HEART RATE ENTRAINMENT TO EXTERNAL AUDITORY RHYTHM: A PILOT STUDY

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ABSTRACT

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Heart rate entrainment to external auditory rhythm has numerous applications to clinical music therapy practice, including increasing arousal or inducing relaxation. However, research regarding the ability of heart rate to entrain to external auditory stimuli is contradictory or incomplete, leading to questions regarding this phenomenon. Thus, the current study was conducted to investigate if heart rate can entrain to external auditory stimuli.

Eighty-four participants were randomly placed into three testing groups. The baseline heart rate of each participant was measured over a 5 minute period, then, depending on the group, 7%, 10% or 15% was subtracted from the baseline to get the target heart rate. An external auditory stimulus was then played at the target rate for a 15 minute period while heart rate was continuously monitored.

Results indicated that there is a possibility of heart rate entrainment at the 7% and 10% level, with statistically significant differences observed between the 7% and 10% groups as well as the 7% and 15% groups. These results align with ideas from previous research and can act as the groundwork for future research exploring heart rate entrainment to other forms of auditory stimuli. The findings from this research could also be used to help music therapists select tempi that are appropriate for relaxation interventions. These findings could also be used for additional research investigating the use of heart rate entrainment as a physiological indicator of consciousness in patients under the disorders of consciousness umbrella.

KEY WORDS: Rhythm, Entrainment, Heart rate, Synchronization, Music therapy

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TABLE OF CONTENTS

CHAPTER I

Introduction

Music involves many different elements, such as rhythm, tempo, melody, meter, and timbre, coming together. When a person is exposed to music, the brain processes all of these elements to make sense of the input provided by the auditory system (Stewart, Von Kriegstein, Bella, Warren, & Griffiths, 2009). This processing occurs bilaterally in the brain, and distinct neural areas are involved in processing the different musical components. For example, rhythm activates regions in the right anterior insula and various cerebellar areas while tempo activates regions in the posterior insula and postcentral gyrus (Stewart, Von Kriegstein, Bella, Warren, & Griffiths, 2009).

As music is processed in the brain, physiological changes begin to occur in a wide variety of body systems including those involved in cardiovascular, respiratory, inner secretion and metabolism, immune, external secretion and exertion, reception and perception, and motor control functions (Leins, Spintge, & Thaut, 2009). In the presence of music, changes in the cardiovascular system may include decreases in heart rate and arterial blood pressure. Additionally, the rhythmic consistency of the heart rate improves because abnormalities are reduced (Leins, Spintge, & Thaut, 2009). Research has also illustrated that breathing, a function of the respiratory system, can synchronize with external auditory rhythm (Cysarz et al., 2004).

While breathing can be controlled with volition, it is intrinsically a function of the autonomic nervous system. By using the six section rhythm of the hexameter verse in ancient Greek poetry, Cysarz et al. were able to synchronize low-frequency breathing patterns as well as sinus arrhythmia (2004). These findings suggest that it might be possible for autonomic bodily functions, such as respiration or heart rate, to entrain to external auditory rhythmic stimuli.

In addition to breathing, research has explored how music affects heart rate and related cardiovascular functions. However, these studies' results are mixed in terms of outcomes. For example, Bernardi, Porta, and Sleight found that fast tempi can raise ventilation rate, blood pressure, and heart rate (2006). The results from their study also indicated that pauses between music can decrease heart rate, blood pressure, and minute ventilation. Overall, they found that music arouses individuals while breaks can help them to relax.

In contrast to the previous study, Bernardi et al. (2006), do Amaral et al. found that neither baroque nor heavy metal music, presented at several different volumes, had an effect on heart rate variability in men (2014). In a follow-up study the next year, do Amaral et al. found that baroque music still did not change heart rate, but that heavy metal music reduced heart rate variability in women (2015).

In addition to mixed outcomes, these studies also utilized small sample sizes (24, 16, and 24 respectively), did not include a variety of musical genres, and did not use standardized procedures for selecting the music. Thus, the studies are difficult to compare even though they attempt to research the same phenomenon. Additionally, the studies explored the uses of music to change the heart rate, but did not attempt to synchronize heart rate to music.

Entrainment, the synchronization of two or more systems, was discovered by Christiaan Huygens in the 17th century and was described in a letter to his father ("Circulation of Knowledge and Learned Practices in the 17th-century Dutch Republic," n.d.). Huygens, who was the inventor of the pendulum clock, noticed that two of his clocks sitting close to each other synchronized after a short period of time. Since then, entrainment has been a concept explored by researchers in many fields such as physics and biology.

In the literature, several distinct types of entrainment are defined. Clayton categorized entrainment into three separate categories: intra-individual, inter-individual or intra-group, and inter-group (2012). Intra-individual entrainment takes place when two or more systems within an individual synchronize. Inter-individual or intra-group is when two or more individuals within the same group synchronize. Inter-group is when the activities of two or more groups synchronize. Huygens' discovery was inter-individual entrainment because it was the synchronization of two pendulums. Circadian rhythm is an example of intra-individual entrainment, since it takes place within an individual.

Another example of intra-individual entrainment involves synchronization of the human motor system to external auditory rhythm, which has numerous implications for music therapy and rehabilitation. One of the most notable researchers in this area, Michael Thaut, published an article exploring the effects of rhythmic auditory cuing on normal gait patterns (Thaut, McIntosh, Prassas, Rice, 1992). The results from this study showed that the rhythmic stimulation was able to entrain individual gait cadences, thereby improving the gait of individuals as well as shortening and decreasing variation in the activation of the calf muscles. This shortened and decreased variation in activation of the muscles was a direct result of motor neuron entrainment to the auditory stimulus. Since this article's publication, researchers in different fields, including music therapy, have continued to explore the idea of motor entrainment to rhythm. The findings from Thaut's study have been replicated many times and with several different populations including stroke (Thaut, Mcintosh, Prassas, & Rice, 1993), traumatic brain injury (Hurt, Rice, Mcintosh, & Thaut, 1998), Parkinson's disease (Thaut et al., 1996), and others.

