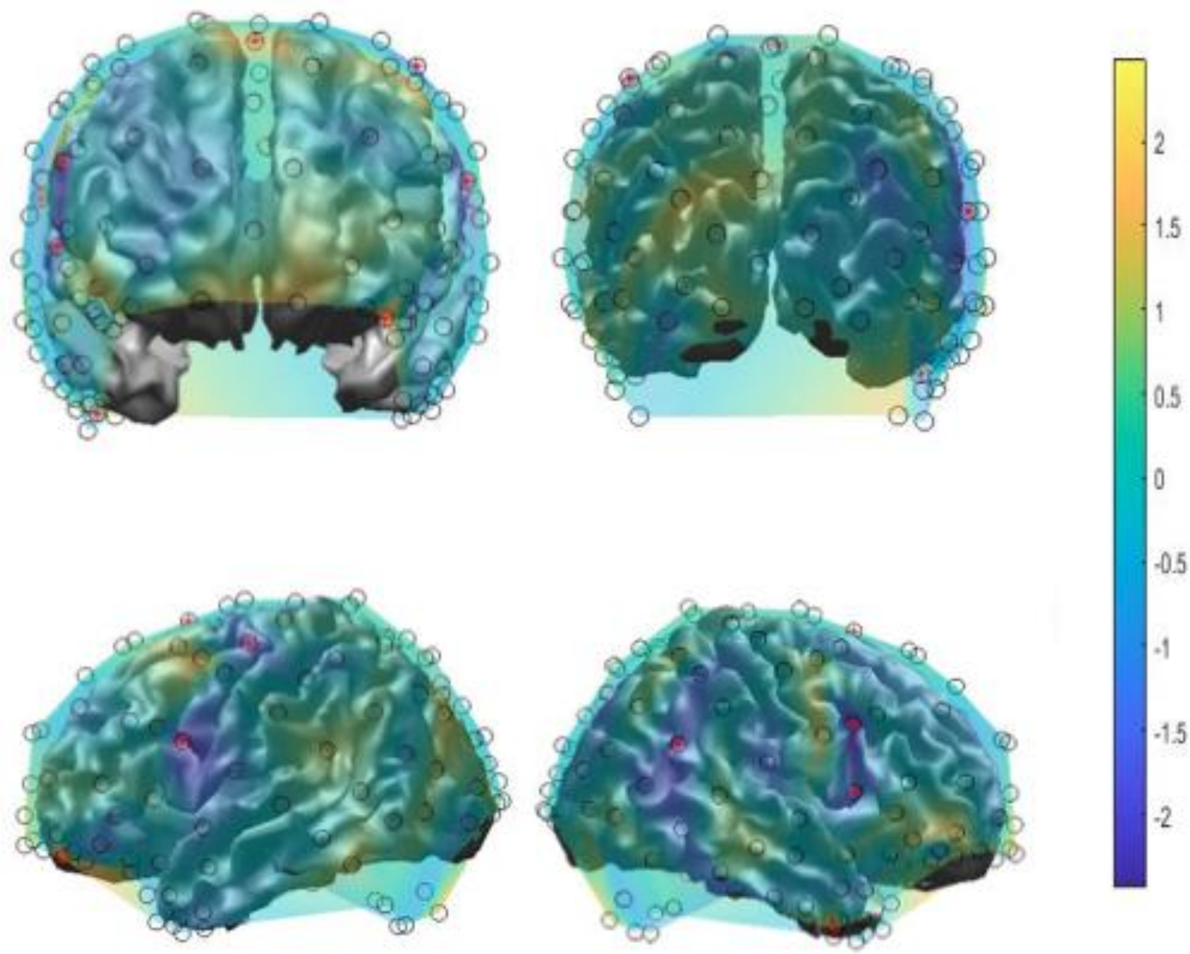


*Figure 2*. Channels reflecting significant changes in hemodynamic activity during live music to recorded music. Red activation patterns correspond to greater oxy-Hb levels while blue regions correspond to reduced oxy-Hb levels. The significant channels are marked with a red cross. Colored bar represents t -statistic.

**Activations Across the Cortical Surface**

In research question two, the researcher investigated changes in blood oxygenation levels across all regions of the cortical surface in all five contrasts.

*Live Stimuli to Recorded Stimuli*

When comparing the differences between live and recorded auditory stimuli, eight channels were significant in measurements of oxygenated hemoglobin levels (Table 3).

Significantly greater activation was found for two channels in the left frontal lobe, the right SMA, and the right cerebellum crus. Significantly decreased activations in oxygenation were found in the right parietal lobe, two channels indicating the right temporal lobe, and the right frontal lobe (Figure 3).

**Table 3.** *Live Stimuli vs. Recorded Stimuli*

| Brain Area | NIRS Channel | S-D Pair | Channel Location X | Y | Z | t value | *p* |
|---|---|---|---|---|---|---|---|
| **Live Stimuli vs. Recorded Stimuli (Contrast 1)** | | | | | | | |
| Frontal Lobe (Left) | 1 | AF3-AFZ | -16.73 | 78.80 | 28.32 | 2.93 | .0069 |
| Frontal Lobe (Left) | 4 | AF7-AFF5h | -52.82 | 66.31 | 6.25 | 2.83 | .0087 |
| Supplementary Motor Area (Right) | 94 | Cz-FCz | .39 | 9.11 | 94.46 | 2.13 | .0421 |
| Cerebellum Crus (Right) | 91 | PO10-P10 | 64.44 | -86.24 | -38.38 | 2.63 | .0138 |
| Parietal Lobe (Right) | 81 | C4-C6 | 75.29 | -11.83 | 46.40 | -2.70 | .0118 |
| Temporal Lobe (Right) | 89 | P8-P10 | 73.48 | -73.73 | -21.88 | -2.35 | .0261 |
| Temporal Lobe (Right) | 18 | FT7-F9 | -75.44 | 27.89 | -30.54 | -2.06 | .0494 |
| Frontal Lobe (Right) | 25 | AF4-F2 | 32.61 | 67.67 | 40.75 | -2.65 | .0134 |

*Notes:Channels with significant changes in HbO levels. Listed for each channel are MNI coordinates, and 10-05 labels are given for source-detector pairs. AAL2 brain areas were determined using the fOLD application for Matlab 2017a.*

