MUSIC AND MEMORY: AN ERP EXAMINATION OF MUSIC AS A MNEMONIC DEVICE

by

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A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Psychology
with a Major in Psychological Research
August 2016

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ACKNOWLEDGEMENTS

I would like to thank my committee, especially Dr. Deason, for their patience during the process of obtaining my Masters. I would also like to thank Katherine Mooney, Ruben Vela, Gregory Caparis, Ilanna Tariff, and David Russell for helping make this research a possibility.

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LIST OF ABBREVIATIONS

Abbreviation **Description**

AD - Alzheimer’s disease

ANOVA - Analysis of variance

CR - Correct rejections

DLPFC - Dorsolateral prefrontal cortex

FN400 - Early anterior negativity (fn400)

EEG - Electroencephalography

ERP - Event-related potentials

FAR - False alarm rate

Gold-MSI – Goldsmiths Musical Sophistication Index

HF - Highly familiar

LPC - Late positive component

LF - Low Familiarity

PFC - Prefrontal cortex

ROI - Region of Interest

UF – Unfamiliar

ABSTRACT

Prior research into music and memory has shown that music can aid in learning educational content (Calvert & Tart, 1993; Fassbender, Richards, Bilgin, Thompson, & Heiden, 2012), and it can be used in populations with Alzheimer's disease to enable learning (Deason, Simmons-Stern, Frustace, Ally, & Budson, 2012; Simmons-Stern, Budson, & Ally, 2010; Simmons-Stern, et al., 2012). However, there is little research into the neural correlates associated with this relationship. The current experiment used both behavioral and electrophysiological measures to further examine the efficacy of music as a mnemonic device. Stimuli consisted of a set of lyrics, either spoken or sung, associated with a single word. Participants were asked to listen to these lyrics and then asked whether or not they recognize the associated word during the test phase. Electroencephalographic (EEG) data was collected during this process and analyzed using event-related potentials (ERPs) to examine components associated with recognition memory and their relation to the benefit of music to memory. The behavioral results revealed no significant effect of encoding condition on memory, with the sung and spoken condition having similar results. There was a marginal increase in amplitude in the old/new ERP effect related to the late positive component for the sung condition compared to the spoken condition. These findings provide more insight into the use of music as a mnemonic device.

I. INTRODUCTION

It has been long thought that music can improve an individual's memory (Anton, 1990; Brown, 1975; Gfeller, 1986). For example a teacher may apply rhythm or melody to study materials as a mnemonic device, which is a strategy used in an attempt to improve memory. The benefit of music as a mnemonic device, however, has not been extensively studied empirically. Research shows that memory improves when information is sung—with or without the presence of music—when compared to information that is spoken (Chazin & Neuschatz, 1990; Campabello, De Carlo, O'Neil, & Vacek, 2002; Wallace, 1994). Although these findings provide some evidence for music improving memory, the beneficial influence of music on memory is not fully understood, particularly in terms of the underlying brain processes as well as the limitations of its successful application. Considering that access to music will only increase in this digital age, more research is needed in order to understand how this relationship truly works so that it can be best used to enhance memory and potentially create effective memory rehabilitation techniques.

The concept of memory has been discussed throughout the ages, from the musings of Plato and Descartes, to the research of modern day neuroscientists. Until a few decades ago, long-term memory had been perceived as a unitary system, but research into this topic over the past several decades has shown that there are multiple types of long-term memory (Tulving, 1972; Nyberg and Tulving, 1996). The current research will be focusing on episodic memory. Episodic memory involves the conscious retrieval of specific information/episodes that occurred at a given place and time (Tulving, 1972). This information must first be encoded, which is the means by which information is transformed into a memory representation (Smith & Kosslyn, 2006). Another topic of importance is consolidation, which is the stabilization of a memory by means of association with related information (Dudai, 2004). By manipulating the means of encoding and measuring the accuracy of retrieval, researchers can determine the efficacy of different methods of encoding, such as the use of music, and how these methods might improve memory and memory consolidation processes.