Need for the Study

While research exists exploring heart rate change in the presence of music and entrainment of motor and respiratory functions to rhythm, respectively, a paucity of research exists specifically exploring the ability for external auditory rhythmic stimuli to entrain heart rate. The research that does exist is reported as having small sample sizes (N = 15-25) and contradictory results.

Theoretical relevance. The present study has several theoretical and practical implications. Theoretically, this study sought to discover if entrainment occurs and at what tempi, slower than the initial value, the heart will entrain to rhythm. The results from this study could be expanded upon in future research exploring the entrainment of heart rate to other stimuli.

Practical relevance. This study also has practical relevance. There is limited information about the actual entrainment of heart rate to various elements of music. The current study addressed this gap by focusing on the entrainment of heart rate to rhythm. This study could also help music therapists to develop intervention protocols for relaxation techniques, such as techniques that involve heart rate reduction, in order to most effectively assist clients during sessions.

Research Questions

The following research questions were addressed in this study:

1. Can heart rate entrain to external auditory stimuli?

2. Does the auditory stimulus's deviation from baseline (-7%, -10%, -15%) have an impact on entrainment?

Definition of Terms

Entrainment. Throughout this study, the term entrainment refers to intra-individual entrainment, unless otherwise specified. Intra-individual entrainment is defined as the synchronization of body parts or systems within an individual (Clayton, 2012). For data analysis, entrainment was classified as the heart rate reaching and maintaining target value or ±1 for at least 10 seconds. Research has not been previously completed exploring the temporal limits required to classify an event as entrainment. Therefore, the 10 second time period was arbitrarily selected by the researcher. The heart rate did not need to synchronize beat-to-beat for entrainment to occur.

Heart rate. Heart rate, according to the American Heart Association, is "the number of times your heart beats per minute" (2016).

Purpose of the Study

The purpose of this study was to determine if heart rate entrained to rhythm presented at 7%, 10%, and 15% slower than the individual's baseline rate.

CHAPTER II

Review of Literature

This literature review first discusses the physiological responses that occur when a person is exposed to music. This section explores both the subconscious, with brain activation and entrainment, and the autonomic nervous system, with the heart. The next section explore research on entrainment of both the sensorimotor system and other physiological responses, such as respiration rate, blood flow, and heart rate. This chapter concludes with a summary of the research and aims of the current study.

Music and Physiologic Responses

Music and brain activation. Music can have a profound impact on the conscious person. It can give a person goosebumps, make a person smile, or even bring a person to tears. Brown, Martinez, & Parsons investigated how the brain would respond to music during a passive listening activity (2004). In their study, 10 individuals who identified as non-musicians were selected as participants. The participants passively listened to researcher-selected musical samples while having a PET scan.

The PET scan results showed activation in multiple regions of the brain, including parts of the primary auditory cortex, temporal sulcus, temporal gyrus, insula, subcallosal cingulate, retrosplenial cortex, and hippocampus. These areas are all part of the limbic and paralimbic systems, and are responsible for tasks such as emotional processing, perception, and cognition. These results indicate that music is processed in multiple areas of the brain of a conscious individual.

Music also has the ability to impact the subconscious of an individual. In 2015, Steinhoff et al. explored how music can affect the subconscious. Specifically, they wanted to see how music therapy would influence the activation of the frontal, hippocampal, and cerebellar regions of the brain in patients with unresponsive wakefulness syndrome (UWS). They selected four individuals who had been previously diagnosed with UWS to participate in the study; two participants were used as the control group and two participants received music therapy. The music therapy sessions occurred over a five week period, three times per week, with approximately 27 minute long sessions. PET scans were used to measure tracer uptake for the selected brain regions.

While the authors cautioned about making generalizations because of the small sample size, their results showed a statistically significant difference in tracer uptake between the control and experimental groups. Throughout the study three different PET scans were taken, one during pre-test and the other two during the first and last music therapy sessions. The largest difference in uptake was noted between the second and third scans. For the frontal, hippocampus, and cerebellar regions, the music therapy group saw a 37%, 28%, and 38% increase in tracer uptake, respectively, between the second and third scans. The difference between the regions for the control group was 7%, 4%, and 2%, respectively (Steinhoff et al., 2015). For the differences in tracer uptake, the experimental group had a larger level of uptake when compared to the level found in the control group. A larger level of uptake represents a larger level of brain activation.

The results from this study indicate that music can have a significant impact on activation in the brain, even in patients with UWS. However, the sample size for this study was very small and conclusions should be tentative. Additional research or replication with a larger sample size is needed to validate these findings. Despite the lack of research in that area, researchers have investigated effects of music and rhythm on other areas of the subconscious, including entrainment.

Music and subconscious entrainment. The effect of stimuli on the various physiological systems has been researched since the 19th century. E.H. Weber, one of the researchers who explored those effects, developed the Weber Law (Epstein, 1985). This law led to the Weber fraction which has been the foundation of research investigating the limits of conscious perception. Research by Mach (1865) and Getty (1975) found that the conscious is not able to perceive an auditory tempo change that is less than 5-7% (as cited in Epstein, 1985). This concept was used as the basis for the determination of the groups in the current study and was also utilized by Thaut, Tian, & Azimi-Sadjadi in 1998 to explore subconscious synchronization to auditory stimuli.

Thaut, Tian, & Azimi-Sadjadi evaluated whether the subconscious could adjust and entrain to changes in tempo (1998). Six participants were instructed to tap a pencil, which was connected to an electrode, in time with the presented auditory stimulus. The stimulus was modulated over time at a level that was below the conscious perceptual threshold and the participants were not informed that there was a modulation.

In analyzing the data from the study, the participants were able to synchronize their tapping with the modulations, even though they could not consciously perceive a change. This shows that there are subconscious processes involved in the entrainment of the motor systems to external auditory stimuli, but does not look at which areas of the brain are involved in this process. Stephan et al. expanded on this study in 2002 to explore which areas of the brain were activated.