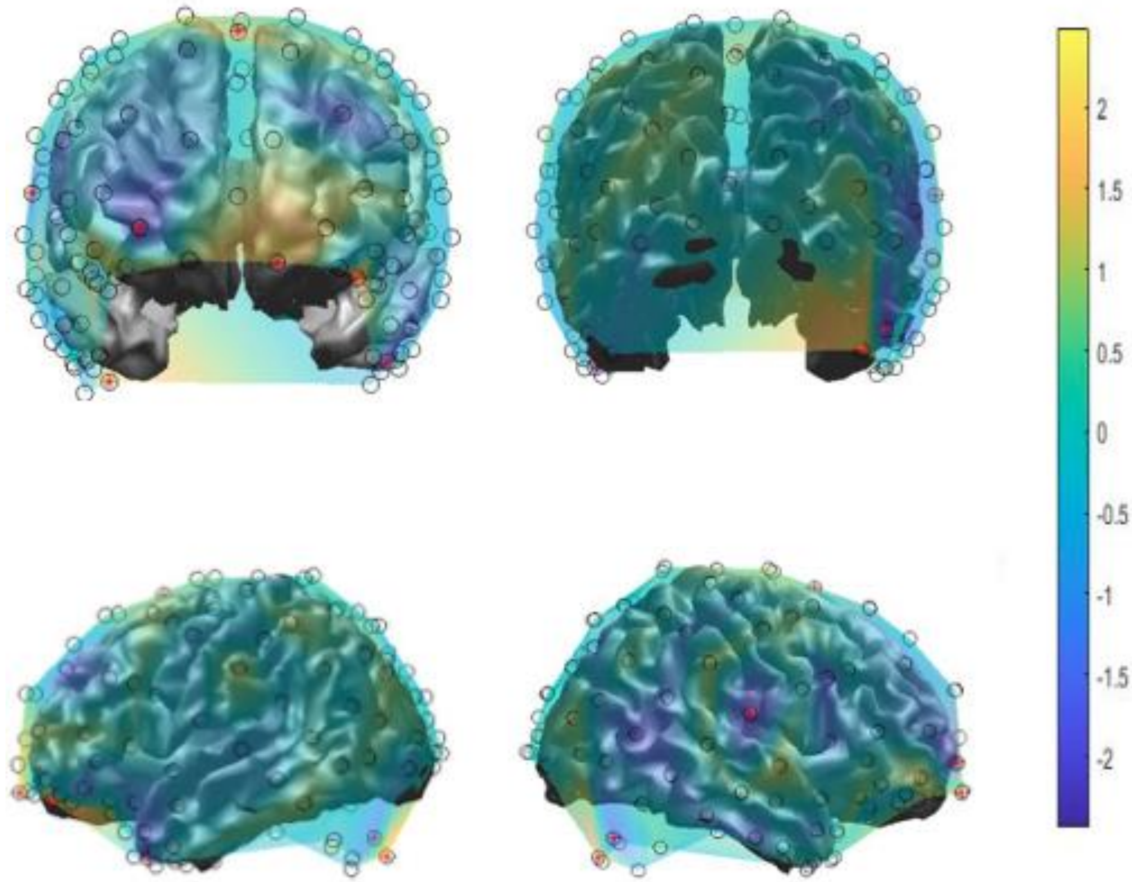


*Figure 3*. Channels reflecting significant changes in hemodynamic activity during live stimuli to recorded stimuli. Red activation patterns correspond to greater oxy-Hb levels while blue regions correspond to reduced oxy-Hb levels. The significant channels are marked with a red cross. Colored bar represents t statistic.

*Live Music to Recorded Music*

When comparing the differences between live and recorded music stimuli across the regions of the cortical surface, significant differences in measurements of oxygenated hemoglobin levels were found in eight channels (Table 4). Significantly greater activation was found for one channel in the left frontal lobe, one channel in the right temporal lobe and the right supplementary motor area. Significantly decreased activations in oxygenation were found in three channels indicating the right precentral gyrus, the left precentral gyrus and the postcentral gyrus (Figure 4).

**Table 4.** *Live Music vs. Recorded Music*

| Brain Area | NIRS Channel | S-D Pair | Channel Location X | Y | Z | t value | *p* |
|---|---|---|---|---|---|---|---|
| **Live Music vs Recorded Music (Contrast 2)** | | | | | | | |
| Frontal Lobe (Left) | 4 | AF7-AFF5h | -52.82 | 66.31 | 6.25 | 3.11 | .0044 |
| Temporal Lobe (Right) | 32 | F4-FFT8h | 78.11 | 28.22 | -50.50 | 2.29 | .0303 |
| Supplementary Motor Area | 94 | Cz-FCz | .39 | 9.11 | 94.46 | 2.68 | .0124 |
| Precentral Gyrus (Right) | 72 | FC6-FC4 | 70.91 | 21.83 | 40.03 | -2.08 | .0475 |
| Precentral Gyrus (Left) | 55 | TP9-FC3 | -62.77 | 5.54 | 60.00 | -2.84 | .0084 |
| Precentral Gyrus (Right) | 96 | FCC4h-FC4 | 57.09 | 15.76 | 64.57 | -3.03 | .0054 |
| Postcentral Gyrus (Left) | 119 | CCP3h-C1 | -44.54 | -19.44 | 85.03 | -2.36 | .0256 |
| Precentral Gyrus (Right) | 72 | FC6-FC4 | 70.91 | 21.83 | 40.03 | -2.08 | .0475 |

*Notes:Channels with significant changes in HbO levels. Listed for each channel are MNI coordinates, and 10-05 labels are given for source-detector pairs. AAL2 brain areas were determined using the fOLD application for Matlab 2017a.*