The current experiment is designed to expand upon research by Simmons-Stern and colleagues, which focused on how music can be used as a mnemonic device to improve episodic memory (Deason, Simmons-Stern, Frustace, Ally, & Budson, 2012; Simmons-Stern, Budson, & Ally, 2010; Simmons-Stern, et al., 2012). These researchers were comparing healthy older adults to those with Alzheimer's disease (AD), a chronic neurodegenerative disease resulting in loss of memory, impairment of learning capacity, and an eventual progressive deterioration of all cognitive ability (Grundman, Peterson, Ferris, et al., 2004). Deason et al. (2012) and Simmons-Stern et al. (2010, 2012) showed that music was an effective mnemonic device for AD patients and healthy older adults, but their behavioral studies were unable to answer the question of why it helped. By using a similar method in healthy young adults, but focusing on examining neural activity through the measurement of event-related potentials (ERP), this study will begin to answer some of the questions raised about what might be leading to the benefit produced by music. This study will be one of the first to examine the ERP correlates of this potential benefit of music to memory, which hopefully will provide important insights into musical mnemonics.

Can Music Enhance Memory?

Music has the potential to be a powerful mnemonic device when applied in a specific manner. This can be seen in Wallace's (1994) study, which focuses on exploring the use of music to improve memory. In this study, participants were tested on their memory of lyrics. Results from this study showed that hearing a single, simple song improved memory for ballad lyrics compared to a spoken condition. Memory was not enhanced for the sung condition over the spoken condition when the melody was not repeated (less well established) or when component parts of the music (e.g., rhythm) were isolated. This study suggested that music and song can enhance memory for information in some situations, but that there are limitations.

Repetition may also increase the effectiveness of music as a mnemonic device, as demonstrated by Calvert and Tart (1993). These researchers examined college students' memory for the preamble to the United States' Constitution and how that related to exposure to an educational cartoon called School House Rock. Participants were asked to recall the preamble, as well as how often they were exposed to the episode during their childhood, and whether they sung or spoke the preamble to themselves as a means to remember the preamble. It was found that those who preferred singing as a mnemonic device had been more frequently exposed to the episode of School House Rock, and that those who used singing to remember the preamble were able to recall more of the words. These findings suggested that music served as a useful mnemonic device for this information.

Calvert and Tart (1993) also experimentally examined the effects of song (sung vs. spoken) as well as repetition (single vs repeated exposure) on memory. Both the sung and spoken condition used the music and video from the School House Rock episode, but the spoken condition was dubbed over so that the lyrics were spoken while maintaining the rhythmic qualities of the song. Those in the repetition conditions were exposed to either the spoken or sung vignettes 2 times a week for 4 weeks. All participants were assessed for immediate retrieval (testing after final exposure) and long-term retrieval (after a 5 week delay). The results for both the immediate and long-term retrieval were similar, with the single exposure having no significant difference when comparing the sung and spoken conditions, but the repeated sung condition resulting in significantly better recall than the spoken condition. Researchers concluded that the chunking of information, such that the music and the preamble were encoded together, allowed for ease of retrieval. The lack of effect found for the single exposure could indicate an effect that is not seen until rehearsed, but when rehearsed becomes more potent than simply speaking the text.

Chazin and Neuschatz (1990) used material from a lecture and presented this material in either a spoken or sung format to a group of children and a group of young adults. Results showed that both the children and young adult groups benefited more from the lecture material that was sung, as their memory scores were significantly higher for the initial memory test occurring immediately after exposure. However, after a week delay there was no significant difference between the scores for either condition in either age group. In contrast, and similar to the results from Calvert and Tart (1993), Rainey and Larsen (2002) found that musical mnemonics may not have an immediately perceivable impact on memory, but potentially can have long-lasting effects. In this study, participants were given a list of words that were either spoken or sung to a well-known melody (Yankee Doodle Dandy and Pop Goes the Weasel). There was no immediate difference in recall for either condition. However, after a week delay, participants were capable of relearning the material much more quickly if they had been in the sung condition. This finding could be a result of music facilitating the integration of information. With the well-known melody already stored in the memory, the accompanying information may have been encoded or retrieved more easily due to the association of this new information with an already pre-existing memory. However, it is unclear what precisely drove their different patterns of results.