Stephan et al. modulated rhythmic sequences both below and above the level of conscious perception (2002). Nine participants were selected and were instructed to tap their finger to the various rhythmic sequences. The percentage difference of conscious perception used in this study was 5%. One modulation was set below (3%), one was set slightly above (7%), and one was set high above (20%) the level of conscious perception.

For the 3% change, none of the participants were able to notice the modulation. For the 7% change, 33% of the participants were able to notice the modulation. For the 20% change, all participants were able to notice the modulation. An anticipatory response (before the beat) was observed in the participants who were not able to notice the modulation during the 3% and 7% change. The participants who were able to notice the modulation in the 7% and 20% change exhibited a reactive response (after the beat) to the stimuli.

These findings indicate that there are different brain regions activated while processing external stimuli at the subconscious and conscious levels. The results from this study also support earlier studies indicating that entrainment to external auditory stimuli can occur at a subconscious level. As mentioned earlier, the brain areas activated during these subconscious processes are part of the limbic system, and include functions of the autonomic nervous system (ANS), such as respiration rate and heart rate.

Music and heart rate variability. The effect of music on heart rate variability (HRV), the change in heart rate over a period of time, has been the subject of many research articles in recent years. The majority of this research is focused on how different genres of music impact HRV. One such article by Pérez-Lloret et al. looked at different styles of relaxing music on HRV (2014). Three different styles of relaxing music were selected for this study and included classical, new age, and romantic. Twenty-eight Participants listened to each selection while their heart rate was continuously monitored with an electrocardiogram.

The results from this study indicated that the new age style had a statistically significant change in HRV when compared to silence. Neither the classical nor romantic styles had a statistically significant change when compared to silence. The authors for this study also compared musical preference to HRV and did not find a statistically significant relationship.

This study utilized a small sample size, making it difficult to generalize these findings. The authors also did not check to see if the participants were familiar with any of the musical excerpts and selected the songs because they were considered relaxing based on a previous study. Other studies have attempted to use genres to organize musical selections to see their effects on HRV, but have ended up with contrasting results.

Two popular genres that have been compared in literature are heavy metal and baroque. One such study was performed by Roque et al. in 2013. Forty participants, who had no previous experience with musical instruments and who did not express preference for either of the two genres, listened to five minutes of each genre while their heart rate was continuously monitored.

The authors concluded that both heavy metal and baroque music decrease HRV. The authors stated that the reason for this decrease was because of equivalent sound levels throughout the tests (Roque et al., 2013). However, the authors did not test various sound levels in order to run a statistical analysis. Instead, they used other research to draw conclusions. The lack of supporting data coupled with the low sample size leaves this study with unreliable generalizability.

Silva, Guida, Antônio, Vanderlei, et al. conducted a similar study in 2014. The participants for this study were 12 men who had no previous experience with musical instruments and who did not express preference for either heavy metal or baroque music. The procedure and songs used were the same as the study by Roque et al. (2013).

Unlike the Roque et al. study (2013), the study by Silva, Guida, Antônio, Vanderlei, et al. showed that only heavy metal music decreased HRV. The authors did not check for familiarity of the pieces for each participant and this study also had a small sample size. Because of these factors, this study cannot be used to easily generalize to other populations.

In 2015, do Amaral et al. performed a study comparable to the two previously mentioned. However, each of the 24 female participants listened to three different intensities of the same song for 5 minutes. The researchers used the same baroque and heavy metal selections used in the previous two studies.

The data from this study indicated that the baroque music did not have an impact on HRV, but that the low and high intensities of the heavy metal music decreased components of HRV. The results from this study directly contradict Roque et al.'s (2013) conclusion that HRV was consistent because of equivalent sound levels. If this were the case, the HRV for each genre would be equal for each varying intensity. do Amaral et al. (2015) speculate as to why there would be a difference between the different intensities of music, but do not offer a conclusive reason.

A follow-up study was performed in 2016 by Vanderlei, de Abreu, Garner, & Valenti. There were 22 female participants who were selected based on exclusion criteria such as weight, blood pressure, disorders, and menstrual cycle. This study followed the method of previous studies, but had a week rest period between musical genre samples.

The study found that there were no changes to HRV during the baroque musical selection but that there were changes to components of HRV during the heavy metal music. While the time difference controlled for the different genres, the study is still difficult to generalize because of the small sample size.

Another major problem for all of the studies mentioned so far in this section, except for the study by Pérez-Lloret et al., was music selection. All of those studies used one song for the heavy metal selection. Each study, except for Vanderlei, de Abreu, Garner, & Valenti (2016), used the same song for the baroque selection. None of these studies test for familiarity of the presented songs. Additionally, the authors used a very small sample of songs to represent an entire genre of music. These factors reduce the validity of the generalizations that the authors make. While results for research involving music's effect on heart rate variability are generally contradictory, research on rhythmic entrainment of the sensorimotor system supports the concept.

Rhythmic Entrainment

Rhythm and sensorimotor response. The idea of using music or rhythm to influence sensorimotor responses has been under investigation for over 20 years. Some of the earliest research exploring this phenomenon was published in 1992 by Thaut, McIntosh, Prassas, & Rice. Sixteen healthy adults without sensory or motor impairments were used as participants for the study. Muscle activity was measured by electromyography and stride data was measured by a pressure sensitive walkway.

Participants were first instructed to walk at a speed that was comfortable. The speed at which each participant walked was then calculated and used as the tempo of an external auditory stimulus for the next round of walking. This process was repeated for a tempo slightly slower and faster than the initial tempo.

The results from this study indicated that participants experienced less deviations in muscle activation onset and duration as well as a decrease in motor neuron activity when the auditory stimulus was present. The data also showed that there was an increased symmetry in the stride pattern. These results demonstrated how the sensorimotor system could use the external rhythm as a priming mechanism for the motor neurons. The rhythm helped gait-related musculature to become more efficient in the movement process.

A follow-up study was performed in 1993 by Thaut, McIntosh, Prassas, & Rice. The 10 participants had recently experienced a cerebrovascular accident (CVA) and were hemiparetic. The method was the same as that of the 1992 study, but without the slower and faster conditions. The study took place over a five week period with a total of three testing sessions per participant.