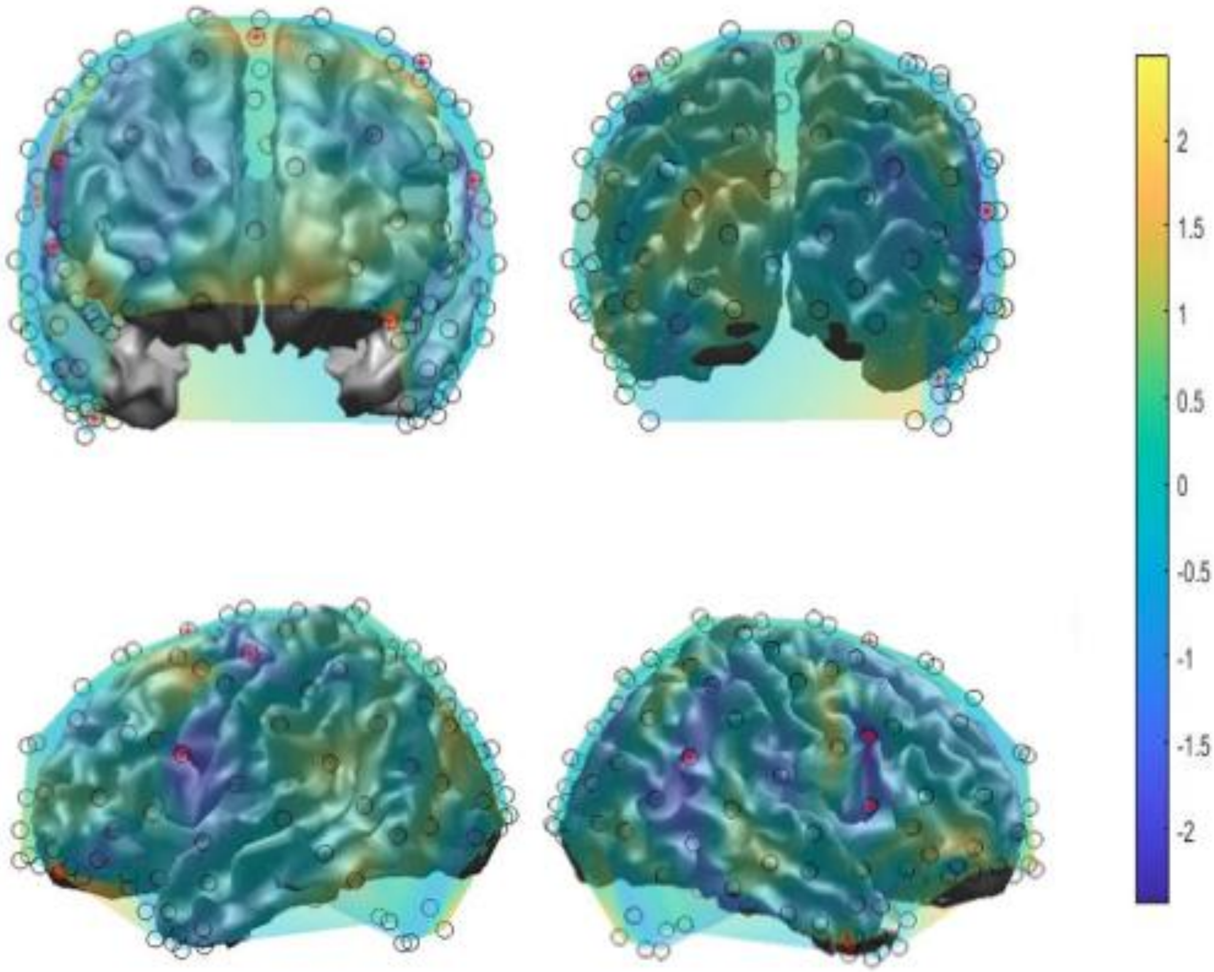


*Figure 4*. Channels reflecting significant changes in hemodynamic activity during live music to recorded music. Red activation patterns correspond to greater oxy-Hb levels while blue regions correspond to reduced oxy-Hb levels. The significant channels are marked with a red cross. Colored bar represents t -statistic.

*Music to Non-Music Stimuli*

When comparing the differences between music and non-music stimuli, ten channels were significant in measurements of oxygenated hemoglobin levels (Table 5). Significantly greater activation was found for two channels in the right frontal lobe, and three channels in the right temporal lobe. Significantly decreased activations in oxygenation were found in two channels indicating the right temporal lobe, the right supplementary motor area, the right frontal lobe, and the left occipital lobe (Figure 5).

**Table 5.** *Music vs. Non-Music Stimuli*

| Brain Area | NIRS Channel | S-D Pair | Channel Location X | Y | Z | *t* value | *p* |
|---|---|---|---|---|---|---|---|
| **Music vs. Non-Music Stimuli (Contrast 3)** | | | | | | | |
| Frontal Lobe (Right) | 27 | AF8-FFT8h | 66.90 | 51.32 | -3.14 | 2.53 | .0177 |
| Temporal Lobe (Right) | 87 | CP6-P6 | 75.60 | -61.00 | 29.65 | 2.66 | .0131 |
| Temporal Lobe (Right) | 89 | P8-P10 | 73.48 | -73.73 | -21.89 | 2.52 | .0178 |
| Frontal Lobe (Right) | 68 | FC2-C2 | 32.15 | 42.02 | 69.17 | 3.82 | .0007 |
| Temporal Lobe (Right) | 85 | CP6-TP8 | 84.44 | -45.37 | 12.04 | 3.58 | .0013 |
| Temporal Lobe (Right) | 32 | FT10-F10 | 78.11 | 28.22 | -50.50 | -2.19 | .0372 |
| Supplementary Motor Area (Right) | 94 | Cz-FCz | .39 | 9.11 | 94.46 | -2.18 | .0382 |
| Temporal Lobe (Right) | 78 | TP10-TP8 | 85.86 | -46.29 | -26.50 | -2.25 | .0330 |
| Frontal Lobe (Right) | 97 | FCC4h-C2 | 44.78 | -0.91 | 80.96 | -2.40 | .0237 |
| Occipital Lobe (Left) | 128 | PO3-P1 | -32.96 | -106.65 | 23.00 | -2.37 | .0254 |

*Notes: Channels with significant changes in HbO levels. Listed for each channel are MNI coordinates, and 10-05 labels are given for source-detector pairs. AAL2 brain areas were determined using the fOLD application for Matlab 2017a.*