Not all of the studies assessing music and memory have shown beneficial results. One study found that correcting for rate of exposure—the rate at which information is conveyed—minimized the benefits that music had on memory (Kilgour, Jackson, & Cuddy, 2000). In an initial experiment on memory and music, the sung stimuli were better remembered than the spoken. However, after slowing the presentation of spoken stimuli to match that of the sung, the spoken condition were better remembered than those in the sung condition. Following this finding, the researchers then manipulated the rate of exposure for both the sung and spoken stimuli so that there was a slow, normal, and fast rate of exposure. Spoken stimuli were better remembered at all three speeds, with increased memory performance for both spoken and sung stimuli as the rate of exposure was slowed down (slow > normal > fast). These results could indicate that the benefits of music found in prior studies could be an artifact of rate of exposure, as lyrics tend to be presented in a slower manner than when the same lyrics are sung.

In a similar vein, Racette and Peretz (2007) used sung and spoken stimuli that were corrected for rate of exposure and examined how taking an active role in the musical encoding could impact the benefit for music. In their experiment, subjects were presented with lyrics paired with music and asked to recite the lyrics aloud by singing or speaking them. The first experiment had a total of three conditions (sung-sung, sung-spoken, spoken-spoken), all of which used music during the encoding phase. The results showed sung-sung to have the lowest levels of text recall, which was significantly lower than both spoken recall conditions. Of the spoken recall conditions, spoken-spoken had higher levels of text recall. After 11 months, the researchers had 12 of the participants return to compare the sung-sung to the spoken-spoken condition. While not significant, the results showed that text recall was still numerically higher for the spoken recall condition. These results indicate that singing oneself might impair the recall of lyrics.

The mixture of positive and negative findings suggests that more careful, controlled research is necessary to fully explore the use of musical mnemonics. The variation in methodologies and stimuli used (both in terms of music and the type of information being paired with it) make it quite difficult to compare the findings and make larger generalizations. It is also important to note the difference between recognition and recall memory tests. Most of the studies reviewed focused on recall, which is the retrieval of details from a given event without providing retrieval cues. The current study will be testing music's impact on recognition memory, which tests the ability to retrieve a memory when given both the cues as well as foils (Haist, Shimamura, & Squire, 2014). In sum, more research is necessary to determine how music interacts with memory.

<u>Memory and Music: Aging and Alzheimer's Disease</u>

The relationship between music and memory has been examined more recently with a growing interest in the use of music as a potential rehabilitation technique to aid patients with memory impairments. One of the first studies to examine musical mnemonics in healthy older adults and patients with AD, Simmons-Stern et al. (2010) compared how studying sung and spoken stimuli affected memory for those items. Using a total of 80 sets of novel four-line lyrics, each with a sung and spoken version, researchers had participants listen to 40 of the stimuli (half spoken and half sung) during an encoding phase. During the test phase, participants were presented all 80 lyrics visually on a computer screen, responding “old” if the lyrics had previously been experienced, or “new” if they had not been previously experienced. Results from this study revealed that the healthy older adults were equally likely to remember the lyrics whether they had previously been presented the spoken and sung versions. For the patients with AD, it was found they were significantly more likely to remember lyrics that had been sung versus those that had been spoken during the encoding phase. Patients with AD showed a benefit of musical encoding while healthy older adults did not. Researchers explained that this outcome could be due to two potential possibilities. The first possibility is that coupling music with information during encoding allows for an association between a piece of information and sensory stimulation, improving the potential for information to be encoded. The other explanation is that some pathways for processing music are impacted less by cognitive deterioration for those with AD, and the presence of music helps integrate information that usually requires those areas of the brain more affected by AD.

Deason et al. (2012) used the same paradigm as the prior study, but included an additional one-week delay between encoding and test for the healthy older adults. It was hypothesized that delay before testing would diminish the healthy older adults’ discrimination performance. If so, this added week between sessions would better match discrimination performance between healthy older adults and patients with AD, potentially resulting in similar benefits of musical encoding. The added time between the encoding and test phase for the healthy adults did accomplish this matching of recognition scores, but it did not lead to a benefit for musical encoding in healthy older adults. The results of this study suggested that musical encoding may only aid those who have impaired memory or potentially that there exist limitations on the benefits of music.