Results were similar to the study from 1992. Participants had better weight bearing distribution, had a more normalized stride, and had decreased variation in muscle activation. The data from this study helped to expand the generalizability of the previous study to a larger population. It also opened the door for rhythmic auditory cuing research with other sensorimotor diseases, such as Parkinson's disease.

Thaut et al. published an article in 1996 exploring the effects of rhythmic auditory stimulation (RAS) on the gait of patients with Parkinson's disease. Each of the 20 participants selected was diagnosed with Parkinson's disease. The study was a pre-test/post-test design with a three week testing period. The control group was instructed to carry out normal activities during the three weeks. The experimental group was given a program for RAS which included different walking exercises at three different tempi.

The data showed no statistically significant difference in the gait from pre-test to post-test for the control group. For the experimental group, there were statistically significant improvements in gait velocity, cadence, and muscle activation as well as an increase in stride length. Additional research by Thaut and others continues to explore how RAS can be used most effectively with a variety of populations.

Over the past few decades, much research has been done on both the effect of music on heart rate and the effect of rhythmic entrainment on sensorimotor function. However, there is a large gap in the research when combining the two by looking at the effect of rhythmic entrainment on heart rate.

Rhythm and physiological response. The research that has been published about physiological responses to rhythm is scarce and contradictory. One such study was published in 2008 by Khalfa, Roy, Rainville, Bella, & Peretz. The authors set out to discover if the psychophysiological responses to happy or sad music were a result of the music itself or were instead caused by entrainment to variations in tempo or rhythm. The authors isolated tempo and rhythm as well as rhythm by itself and compared the results to the original music.

Participants for the study were 50 healthy volunteers who had never received musical training. Data were collected for several different psychophysiological responses, but only heart rate will be examined during this review. The results showed that there was not a statistically significant effect of heart rate on differentiation of happy and sad music. Thus, the music's emotional content did not have an impact on physiological responses of the participants.

The authors did note there was a tempo entrainment which occurred in the tempo only condition. The results showed that the effect seemed to disappear if the tempo was embedded in music. While it was not the aim of the study, these results could imply that tempo entrainment is possible as long as the stimuli presented is solely rhythm. Unfortunately, the research in this area can be contradictory.

Silva, Guida, Antônio, Marcomini, et al. published an article looking at how the heart rate responds to different rhythm and tempi (2014). The authors selected 11 male students with no known health issues as participants, excluding those with physiological, psychological, or neurological disorders. The experiment was run as a pre-test/post-test with a 40 minute experimental window. During the 40 minutes, participants listened to 20 minutes of heavy metal and 20 minutes of baroque music.

Results from the experiment did not show a statistically significant change in HRV, even when measured on 5 minute increments. Similar to other studies discussed thus far (Roque et al., 2013; Silva, Guida, Antônio, Vanderlei, et al., 2014; do Amaral et al., 2015; Vanderlei, de Abreu, Garner, & Valenti, 2016), the musical selection was limited in scope. For the Silva, Guida, Antônio, Marcomini, et al. study, only one piece of music was selected to represent an entire genre. Additionally, the familiarity of the song to the participants is not discussed.

By contrast, Bernardi et al. conducted a study in 2009 exploring the relationship between music and physiological functions. The responses to rhythmic phrases will be discussed in this review. Bernardi et al. selected a specific piece to use because of the length of its musical phrases. The musical phrases in the specific piece were similar to that of the circulatory oscillations, Mayer waves of blood pressure, found in humans. Participants in the study were 24 healthy subjects, 12 of whom had extensive music training while the other 12 subjects had no previous musical training.

The study found that the inherent cardiovascular rhythms were able to synchronize throughout subjects to around .1 Hz. This synchronization occurred without the entrainment of respiration to the phrase. Because of the results from this study, the authors speculate that there is the possibility of modulating cardiovascular rhythm once it has entrained by changing the length of the musical phrase.

Summary of the Literature Review

As stated above, there is a gap in research involving heart rate entrainment to rhythm. The research that has been done has small sample sizes, involves speculation on the part of the authors, and yield contradictory results. Additionally, this research is focused on heart rate variability or other physiological responses, but not heart rate entrainment.

The aim of the current study was to bridge this gap and to provide basic research for the field of music therapy. If the correct tempo and amount of time it takes for the heart to entrain to rhythm can be discovered, it would be beneficial to both the clinical and research fronts of music therapy. Clinically, this study provides a basic framework from which interventions could be developed for seeing physiological responses from the disorders of consciousness population. Information from this study may also be used to help set guidelines for the correct tempi at which music therapists should conduct relaxation exercises. On the research front, data compiled from this study could be used as the foundation for future research focused on modulating heart rate once it has entrained to the rhythm.

CHAPTER III

Method

Research Design

The current study was an experimental study and utilized a single-factor (tempo change: -7%, -10%, -15%) design. The dependent variable was heart rate entrainment to the target value. The purpose of this study was to determine if heart rate will entrain to external auditory rhythm presented at 7%, 10%, and 15% slower than baseline.

Sample

Eighty-four Sam Houston State University Students (20 male and 64 female) were selected through convenience sampling as participants for this study. The age of the participants ranged from 18-54 (average age of 22.6 years). The data from 84 participants were used during data analysis. While a total of eighty-six individuals initially met with the researcher to participate in the study, two participants were excluded from taking part due to having either a resting or target heart rate below 50 bpm; and no data was collected from these individuals. Participants were randomly sorted into the testing groups. Thirty-one participants were in the 7% group, 26 participants were in the 10% group, and 27 participants were in the 15% group. Participants were obtained through the Sam Houston State University Psychology Experimental Research Participation (PeRP) System (see Appendix A).