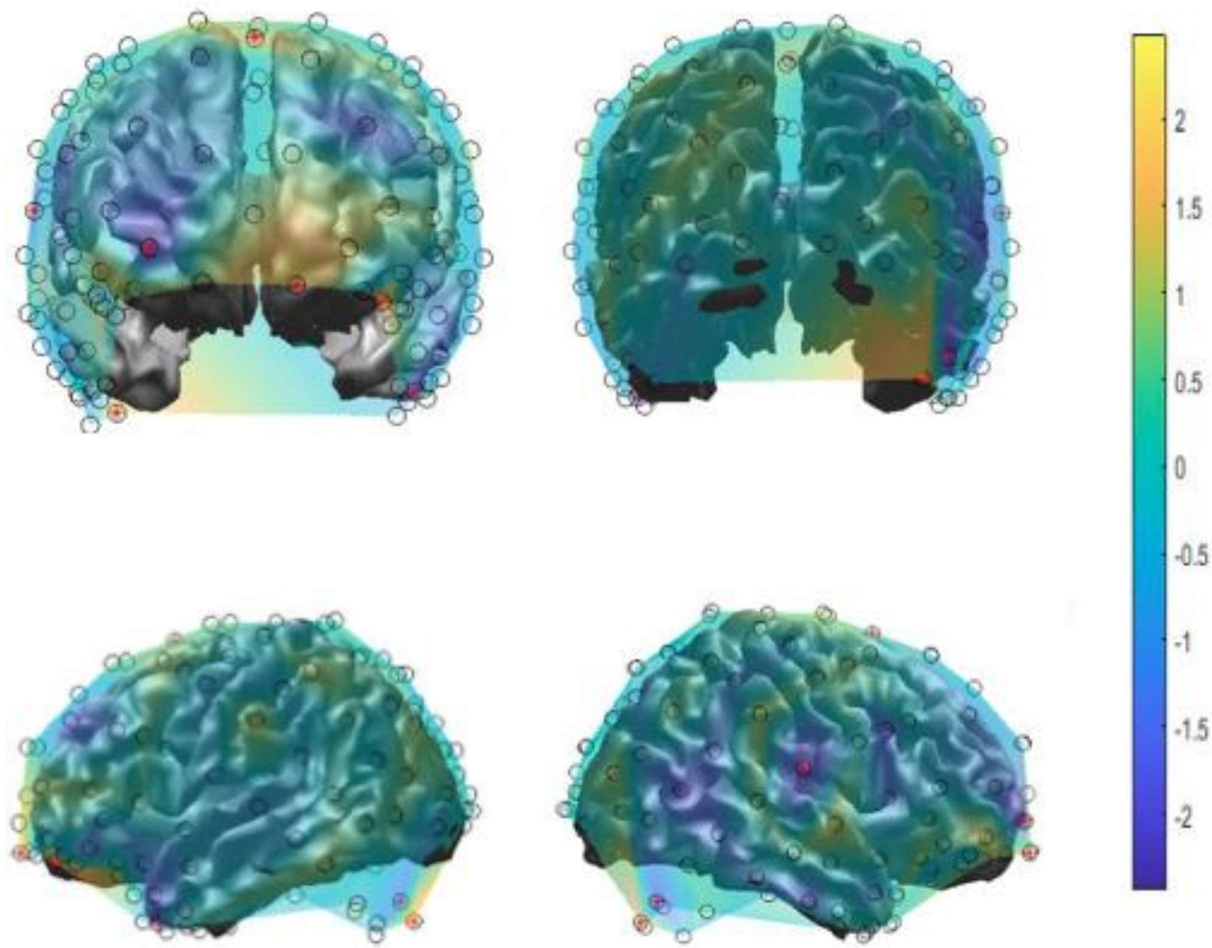


*Figure 5.* Channels reflecting significant changes in hemodynamic activity during music stimuli to non-music stimuli. Red activation patterns correspond to greater oxy-Hb levels while blue regions correspond to reduced oxy-Hb levels. The significant channels are marked with a red cross. Colored bar represents t -statistic.

*Live Music to All Other Conditions*

The fourth contrast, live music compared to the remaining three conditions, resulted in eight channels indicating significant changes in blood flow (Table 6). Significantly greater activation was found for one channel in the left frontal lobe, one channel in the right frontal lobe, two channels in the right temporal lobe, one channel in the right SMA, and one channel in the left precentral gyrus. Significantly decreased activations in oxygenation were found in two channels indicating the left postcentral gyrus (Figure 6).

**Table 6.** *Live Music vs. All Other Conditions*

| Brain Area | NIRS Channel | S-D Pair | Channel Location X | Y | Z | *t* value | *p* |
|---|---|---|---|---|---|---|---|
| **Live Music vs. All Other Conditions (Contrast 4)** | | | | | | | |
| Frontal Lobe (Left) | 4 | AF7-AFF5h | -52.82 | 66.31 | 6.25 | 5.13 | <.0001 |
| Temporal Lobe (Right) | 38 | F4-FFT8h | 64.94 | 43.64 | 22.64 | 3.37 | .0023 |
| Frontal Lobe (Right) | 68 | FC2-F2 | 32.15 | 42.02 | 69.17 | 4.95 | <.0001 |
| Temporal Lobe (Right) | 90 | P8-P6 | 70.47 | -74.49 | 12.78 | 2.37 | .0253 |
| Supplementary Motor Area (Right) | 94 | Cz-FCz | .39 | 9.11 | 94.46 | 2.26 | .0320 |
| Precentral Gyrus (Left) | 118 | FCC3h-C1 | -43.60 | -1.40 | 82.06 | 2.48 | .0198 |
| Postcentral Gyrus (Left) | 119 | CCP3h-C1 | -44.54 | -19.44 | 85.03 | -2.81 | .0091 |
| Postcentral Gyrus (Left) | 120 | CCP3h-CP3 | -58.24 | -37.96 | 72.96 | -3.15 | .0039 |

*Notes:Channels with significant changes in HbO levels. Listed for each channel are MNI coordinates, and 10-05 labels are given for source-detector pairs. AAL2 brain areas were determined using the fOLD application for Matlab 2017a.*

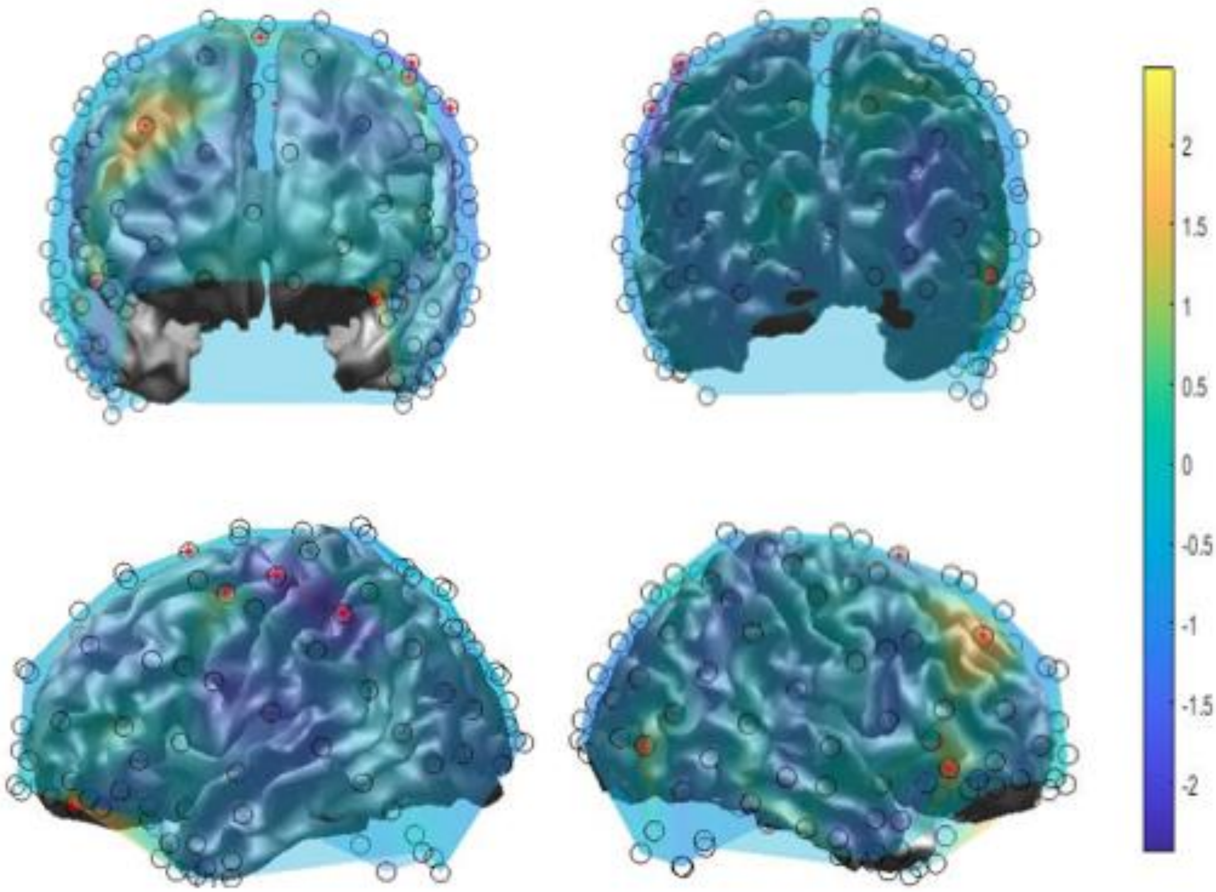


*Figure 6.* Channels reflecting significant changes in hemodynamic activity during live music stimuli to all other conditions. Red activation patterns correspond to greater oxy-Hb levels while blue regions correspond to reduced oxy-Hb levels. The significant channels are marked with a red cross. Colored bar represents t -statistic.