Interested in further exploring the results of the first two experiments, Simmons-Stern et al. (2012) conducted another study comparing healthy older adults to patients with AD. The stimuli were also songs, but the lyrics related to activities of daily living for healthy older adults and patients with AD (e.g., "fill the pillbox"). In all, there were 40 reference words (e.g., pills), each with two sets of lyrics describing a potential action with the reference word (e.g., "fill the pillbox" and "take your pills"), resulting in a total of 80 sets of lyrics, each of which had a sung and spoken version. Participants were presented with 40 lyrics (half sung, half spoken; only exposed to one set of lyrics for each reference word) during encoding and then tested on whether they had heard a song about each given reference word (e.g., "Did you hear lyrics about pills?"). The test phase included 80 of these questions, with 40 questions asking about "dummy" reference words not used in any of the recordings. If the participant answered "Yes" they had heard lyrics about the particular reference word, they were then asked about the specific content of the song (e.g., "According to the lyrics, what should you do with your pills? Take them or Fill your pillbox?"). If the participant responded "No" they hadn't heard a song about a particular reference word, they would be asked what they would do in a hypothetical situation with the object in question. After a 40-minute distractor task, the participants were presented with the complete set of 80 songs, both those presented in the encoding phase and those with alternative lyrics (e.g., both "fill your pillbox" and "take your pills"), via audio recording. Those stimuli not experienced in the encoding phase were presented in the same sung/spoken format as their lyrical counterpart. After hearing each individual song, the participants assessed whether it was "old" or "new."

The results from this follow-up study showed that healthy older adults again performed better on the recognition task than patients with AD. The accurate recognition of presented lyrics was higher in the sung version for both groups of participants when compared to the spoken version of the stimuli. Analyzing the 2-part question that followed the encoding phase revealed that general content memory (the first question) was significantly higher for the sung versions than the spoken for both groups. This effect did not carry over to the test of specific content memory (the second part of the question), as there was no difference between the accuracy of response to the second question between the sung and spoken versions. This study suggested that the benefit of music might be most suited to improving general content memory and that this benefit could be shown for both healthy older adults and patients with AD.

This difference in effect that music has on general and specific content memory could be explained by the results from a study by Moussard, Bigand, Belleville, and Peretz (2012), which assessed the effect of sung and spoken lyrics on a single patient with mild AD. The study included an initial learning/test session, followed by five more sessions, with a week delay between the first four sessions, and a four week delay between the fourth and fifth session, resulting in a 9-week long assessment. Stimuli used in this study consisted of four novel sets of lyrics (one spoken, three sung). The sung stimuli were eight lines long, without instrumental accompaniment, and characterized by level of familiarity the participants would have with the melody (unfamiliar—UF, low familiarity—LF, or highly familiar—HF). All stimuli were used during the initial learning/test phase, and only the spoken and UF stimuli were used in the other five sessions. Within each session, the patient listened to a single line of the recording, and was then asked to reproduce that single line of recording from memory (immediate recall). For any of the lines following the first, the participant was then asked to reproduce each line previously presented in order without the recording. If the patient could not remember at least 65% of the lyrics, the recall test was stopped. Following a short delay, the patient was asked to reproduce as many words as possible (delayed recall).

Over the 9-week period, the spoken condition appeared to be more beneficial than UF sung condition for immediate recall. However, UF sung condition had higher scores for delayed recall, and even showed to be a better influence on recall after the four-week delay than did the spoken condition. While the results of this study indicate that, initially, new verbal information is less likely to be remembered when presented with an unfamiliar melody, they also reveal that repeated exposure to unfamiliar melodies with sung lyrics is superior to studying spoken lyrics. This could explain the disparities between general content memory and specific content memory within the study by Simmons-Stern et al. (2012), as the participants were exposed to lyrics accompanied by unfamiliar melodies with only one study session. Moussard et al. (2012) explained that this could be due to the dual coding of melody and lyrics, with an unfamiliar melody initially resulting in more difficulty with learning the explicit content (words) of the stimuli, but ultimately leading to a robust improvement in memory due to the increased association between melody and lyrical content over time.