Materials

At the beginning of the study, participants completed a written questionnaire with demographic questions (see Appendix B). Heart rate during the experiment was measured using the INNOVO CMS 50F Plus Pulse Oximeter. Participants were given a pair of Sony headphones, Model MDR-NC7. The Android application, Mobile Metronome by Gabriel Simões was used for the metronome. The application was run on a Samsung Galaxy S4 with the phone volume at 66% and the application volume at 25%. A headphone splitter was added to the headphones with an auxiliary cable leading to a portable speaker. The speaker was set to the lowest volume and positioned next to a microphone. The microphone was attached to a speaker in an observation room. An iPad Air 2 was used to show a 15-minute segment of a nature video, with the audio muted, during the experiment. This video was used as a visual distraction from the auditory stimulus during the testing period. The heart rate from the pulse oximeter was sent to a computer via Bluetooth and was monitored and recorded in real time. Two privacy walls were made of PVC pipe and white sheets were set up to block a portion of the room.

Figure 1. Room setup.

Participants were seated on a couch situated next to a table slanted at a 45-degree angle. A paper instructing the clients to remove the headphones after the video ended was placed in front of the iPad on the table (see Figure 1).

Procedural Details

Participants registered for the study through university PeRP system. On the day of testing, the participants came to the Music Therapy Clinic on Sam Houston State University's campus. The participants were led into the clinic and asked to have a seat on the couch next to the table. After the participants were seated, they were given an informed consent form(see Appendix C). Once the participants read and signed the informed consent, they were given a questionnaire to complete.

Once the participants finished the questionnaire, the researcher attached the pulse oximeter to their left wrist and index finger. The researcher instructed the participants to place their left hand on the couch and move it as little as possible during the study. The researcher told the participants that they could sit back and relax for the first five minutes and asked the participants to stay off their phones for the duration of the study. Baseline heart rate data was taken during the first five minutes. The baseline average was calculated by taking the average of the heart rates at 3:30, 4:00, 4:30, and 5:00 minutes in to the study. The target value was then calculated based on the participant group (7%, 10%, or 15% lower than the baseline heart rate).

After the first five minutes, the researcher came back into the testing area. The researcher informed the clients that they would be wearing headphones for the next portion of the study. The researcher also informed the clients that there would be a video playing on the iPad and to use their right hand to remove the headphones at the conclusion of the video. The researcher set the target value on the metronome and placed the headphones on the participants. The researcher then started the video and went into the observation room to watch the participants through a one-way mirror for the duration of the study.

The researcher then entered the testing area and informed the participants that the study was over. The researcher informed the participants what the study was measuring and asked the participants if they had any questions, comments, or concerns. The researcher told the participants that they would be receiving credit for the study in the following days and thanked them for participating.

CHAPTER IV

Results

The purpose of this study was to see if heart rate could synchronize to external auditory rhythm and if the group that participants were placed into had an impact on the percentage of participants who entrained. Participants were divided into three different groups (-7%, -10%, and -15%) and rhythm was presented below baseline according to the group placement. Data was measured five minutes before the rhythm was presented and for the 15 minute duration of the rhythm presentation.

Participant Demographics

Eighty-four Sam Houston State University Students (20 male and 64 female) were selected through convenience sampling as participants for this study. The age of the participants ranged from 18-54 (average age of 22.6 years). Table 1 displays frequency counts for participants' ages and genders. The average height of the participants was 65.81 inches (*SD* = 3.63) and the average weight of participants was 162.89 (range of 102-310) pounds. Twenty-three participants said they participated in sports, 23 considered themselves athletes, and 20 considered themselves musicians. The average number of days per week that participants played sports was .46 (*SD* = .94) and the average years participants took music lessons was 2.26 years (*SD* = 2.81). Three participants reported that they were on medication that could affect heart rate and 3 participants stated that they smoked at least once a day.

Table 1

Frequency of Participant Demographics

Demographic Variable		Frequency
Age (in years)		
	18	25
	19	25
	20	17
	21	2
	22	6
	23	4
	28	1
	34	1
	38	1
	42	1
	54	1
Gender		
	Male	20
	Female	64

Three participants also reported that they had heart rate abnormalities. Participants exercised for an average of 2.85 days per week (see Figure 2).

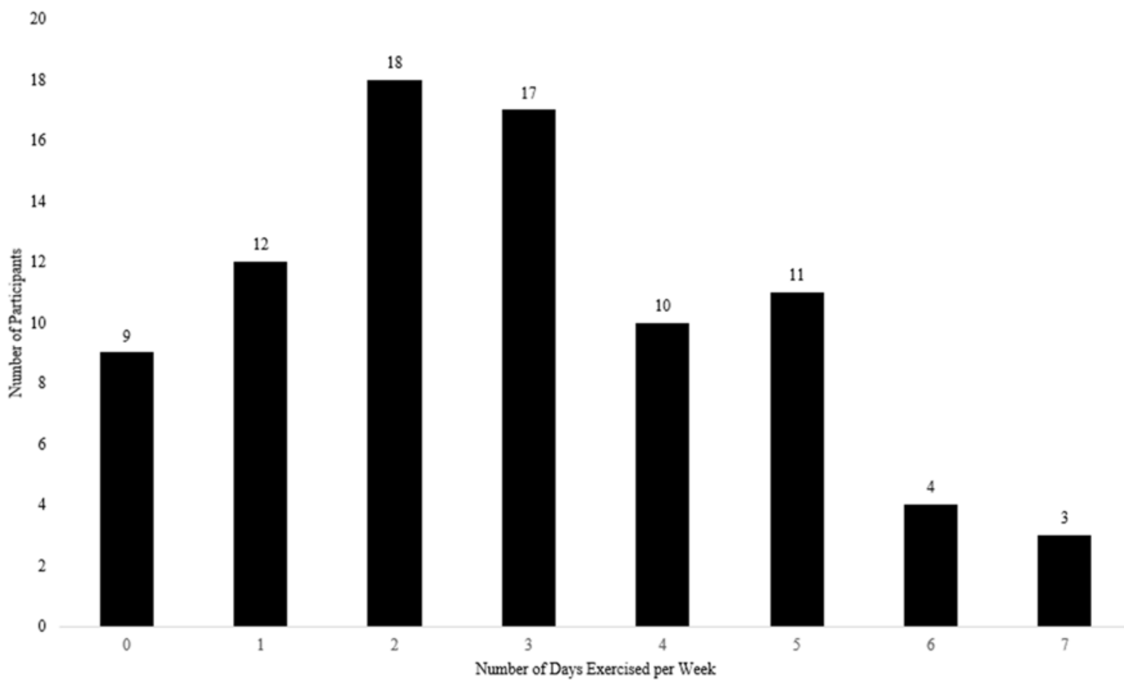

Figure 2. Days exercised by participants.