*Live Spoken to Recorded Spoken*

Lastly, there were eight channels indicating significance in the remaining contrast, live spoken stimuli compared to recorded spoken stimuli. These brain regions with significant findings can be accessed in Table 7. Significantly greater activation was found for one channel in the left frontal lobe, one channel in the right occipital lobe, one channel in the right parietal lobe, in the right postcentral gyrus, and the left precentral gyrus. Significantly decreased activations in oxygenation were found in the right temporal lobe, the right frontal lobe, and the left temporal lobe (Figure 7).

**Table 7.** *Live Spoken to Recorded Spoken Stimuli*

| Brain Area | NIRS Channel | S-D Pair | Channel Location X | Y | Z | *t* value | *p* |
|---|---|---|---|---|---|---|---|
| **Live Spoken to Recorded Spoken (Contrast 5)** | | | | | | | |
| Frontal Lobe (Left) | 1 | AF3-AFZ | -16.73 | 78.80 | 28.32 | 2.17 | .0389 |
| Occipital Lobe (Right) | 113 | PO4-P6 | 52.33 | -88.38 | 32.24 | 2.35 | .0262 |
| Parietal Lobe (Right) | 83 | C4-CP4 | 66.86 | -28.77 | 64.58 | 2.05 | .0499 |
| Postcentral Gyrus (Right) | 73 | FC6-C6 | 81.50 | 3.58 | 26.82 | 2.22 | .0348 |
| Precentral Gyrus (Left) | 55 | TP9-FC3 | -62.77 | 5.54 | 60.00 | 2.49 | .0192 |
| Temporal Lobe (Right) | 21 | FT9-F9 | -77.09 | 28.11 | -50.19 | -2.08 | .0470 |
| Frontal Lobe (Right) | 25 | AF2-F2 | 32.61 | 67.67 | 40.75 | -2.14 | .0419 |
| Temporal Lobe (Left) | 17 | FT7-FTT7h | -77.64 | 22.71 | -3.14 | -2.44 | .0217 |

*Notes:Channels with significant changes in HbO levels. Listed for each channel are MNI coordinates, and 10-05 labels are given for source-detector pairs. AAL2 brain areas were determined using the fOLD application for Matlab 2017a.*

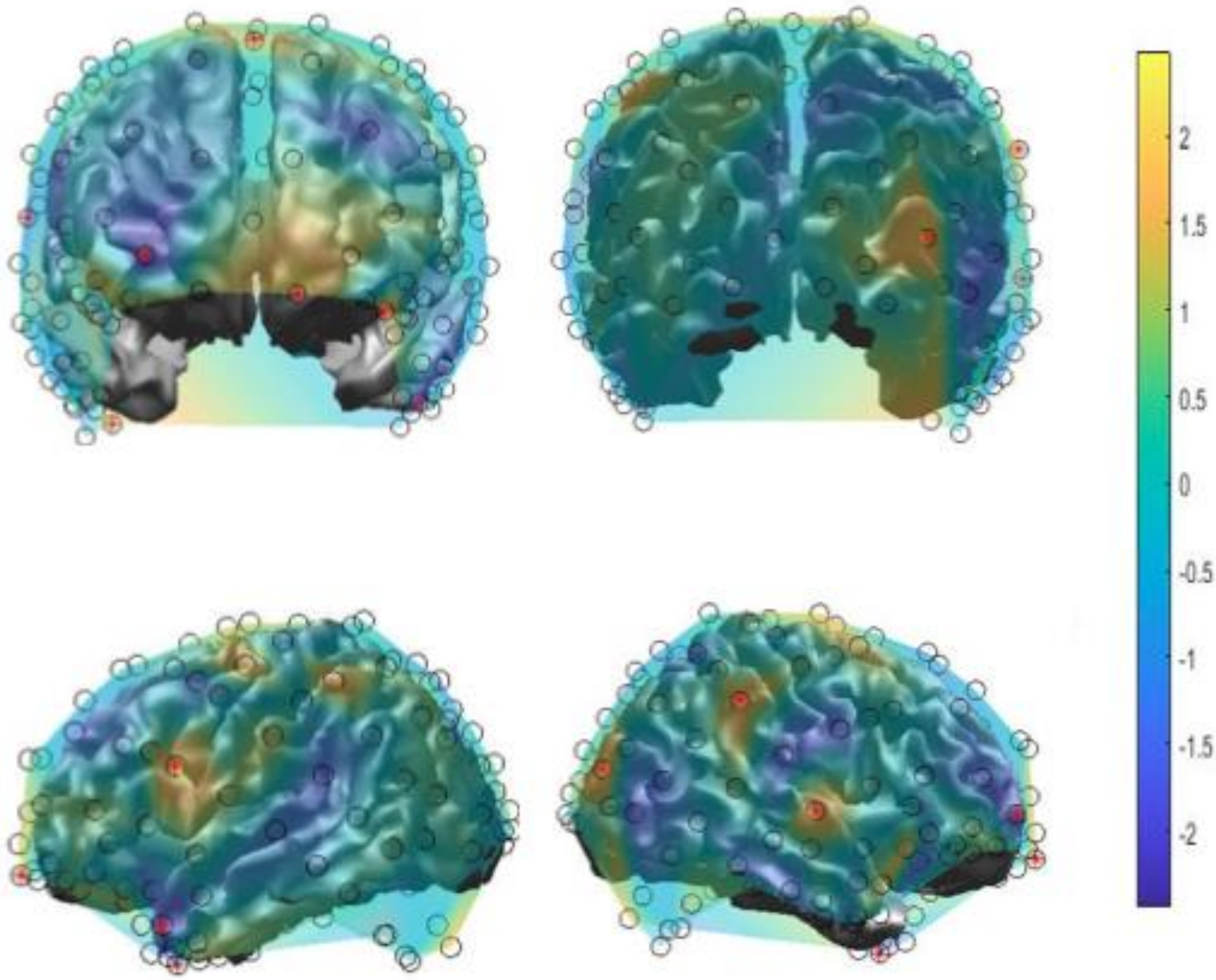


*Figure 7.* Channels reflecting significant changes in hemodynamic activity during live spoken to recorded spoken. Red activation patterns correspond to greater oxy-Hb levels while blue regions correspond to reduced oxy-Hb levels. The significant channels are marked with a red cross. Colored bar represents t statistic.

# CHAPTER FIVE: DISCUSSION

The results of this study indicated significant differences in hemodynamic activity in all five contrasts, located at different brain regions. These results will be discussed in terms of the research questions.