Another study that assessed the differences between healthy older adults and patients with AD was conducted by Palisson, Roussel-Baclat, Maillet, Belin, Ankru, and Narme (2015). They showed that memory for text is influenced when presented in different formats (spoken, sung with music, or paired with a film clip). The two groups of participants were compared to assess how the different formats influenced explicit recall. The stimuli consisted of lyrics that were either sung or spoken. The sung lyrics were paired with Beethoven's Ode to Joy, and the spoken lyrics were either paired with a clip from a silent film, or presented alone. Similar to the method of Moussard et al. (2012), participants were given a single line at a time to recall, then another line of information was added, with this continuing until all lines were presented or the participant was unable to recall 65% of the information.

The participants were assessed for number of lines learned, immediate recall, and delayed recall. The results were similar for each of these tests, with the healthy controls performing better than patients with AD on each. Sung lyrics were recalled significantly more than either of the spoken conditions, and spoken text paired with a silent film was remembered significantly more than the spoken without accompaniment. This shows that sung lyrics had more of an impact on memory than spoken lyrics in both healthy older adults and patients with AD. Not only that, but it also shows that music's benefits can be seen in both immediate and delayed recall tests. These findings contradicted those of an earlier study conducted by Moussard, Bigand, Belleville, and Peretz (2014). While

Moussard et al.'s (2014) study showed that AD patients had better memory for physical gestures when exposed to music and a metronome during encoding for immediate recall tests, there was a lack of an effect for delayed recall. Palisson et al. (2015) suggested that the metronome may improve the memory for hand gestures in patients with AD in the same way music improves memory for lyrics as rhythm is a core component of music. Potentially the difference between the findings might result from the different stimuli used, as Moussard et al. (2014) examined memory for movement, but Palisson et al. (2015) were examining memory for lyrics/verbal information. Music appears to have an influence on memory, in both healthy adults and in patients with AD, but the extent and limitations of this influence are not well understood.

In sum, the previous studies suggest that music can aid memory, but the influence of music on memory potentially varies depending on the participants being assessed, the type of memory test, and the time at which the participants are being tested. While these factors need to be explored more thoroughly using behavioral methods, additional investigation into the neural correlates of music's influence on memory could help explain the variation in these results. If the neural mechanisms of musical mnemonics are understood more fully, then the application of this research can be better tailored to suit populations with memory deficiencies, potentially leading to rehabilitative interventions.

Memory and Music: Neuroimaging Findings

To fully understand the relationship between music and memory, it is important to examine the neural correlates of musical mnemonics, but there has been little research directly addressing this question. One method used to assess these neural correlates is ectroencephalography (EEG), which measures the electrical activity in the brain by electrodes attached to the scalp of participants. Two different studies used EEG to examine music as a mnemonic device, wherein participants listened to a sung or spoken version of the Rey Auditory Verbal Learning Test (AVLT), a neuropsychological measure designed to examine memory for words (Thaut, Peterson, & McIntosh, 2005; Peterson & Thaut, 2007). Each study had participants undergo either a musical or a spoken condition, using an identical list of words for each. In the music condition, words were paired with a piece of novel music. The words were presented as lyrics accompanying the music, with syllables being paired to the music to create rhythmic intonation. These two studies found increased synchronization in the theta, alpha, and gamma bands for the sung conditions when compared to the spoken conditions. Synchrony, in reference to EEG, is the coherence of oscillations measured at different electrodes, and the sung condition induced a synchronization of theta, alpha, and gamma frequency bands within the left and right frontal areas related to learning. While the results were not necessarily related to a difference in behavioral recognition memory performance, as the scores on the test were similar, the EEG data did show that learning via the utilization of music results in differences in neuronal synchrony within the brain. These studies show that music does have an effect on neuronal activity, even without the presence of an obvious cognitive difference.