Inferential Results

A binary logistic regression analysis was performed to predict the entrainment of heart rate to one of three testing tempi. According to the guidelines set forth in this study, where heart rate is considered to entrain if it is in synchrony with the rhythm for at least 10 seconds, 93.55% of participants in the 7% group, 73.08% of the participants in the 10% group, and 25.93% of the participants in the 15% group were able to entrain (see Figure 3). Of the participants who entrained, 13 participants (41.94%) in the 7% group and four participants (15.38%) in the 10% group met the requirements for entrainment during the five minute period before the auditory stimulus was introduced. The data from these participants was included in the binary logistic regression analysis.

When comparing the full model to the constant only model the resulting difference was statistically significant, $\chi^2 = 35.802$, $p < .001$ with $df = 6$. This result indicates that the independent variables and covariates had a significant impact on the model. The value for Nagelkerke R^2 was .479, showing a medium relationship between the prediction and the predictors. Before the predictors are added to the equation, the model could predict the outcome with 65.5% accuracy. After the predictors were added, the model could predict the outcome with 81.0% accuracy, indicating an improvement with the addition of the predictors.

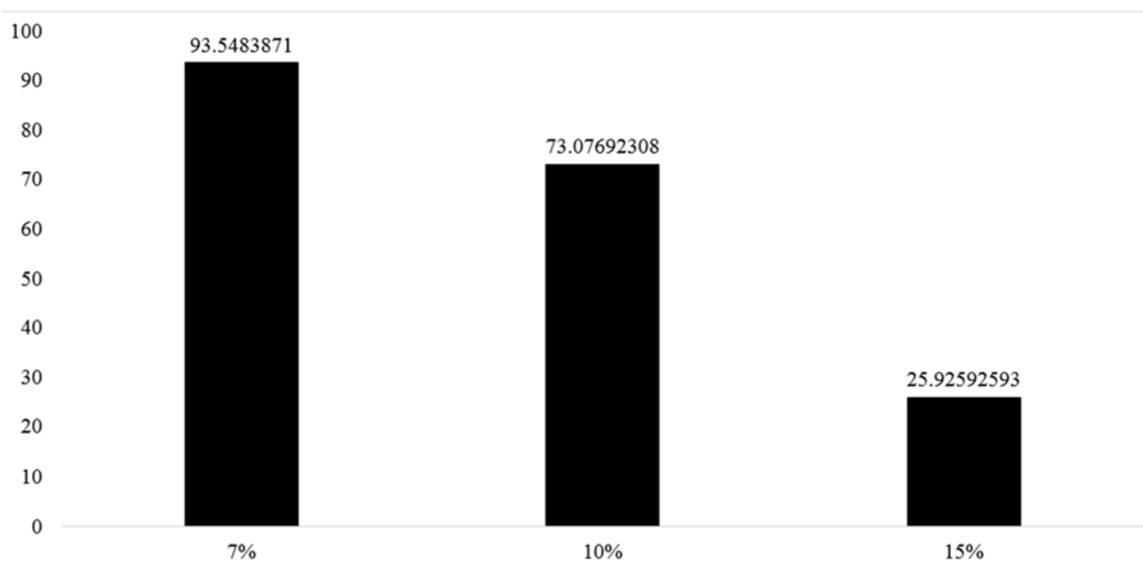

Figure 3. Percentage of participants who entrained. This graph shows the percentage of participants in each group whose heart rate entrained to the target value.

The Homer and Lemeshow Test was not significant with a value of .657, indicating a strong goodness-of-fit. This means that there is not a statistically significant difference between the predicted model and the observed values. Only one participant was placed on the casewise list, meaning there was only one case which could be considered an outlier in the data set.

When looking at the independent variables and covariates, the number of days that the participant exercises per week, heart rate medications, heart abnormalities, and gender were not statistically significant. The Wald χ^2 statistics for the 7%, 10%, and 15 % groups were statistically significant, $p < .001$, $p < .05$, and $p < .001$ respectively. The 10% group was 9.01% less likely than the 7% group to entrain to the tempo. The 15% group was 90.91% less likely than the 7% group to entrain to the tempo.

CHAPTER V

Discussion

This study was one of the first studies to explore the relationship between heart rate entrainment and rhythm, and the findings appear to be significant. This discussion will begin by exploring the data and comparing it to past research. Implications of the results will then be considered, followed by some of the study limitations. Finally, suggestions for future research on this topic will be discussed.

Heart Rate Entrainment

Results indicated that participants' heart rates entrained at external auditory stimuli presented at 7%, 10%, and 15% lower than baseline, respectively. Most of the participants in the 7% group were able to entrain, and the majority of the 10% group also entrained. By contrast, about one-quarter of the 15% group entrained.

Since this study was exploring an area that had not been previously researched, heart rate entrainment, the outcome of the study could not be confidently predicted. The data seems to indicate the possibility that the heart can entrain to external auditory rhythm at the -7% and -10% levels. Additionally, there was a statistically significant difference between the possibility of entrainments between the groups with the entrainment rates of -7% > -10% (9.01% difference) and -7% > -15% (90.91% difference).

This study's findings align with the concept of the Weber fraction, which refers to individuals being able to consciously perceive change between a 5-7% difference (Epstein, 1985). In the present study, participants had a higher chance of entraining the closer the group percentage was to the Weber fraction. In past research on Rhythmic

Auditory Stimulation (Thaut et al., 1992; Thaut et al., 1993; Thaut et al., 1996, Hurt et al., 1998), participants were instructed to listen to the rhythm and tap along. In the current study, participants were not instructed to listen to the rhythm nor told that there would be rhythm present. Unlike the previous studies, participants were able to entrain to the stimulus without any verbal cues. Furthermore, the entrainment process happened to a body system that individuals do not have conscious control over, unlike walking.