## Activations in Frontal Regions

In research question one, the researcher investigated differences in cortical activations in the frontopolar area, orbitofrontal area, and the right pre-frontal cortex in the live music condition compared to the recorded music condition (contrast two). There were no significant differences in the right hemisphere, and only one significant difference in the left hemisphere, which was in the orbitofrontal area/left middle frontal gyrus (Figure 2). Previous research indicated that live stimuli may have greater activation in the brain than recorded stimuli (Jones, et al., 2015; McDonald & Perdue, 2018) and that key regions of the brain associated with social processing were the right pre-frontal cortex, orbitofrontal cortex, frontopolar cortex (Grossman, 2013; Sulpizio et al., 2018). The presentation of live music stimuli differed from the presentation of recorded music stimuli in this study in that the CR either sang (live music) or played (recorded music) the stimuli for the participant. It was expected that the changes in the delivery might influence changes in regions of the brain that are associated with social processing. However, when comparing live music to recorded music, the social differences between the presentation of the live and recorded music delivery only resulted in greater activation in one area within the frontopolar, orbitofrontal, and the right pre-frontal cortex. A more widespread pattern of activation in these areas would have leant more support to live music having producing greater levels of brain activation in social regions than recorded music. The results from the frontopolar, orbitofrontal, and right pre-frontal cortex could be due to the simplicity of the social task present during the administration of the auditory stimuli. The social aspect of this study included imitation and engaging in synchronous behavior through a joint rhythmic tapping task. Both of the studies cited in the literature review that were comparing live stimuli to recorded stimuli in the neuroscience research base involved greater social interactions (Shimada & Hiraki, 2006; Jones et al., 2015). Because the frontopolar, orbitofrontal, and pre-frontal cortex are involved in more complex social tasks, it may be that those areas were not recruited due to the simplicity of the task in the present study.

**Activations Across the Cortical Surface**

The second research question prompted the CR to examine changes in blood oxygenation levels across the entire cortical surface between all four conditions. In the music versus non-music contrast (contrast 3), all of the significant activations were from channels lateralized on the right side of the brain, except for one (occipital lobe). All other contrasts (contrast 1, 2, 4, and 5) had a fairly even distribution of left and right distribution. Although music is processed bilaterally in the brain, researchers have shown a right lateralization in the brain when listening to music (Santosa et al., 2014). Previous research indicating that music listening is right lateralized corroborates with the results in this study.

The CR found significant changes in hemodynamic activity channels reflecting significant changes in hemodynamic activity in the left middle frontal gyrus in all of the contrasts comparing live stimuli to other stimuli except for live spoken to recorded spoken. This finding may be explained by emotional connection to the music, as Karmonik and colleagues (2013), found a similar pattern of activation when a participant listened to two musical pieces. The first of which the participant had no emotional connection and the second piece with which the participant had emotional attachment. BOLD (blood oxygen level-dependent) activation “during listening included bilateral auditory cortex, bilateral inferior and superior parietal lobule, bilateral insula, bilateral precuneus, left inferior frontal gyrus, left superior and middle temporal gyrus and left inferior and middle frontal gyrus” (Karmonik et al., 2013, p. 6527) during the second piece with which the participant had emotional attachment. Although this study had only one participant, it is possible that the left middle frontal gyrus is a key region of the brain for emotional responses to music. Additionally, the left middle frontal gyrus has been linked to the processing of emotionally empathetic social responses (Seehausen et al., 2016). The present study was looking at differences in cortical activation between live and recorded stimuli in a social setting. The results may indicate that live music evokes greater social responses than recorded music.

The contrast in which there was the greatest amount of significant activations was the comparison of live music against all other conditions. The six channels indicating significantly increased activity for live music compared to all other conditions corresponded to the left and right frontal lobe, right temporal lobe, and supplementary motor area. This widespread pattern of activity may support the idea that live music is a dynamic condition, promoting more cortical activation across areas of the brain involved in auditory processing. Aside from the widespread pattern of activation that occurs when comparing live music to all other conditions, more research is needed to better understand brain function and music.

The supplementary motor area (SMA) was identified as a brain region with significantly higher levels of oxygenation with live music compared to all other conditions (higher levels for the live music condition), live stimuli compared to recorded stimuli (higher levels for the live stimuli condition) and live music compared to recorded music (higher levels of oxygenation for the live music condition. The SMA also appears as a brain region where there were significantly lower levels of oxygenation in the music stimuli compared to non-music stimuli contrast (with lower levels for the music condition). A way that this could be interpreted is that live stimuli alone do not produce a significant pattern of activation in the SMA. Nor do music stimuli alone produce a significant pattern of activation in the SMA. But when auditory stimuli are both live and musical, there was a significant pattern of activation in the SMA.

The SMA is involved with processes including movement preparation, sequencing movement, and motor coordination (Stegemöller, 2018). There have been researchers that have shown that the SMA has greater patterns of activity in music vs non-music conditions. Stegemöller, Izbicki, and Hibbing (2018) compared activity in the SMA and the sensorimotor region using electroencephalography in participants during a finger tapping exercise. Participants either listened to two styles of recorded music or a tone. Results "revealed a significant difference between both music conditions and the tone only condition for both the regions" in favor of the two music conditions (Stegemöller et al., 2018, p. 27). However, these exploratory data suggest it is possible that live music has greater access to the SMA than recorded music or non-music stimuli. Clinically, this has potential to impact music therapy clinicians working with patients who have a weakened SMA, such as patients with Parkinson's disease. Stegemöller discussed patients with Parkinson's disease, stating that rhythmic cueing paired with movement decreases the reliance on the SMA. This may be helpful to patients with Parkinson's, as the SMA may be affected by reduced activity resulting in freezing movement. Decreasing the demands on the SMA may lead to the patient using a less affected alternative pathway to produce movement (Stegemöller, 2018). Based on previous research indicating positive results using recorded music, and the findings of this research study, more research should be conducted to determine if combining live and recorded music delivery would promote optimal therapeutic outcomes. For example, if live music does impact the SMA in persons with PD, the music therapist could use live music and a metronome for movement cues when present with the patient and then could send the patient home with recorded music to generalize the skill in naturalistic environments.

Researchers of past studies have indicated that singing has a greater effect than speech in the superior temporal gyrus (Armony & Whitehead, 2018). The superior temporal gyrus is also a region in which researchers have indicated that there is the potential for neural networks that are specific to the processing of music (Armony et al., 2015). Conversely, the music versus non-music contrast in this study did not yield similar results. Regions with greater levels of oxygenation included two in the right frontal lobe and three in the right temporal lobe. Using fOLD, the three regions in the right temporal lobe were most likely to be the middle temporal gyrus with a 43.3% specificity or percentage likelihood of being correct (channel 87), the inferior temporal gyrus with a 49.2% specificity (channel 89), and the middle temporal gyrus with a 65.9% specificity (channel 85). Although there were increases of oxygenation in the temporal lobe, there was not a direct result for the superior temporal gyrus. This may be due to the element of pitch being present in the spoken stimuli as well as the researcher's inflection which varied often.