Another form of analysis that uses EEG data is ERP, which uses EEG data to look into the variation of voltage deflection (positive or negative) across the scalp after the onset of a stimulus. Averages are taken from multiple trials, which reduces any noise that may not be associated with the process in which the researchers are interested. These averages give researchers insight into how the brain functions on an electrophysiological level, which aids in understanding the neurological processes associated with cognition. It also allows an understanding of how the brain processes stimuli over time.

As has been shown, the benefit of music to memory is only just starting to being explored empirically and there has been little work done to examine its neural correlates. Our study is designed to use ERPs to further examine these issues and gain insight into why music might be useful in improving memory. The current study used a paradigm based on the work of Simmons-Stern et al. (2010; 2012), and Deason et al. (2012), but adapted to ERP data collection. The importance of this study stems from how it will further the understanding of music's influence on memory by examining these ERP correlates. By having younger adults as participants, it is possible to look into the processes of memory unaffected by the natural process of aging or the neurodegenerative process of AD. If the mechanisms of this interaction are understood more fully, then the application of this research can be better tailored to suit populations with memory deficiencies, potentially leading to rehabilitative interventions.

II. PURPOSE OF CURRENT STUDY

The current study is designed to examine electrophysiological correlates of memory and the potential benefit to memory from pairing information with music in young adults. Specifically, ERPs will be used to determine what neural correlates are related to these effects within a young population. Specific variations in potentials over time that have been found to be related to cognitive processes are referred to as components. When assessing memory at time of test, typically researchers examine differences between the mean amplitude of correct rejections (CR; accurately stating the stimuli had not been experienced during the study phase) and hits (accurately stating the stimuli had been experienced during the study phase), resulting in the subtraction (Hits-CR). This method of subtraction allows for researchers to understand neural activity associated with accurate memory.

In examining recognition memory, there are two key components for ERPs. The first, chronologically, is an early anterior negativity (FN400), occurring around 250-500 milliseconds, and the second is a late positive component (LPC) of the parietal area of the scalp occurring around 500-800 milliseconds (Addante, Raganathe, & Yonelinas, 2012). Recognition memory is generally though to consist of both recollection and familiarity. Recollection is the ability to retrieve specific information from memory, while familiarity is a feeling of having previously experienced an event without recalling any specific details. The LPC is thought to be a result of the difference between stimuli that have been previously experienced (old) and stimuli that have not been experienced (new), with old stimuli evoking a more positive potential. Thus, this positive effect is known as an "old/new" effect and is generally associated with recollection. Familiarity has been associated with the presence of an FN400 component, which often occurs as an early non-lateralized anterior negativity (Ally & Budson, 2007; Curran, 2000; Rugg & Curran, 2007; Wolk, Schacter, Lyzigos, Sen, Holcomb, Daffner, & Budson, 2006), but exactly what this component reflects is still under debate. The association of FN400 with familiarity has been argued to be the result of dissociation between the FN400 and recollection, as the FN400 component is not responsive to manipulations associated with recollection (Paller, Voss, & Boehm, 2007). By the process of elimination, it has been assumed that the variations occurring in the FN400 component are a result of the interactions occurring within the brain associated with familiarity/recognition when it could be a combination of a multitude of cognitive factors resulting in the modulation of this component.

The studies by Simmons et al. (2010; 2012) and Deason et al. (2012) suggested that music could serve as a successful mnemonic device for learning new information and may be particularly suited for the learning of general content information. In this study, we will examine whether hearing lyrics either spoken or sung will impact memory for a reference word related to the general content of those lyrics. We will test memory for this general content word rather than specific lyrics as a result of the findings from Simmon-Stern et al. (2012), which found a benefit for musical encoding for both healthy older adults and patients with AD for this type of memory. This prior study suggested that this more general type of memory might show the most benefit from musical encoding and thus might be the best first step for examining the ERP correlates of this effect.