These results also fall in line with the results published by Khalfa, Roy, Rainville, Bella, & Peretz in 2008. The authors noted that rhythmic entrainment of physiological responses seemed possible when only rhythm was presented. The current study expanded previous research by further exploring the possibility of physiological entrainment and specifically looked at heart rate entrainment, a process that occurs subconsciously.

Study Implications

Theoretically, this study's results provided evidence of heart rate entrainment to rhythm at 7% and 10% lower than the baseline heart rate. This is a novel finding because of a lack of previous research in this area. These findings could be used as a starting point for future research exploring heart rate entrainment to rhythm embedded in music or other stimuli.

Practically, this study's findings have several implications for both the current state of music therapy and research. One use of music therapy is for relaxation, and a reduction in heart rate may be one physiological indicator of a relaxation response. Up to this point, researchers and clinicians have speculated and attempted to design best practice models used to select music for the relaxation interventions. Thus, this study's results contribute to this growing knowledge base.

While this study's results should be considered preliminary in nature, music therapists may use them as a starting point for designing music therapy relaxation interventions. Specifically, music therapists may use the data from this study to choose music with an optimal tempo for music-assisted relaxation interventions; the therapists could select music between 7-10% slower than the baseline heart rate of the client in order to maximize the potential for slowing the heart rate, which would physiologically indicate a relaxation response. Additionally, information from this study could be useful for therapists in regulating or reducing the heart rate for other purposes.

Study Limitations

The results from this study should not be considered definitive. The current study is one of, if not the first of its kind to explore the entrainment of heart rate to an external auditory stimulus. As with any pilot study, there are several limitations. A few of the participants commented on the video material. Some were worried that something was going to jump on the screen and scare them while others commented on how much they liked one of the animals that was shown. Either of these reactions could have had an effect on the heart rate and arousal of the participants, potentially affecting the data. Since the study took place in an academic building on a university campus, there was not a way to control the noise outside of the room. Efforts were made by the researcher to limit the noise that reached the participants, but sounds, such as doors slamming or students talking were present in the environment at times. Any of these sounds could have startled or had some sort of impact on the physiological state of the participants.

These issues could be resolved in future studies by selecting a video based on questionnaire responses, not having visual stimulus, or having a more controlled testing environment.

Suggestions for Future Research

Since this research was a pilot study, more research needs to be completed in order to fully understand the concept. While this study suggests that entrainment to tempi lower than the baseline heart rate is possible, there is no data available exploring entrainment to tempi higher than the baseline heart rate. Research could also be pursued exploring entrainment to rhythm that is embedded in different types of music. Studies in this area could be useful for purposeful modulation of heart rate or for using the entrainment as a physiological indicator of awareness or arousal, similar to the study performed by Steinhoff et al. in 2015.

Conclusion

The results from this pilot study indicate that it is possible for heart rate to entrain to external auditory stimuli and that the possibility of entrainment is inversely correlated to the percentage change. These findings are novel; there has been little research completed in this area in the past. This study can be used as a stepping stone for future research exploring heart rate entrainment to both isolated and embedded rhythm. These findings could be used to develop protocols or treatments used to modulate or maintain an individual's heart rate.

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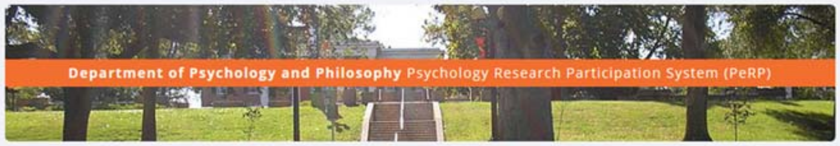
APPENDIX A

Sam Houston State University



Study Information

Study Name	Physiological Responses to Auditory Stimuli
Study Type	**Standard (lab) study** This is a standard lab study. To participate, sign up, and go to the specified location at the chosen time.
Credits	1 Credits
Duration	30 minutes
Abstract	The purpose of this study is to investigate physiological responses to auditory stimuli.
Description	Length of Study: The total length of this study will be 30 minutes. Risks and/or Discomforts: You may feel discomfort answering some personal questions on the "Participation Information" form. You may decline to answer any question or questions that make you feel uncomfortable. Benefits: No benefit can be promised to you for participating in this study. You may enjoy participating in the research condition with the investigator. The information gained in this study may be useful in developing future music therapy interventions. Compensation: You can receive course credit through the University PeRP program to compensate you for the time you take to participate in this study. The compensation will be provided once you have completed your participation in the study.
Preparation	Please do not consume any caffeine two (2) hours prior to your scheduled time slot. Please arrive at least 10 minutes before your scheduled time slot.
Researcher	Michael Way 7134495578
Deadlines	Sign-Up: 24 hour(s) before the appointment Cancellation: 24 hour(s) before the appointment

Email questions to ISA001@shsu.edu

(3:24 PM)

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PeRP Information

Title: *"Physiological Responses to Auditory Stimuli"*

Purpose of Study:

You are being asked to participate in a research study. The purpose of this study is to investigate physiological responses to auditory stimuli.

Length of Study:

The total length of this study will be 30 minutes.

Risks and/or Discomforts

You may feel discomfort answering some personal questions on the "Participation Information" form. You may decline to answer any question or questions that make you feel uncomfortable.

Benefits:

No benefit can be promised to you for participating in this study. You may enjoy participating in the research condition with the investigator. The information gained in this study may be useful in developing future music therapy interventions.

Compensation:

You can receive course credit through the University PeRP program to compensate you for the time you take to participate in this study. The compensation will be provided once you have completed your participation in the study.

APPENDIX B

Questionnaire

1. Name?
2. Age?
3. Gender?
4. Height?
5. Weight?
6. Current major?
7. How many days per week do you exercise?
8. Do you play any sports? If yes, which sports do you play?
9. How many days per week do you play sports?
10. Do you consider yourself an athlete?
11. Do you consider yourself a musician? If yes, what is your primary instrument?
12. Have you taken music lessons in the past? If yes, how many years did you take lessons?
13. Do you currently take music lessons?
14. Are you currently taking any medications? If yes, what are you taking?
15. Do you smoke? If yes, how often do you smoke?
16. Do you have any heart abnormalities (arrhythmia, murmur…)?