This research should be interpreted with caution as it is one of the first studies to look at the differences in cortical activation when comparing live and recorded music. It is possible that some hypotheses based on the data can be drawn from this study. However, more studies asking research questions concerning the neurologic differences between live and recorded music are needed to make any conclusions.

**Limitations**

There were questions that came up during the data collection as to whether or not they would affect the quality of the data that had not been considered by the CR during the planning stage. For instance, eye contact of each participant was slightly varied with some participants ranging from no eye contact to a few making sustained eye contact throughout. Eye contact typically plays a part in social interaction and therefore could have affected changes in cortical activation in areas of the brain that are involved in social interaction. Additionally, there were a few participants that had difficulty maintaining synchronous and mirrored tapping on their legs.

Furthermore, as this experiment was designed to fit into a "social context" it is important to note participant differences and variations in how comfortable they felt interacting socially. The CR predicted that greater activation would happen in areas of the brain that are associated with social skills during the live music. However, no behavioral data was collected to ascertain how comfortable the participants were in the setting overall which may affect neurologic responses fueled by socializing. If the participant was uncomfortable to be in a small room with a stranger while they sing within close proximity of their space, it could have changed their responses overall and therefore affected the data.

The social context itself was simplistic in nature. Each participant had to mirror the CR in a tapping task on their legs. While imitation is a social behavior, and playing rhythm in synchrony has been shown to increase prosocial behavior (Kokal et al., 2011), this was not a dynamic social task. Perhaps a task that involved more complex or collaborative tasks would be better for a study looking at changes in cortical activation in social areas of the brain.

In consideration to the social context of the study, the lack of control for gender could have been a confounding factor in the data. There was only one CR, who was female and the study recruited both men and women. There could be gender differences based on how females relate to females and how males relate to females in social settings. One way that gender could have been controlled is with the addition of another CR who was male. If it were randomized which participant received which CR, there would have been a possibility of reducing confounds stemming from gender differences. Moreover, there were 27 participants included in the analyses and only 5 of them were men. Therefore, the results shown in this study may be influenced by the unequal representation of genders. It may have been beneficial to have an equal number of men and women to compare gender differences in the analysis of the data.

As to the elements that were present in the study design, there could be ways to change or design the experiment that may offer better results. In this study, there was only a cappella singing present. However, many participants remarked that they were expecting a musical selection or a more complex music listening experience. Perhaps even adding guitar chords to the singing in both the recorded and live music examples would make the experience more realistic to what people typically expect from “live” music. Additionally, it should be considered that each condition was only repeated five times which only allows for a small amount of conditions to be averaged to get each participant’s grand average for that condition. Increasing the amount of condition repetitions as well as the number of participants could also provide a more definitive picture of what patterns of activations will be mostly likely when comparing live and recorded auditory stimuli.

**Recommendations for Future Research**

There still exists a gap in the literature for research that more clearly describes and helps to elucidate the differences between live and recorded music stimuli in the brain. It would be worthwhile to continue to explore this question in the literature, refining what was done in this study, and improving upon the methods. It would also be beneficial to attempt a study with similar research questions as the present study using different neuroimaging methods to either support or provide potentially meaningful contrasts to this study. Deepening the understanding differences in cortical activation when people are exposed to either live or recorded music stimuli could give further insight to music therapists, music teachers, and perhaps many other disciplines whose practice can or does involve music as a/the tool. Additionally, further understanding of this question could teach us more of what it is to be human and to experience art in its different forms and permutations.

**Conclusion**

The purpose of this study was to provide initial information about the level of activation in cortical areas of the brain during social interactions when exposed to varied auditory stimuli and to determine if there is a difference in cortical activation across the four conditions. Portions of these exploratory data present in this study were corroborated with previous research in cognitive neuroscience and music. Other points of data in this study showed different results than previous research. Further research is needed to make meaningful conclusions. However, this study being the first of its kind to look at the neurological differences between live and recorded music may help future research in determining the next best steps to increasing the knowledge base on this topic.

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APPENDIX A

**Pre-Screening Document**

Name:

1. Are you between the age of 18 and 60? Yes/No (please circle one)

2. What is your gender? ________

3. Are you right-handed or left-handed?

4. Have you played or studied an instrument (including vocal studies) in private instruction for longer than one year over the past five years?

5. Do you have a diagnosis that may affect processing in the brain?
   Yes/No (please circle one)
   If you answered yes, please list:
   ______________________________________________
   ______________________________________________
   ______________________________________________

APPENDIX B

## Musical Background Questionnaire

Participant Number _______

1. Which of the following activities have you participated in?

a. Play in a band Yes_____ No______

If you answered yes, for how long did you participate in this activity?

0-6 months_______6 months-1 year________1 year to 2 years_________2+years________

b. Play in an orchestra Yes_____ No______

0-6 months_______6 months-1 year________1 year to 2 years_________2+years________

c. Sing in a chorus or choir Yes_____ No______

0-6 months_______6 months-1 year________1 year to 2 years_________2+years________

d. Take private singing lessons Yes_____ No______

0-6 months_______6 months-1 year________1 year to 2 years_________2+years________

e. Take private lessons on an instrument Yes_____ No______

0-6 months_______6 months-1 year________1 year to 2 years_________2+years________

f. Participated in musical theatre Yes_____No_______

1-3 times________4-6 times________7+ times________

2. Do you have your own musical instrument? Yes_____ No______

If you answered yes to this question, how often do you play it?

Never_______Almost never________Occasionally_________Often________Frequently______

3. Do you have any family members that play a musical instrument? Yes______ No________

4. What kinds of musical experiences have you had that were not listed above?

APPENDIX C

## Neurologic History

1. Do you have any past history of head injury? Yes/No
   If you answered yes, please describe approximate location (e.g. back of head), severity, and diagnosis if applicable:
   ________________________________________
   ________________________________________
   ________________________________________

2. Have you ever experienced loss of consciousness? Yes/No
   If you answered yes, please describe approximate length of time consciousness was lost.
   ________________________________________
   ________________________________________
   ________________________________________

3. Do you have any neurological conditions or disorders? Yes/No
   If you answered yes, please list:
   ________________________________________
   ________________________________________
   ________________________________________

4. Have you ever experienced a seizure?
   0 times 1-2 times occasional seizures frequent seizures

5. Do you have any cognitive difficulties such as memory loss, facial recognition, difficulty with recall, etc.? Yes/No
   If you answered yes, please describe
   ________________________________________
   ________________________________________
   ________________________________________

APPENDIX D

## Substance Use

Participant Number _______

Please answer the following questions to the best of your ability. Leaving any question blank will not affect your eligibility to participate.