APPENDIX C

I R B APPROVED

Consent to Participate in a Research Study

TITLE: *"Physiological Responses to Auditory Stimuli"*

The following describes a research study in which you are being asked to participate. Please read the information carefully. At the end, you will be asked to sign if you agree to participate.

PURPOSE OF STUDY:

You are being asked to participate in a research study. I am conducting this research under the direction of Dr. Carolyn Dachinger. The purpose of this study is to investigate physiological responses to auditory stimuli.

PROCEDURES:

If you agree to participate, the following steps will take place:

Step One: Eligibility Screening. This step will be completed prior to the start of any interventions and should take about 5 minutes to complete.

1. The investigator will administer a demographics survey to determine your eligibility to participate in the research activities.

2. The investigator will review your survey and determine if you are eligible to participate in the research activities. If you are eligible to participate, you will complete the procedures listed below. If you are not eligible to participate, you will not complete the procedures listed below.

Step Two: Pretest measures. This step will take will be completed prior to the start of the research conditions and should take about 20 minutes to complete.

1. You will be asked to sit in the testing center while the researcher sets up equipment for measurements. Your physiological responses will be measured using this equipment throughout the testing period.

I R B APPROVED

2. You will be asked to sit in the chair for 22 minutes and watch the video on the screen. During this time period, the researcher will ask you to refrain from moving your arms, hands, or fingers.

RISKS AND/OR DISCOMFORTS

You may feel discomfort answering some personal questions on the "Participation Information" form. You may decline to answer any question or questions that make you feel uncomfortable. In the event of injury related to this research study, you should contact your physician or the University Health Center. However, you or your third party payer, if any, will be responsible for payment of this treatment. There is no compensation and/or payment for medical treatment from Sam Houston State University for any injury you have from participating in this research, except as may by required of the University by law.

BENEFITS:

No benefit can be promised to you for participating in this study. You may enjoy participating in the research condition with the investigator. The information gained in this study may be useful in developing future music therapy interventions.

CONFIDENTIALITY:

Records related to this study will be kept in a locked filing cabinet within an office environment and on a password-protected desktop computer. Only the Primary Investigators and other approved research personnel will have access to this information.

Identification Codes will be used in place of your name on all forms or files. When the results of the research are published or discussed in conferences, no information will be included that would reveal your identity.

The investigator will consider your records confidential to the extent permitted by law. The U.S. Department of Health and Human Services (DHHS) may request to review and obtain copies of

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your records. Authorized University or other agents who will be bound by the same provisions of confidentiality may also review your records for audit purposes

COSTS:

There are no costs associated with your participation in this study.

COMPENSATION:

You can receive course credit through the University PeRP program to compensate you for the time you take to participate in this study. The compensation will be provided to you once you have completed your participation in the study.

RIGHT TO DECLINE OR WITHDRAW:

Your participation in this study is voluntary. You are free to refuse to participate in the study or withdraw your consent at any time during the study. Your withdrawal or lack of participation will not affect your relationship with the university sponsoring this research. The investigators reserve the right to remove you from participation without your consent at such time they feel it is in the best interest for you.

CONTACT INFORMATION:

Michael Way, Music Therapy Graduate Student at Sam Houston State University, serves as the Principal Investigator. This research is being completed in partial fulfillment of the requirements for the Master of Music (M.M.) in Music Therapy at Sam Houston State University. Michael can be reached at mhw003@shsu.edu or by phone at 713-449-5578.

Dr. Carolyn Dachinger, Assistant Professor of Music Therapy at Sam Houston State University, serves as the Thesis Director. Dr. Dachinger can be reached at cdachinger@shsu.edu or by phone at 936-294-1366

IRB APPROVED

If you have any questions about your rights as a research subject, you may contact Sharla Miles at the Office of Research and Sponsored Programs at Sam Houston State University at irb@shsu.edu or by phone at (936) 294-4875 or email ORSP.

PARTICIPANT AGREEMENT:

I have read the information in this consent form and agree to participate in this study. I have had the chance to ask any questions I have about this study, and they have been answered for me. I am entitled to a copy of this form after it has been read and signed.

Signature of Participant

Date

Signature of Person Obtaining Consent

Date

VITA

Michael H. Way

EDUCATION

Master of Music student in *Music Therapy* at Sam Houston State University, January 2016 – present. Thesis title: "Heart rate entrainment to external auditory rhythm: a pilot study."

Bachelor of Music (December 2015) in *Music Therapy*, Sam Houston State University, Huntsville, Texas

PROFESSIONAL EXPERIENCE

Neurologic Music Therapist, Independent Board-Certified Music Therapy contractor, January 2016 – present. Working with individuals diagnosed with intellectual disabilities and neurological impairments (stroke). Responsibilities include scheduling, session planning, implementation, evaluations, and billing.

PRESENTATIONS AT PROFESSIONAL MEETINGS

Way, M. (2017, February 25). *Tips for the internship process*. Lecture presented at SHSU Music Therapy Awareness Weekend in Sam Houston State University, Huntsville.

Way, M. (2016, September 09). *Technology in music therapy*. Lecture presented in Sam Houston State University School of Music, Huntsville.

Dachinger, C., Miller, K., Way, M., & Hughes, M. (2016, April 02). *A music therapist's guide to a master's degree*. Lecture presented at 2016 SWAMTA Regional Conference in The Westin Austin at The Domain, Austin.

Way, M., & Salinas, M. (2016, March 31). *Mastering the iPad, one app at a time: An introduction to Garageband and other applications*. Lecture presented at 2016 SWAMTA Regional Conference in The Westin Austin at The Domain, Austin.

Way, M. (2016, February 20). *Intern interviewing session*. Lecture presented at SHSU Music Therapy Awareness Weekend in Sam Houston State University, Huntsville.