1. How old are you? ______

2. What is your gender identity? ________

3. In the past 24 hours, have you used the following?
   Alcohol
   1-2 drinks______3-4 drinks______4+ drinks_________
   Tobacco products
   Yes____ No_____
   Prescription Drugs for Non-Medical Reasons
   Yes____ No_____
   Illegal Drugs
   Yes____No_____

4. In the past year how often have you used the following?
   Alcohol
   Never____Once or Twice____Monthly____Weekly____Daily or Almost Daily______
   Tobacco product
   Never____Once or Twice____Monthly____Weekly____Daily or Almost Daily______
   Prescription Drugs for Non-Medical Reasons
   Never____Once or Twice____Monthly____Weekly____Daily or Almost Daily______
   Illegal Drugs
   Never____Once or Twice____Monthly____Weekly____Daily or Almost Daily______

APPENDIX E

## Consent to Participate in a Research Study
## Colorado State University

**TITLE OF STUDY**: *Differences in Cortical Activation with Live Music Compared to Recorded Music: A fNIRS Study*

**PRINCIPAL INVESTIGATOR**: Blythe LaGasse, PhD; Music, Theatre and Dance; Blythe.LaGasse@colostate.edu; 970-491-4042

**CO-PRINCIPAL INVESTIGATOR**: Carly Flaagan, MT-BC, Graduate Student; Music, Theatre and Dance; carly.flaagan@colostate.edu; 701-215-0529

**WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?** You qualify for this research
study if you are a right-handed adult between the ages of 18 and 60 who has not played or studied an instrument for longer than one year over the past five years. Your participation may help create better understanding of how our brains react to varied music stimuli.

**WHO IS DOING THE STUDY?** The research team consists of music therapist Dr. Blythe LaGasse,
And graduate music therapy student and music therapist Carly Flaagan
Carly will be the interventionist in this study.

**WHAT IS THE PURPOSE OF THIS STUDY?** The purpose of this study is to see if there are differences in cortical activation between live and recorded music stimuli.

**WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST**? Should you fit the eligibility criteria, Carly will ask that you complete a musical background questionnaire, neurological history questionnaire and a pretest questionnaire regarding drug and alcohol use. All answers will be confidential. These will take approximately an hour or less. One fNIRS neuroimaging session will be required which will be held at Clark A on Colorado State University Campus. The session will last 75 minutes or less. The total time commitment is approximately 2-3 hours.

**WHAT WILL I BE ASKED TO DO**? You will be asked to complete the above mentioned questionnaires and attend one fNIRS session. During the fNIRS session, you will be fitted with a cap containing light emitters and detectors that will measure blood oxygenation level changes during the interventions. There is no risk with wearing this cap. You will be asked to listen to auditory stimuli while tapping your legs in synchrony with researcher. No musical ability is required.

**ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?** You must be between the ages of 18 and 60 years old to participate in the study. You must also be right-handed, have no previous association with the researcher, and not have played or studied an instrument for longer than one year over the past five years.

**WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?**
➢ It is possible that it may be slightly uncomfortable to wear fNIRS cap as it fits snugly on your head.

**ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY?** There are no direct benefits that are anticipated to occur from taking part in this study.

**DO I HAVE TO TAKE PART IN THE STUDY**? Your participation in this research is voluntary. If
you decide to participate in this study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

**WHO WILL SEE THE INFORMATION THAT I GIVE?** We will keep private all research records
that identify you, to the extent allowed by law. For this study, we will assign a code to your data (i.e. 0001) so that the only place your name will appear in our records is on the consent and in our data spreadsheet which links you to your code. Only the research team will have access to the link between you, your code, and your data. The only exceptions to this are if we are asked to share the research files for audit purposes with the CSU Institutional Review Board ethics committee, if necessary. When we write about the study to share with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study, however, we will keep your name and other identifying information private.

You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court or tell authorities if we believe you pose a danger to yourself or someone else, you have abused a child, or someone who is in a position of power over a minor has abused a child.

**CAN MY TAKING PART IN THE STUDY END EARLY?** You can choose to leave the study at any
time without penalty.

**WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?**
Your name will be entered in a drawing for one of two $25 gift cards.

**WHAT IF I HAVE QUESTIONS?** Before you decide whether to accept this invitation to take part inthe study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the co-principal investigator, Carly Flaagan, at Carly.flaagan@colostate.edu. If you have any questions about your rights as a
volunteer in this research, contact the CSU IRB at: RICRO_IRB@mail.colostate.edu; 970-491-1553. We will give you a copy of this consent form to take with you.

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing two pages.

______________________________________________ ____________
Signature of person agreeing to take part in the study Date

______________________________________________
Printed name of person agreeing to take part in the study

____________________ ____________
Signature of Research Staff Date

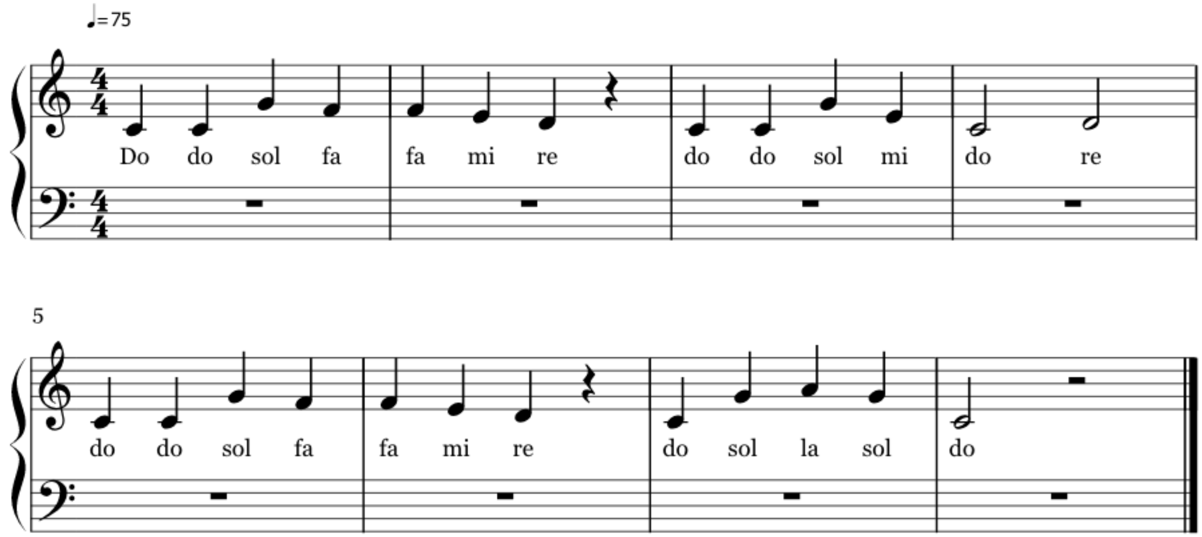


*Figure 8.*
Musical Excerpt

Spoken:
Do, do, sol, fa, fa, mi, re,
do, do, sol, mi, do, re,
do, do, sol, fa, fa, mi, re,
do, sol, la, sol, do

*Figure 9.*
Spoken Word Transcript