This leads to the hypotheses of the current study, with the first being that the current study will show similar results to Simmons-Stern et al. (2012), such that music will have the same benefits for young adults as shown in healthy older adults and patients with AD. The other two hypotheses are that recognition of a word will improve if the lyrics are sung versus spoken during encoding, and that this improved recognition will result in the enhancement of electrophysiological components associated with recognition memory (FN400 and LPC). One focus in the current study is to target general content memory, which was found to be improved by music in Simmons-Stern et al. (2012). General content memory is distinguishable from more item specific content, or the recollection of context and details. In relationship to ERP components, prior findings (Ally & Budson, 2007; Curran, 2000; Rugg & Curran, 2007; Wolk, Schacter, Lyzigos, Sen, Holcomb, Daffner, & Budson,2006), have shown increased accuracy for general content memory results in a decrease the negative amplitude of the FN400, as this component is associated more with familiarity. Additionally, participants may have richer, more detailed memories associated with the sung condition which could boost recollection as well. This could potentially result in the presence of increased positivity of the LPC, as increase in activity has been associated with recollecting context information about previously encountered stimuli (Henson et al., 1999).

III. METHOD

Participants

A total of sixteen individuals (age range:18-30 yrs old) were recruited as participants. They received payment ($10/hour) to compensate them for their participation. Inclusion criteria for this study included right-handedness, normal or corrected-to-normal vision and hearing, and no existing neurological problems. Of the sixteen participants, fifteen had usable data for EEG analysis. One participant's data was excluded from both the behavioral and the electrophysiological analyses.

Stimuli

A total of 40 sets of lyrics from the Deason et. al (2012) study and then another 110 new sets were used, totaling 150 songs. Each song has been created with its own unique reference word (e.g., Word: Anchor- Lyrics: "If you're in open water, you will need an anchor. They allow you to float and not drift in anger"). At test, instead of the full set of lyrics, the single reference word was individually displayed on the monitor. Each set of lyrics has a sung and spoken version, resulting in 300 auditory stimuli. In order to diminish any differences between the 40 adopted songs and the new 110, the adopted 40 songs were rerecorded to meet the standards of the other 110. This was done in order to have the same vocalist/instrumentation across all stimuli. The average length of the recording is 18.3 seconds and the average word count for each recording is 23 words. Recordings were composed with the use of Logic Studio software, each having a sung and spoken vocal track, with piano accompaniment for those that were sung.

The 150 sets of lyrics were divided into 3 counterbalanced lists of 50. Each of these lists were matched on number of words, length of auditory recording, length of content word, word frequency of content word, beats per minute of auditory recording, and key of song. These lists were rotated across conditions (sung, spoken, new) across participants so that each set of lyrics appeared in each condition an equal number of times. Along with this, there was an additional set of 50 filler words presented in the test phase to equate the number of old/new items in the recognition memory test.

Behavioral Procedure

This study utilized a within-subjects design. Each participant underwent a two-hour session consisting of an encoding phase, and a test phase. While the participant was being prepped for EEG recording, they were asked to fill out the Goldsmiths Musical Sophistication Index (Gold-MSI), which uses multiple measurements to determine an individual's ability to engage with music (Müllenseifen, Gingras, Stewart, & Musil, 2014). During the encoding phase, participants listened to 100 audio recordings (half sung and half spoken, randomly intermixed). Participants listened to the auditory stimuli through a set of headphones at a comfortable volume determined during a practice trial. Prior to each recording, the lyrics were presented on screen for a period of four seconds, after which the recording (either sung or spoken) was played. Following the recording, participants were asked to judge whether they liked the lyrics or not by pressing one of two buttons on a button box that corresponded to "like" or "dislike".

Upon finishing the encoding task, participants were given a 5-minute break. In the test section, participants were presented with 200 words (100 associated with the lyrics presented during encoding, 50 associated with the other stimuli not experienced during encoding, and 50 dummy words). Each word was presented one at a time in the center of the screen, and remained on the screen until the participant responded "old" if the word is related to lyrics encountered during the encoding phase or "new" if the word was not one associated with any set of lyrics in the encoding phase. Participants responded "old" or "new" by means of pressing one of two buttons on a button box that corresponded with these responses. After each response, a blank screen appeared for 1.5 seconds before the appearance of a fixation cross that remained on the screen for 1.5 seconds, which was then followed by the next word. Words were presented in black text on a white background, in a 24 point Arial font. The encoding and test phase were conducted using the program ePrime (Psychology Software Tools, Pittsburgh, PA).

Electrophysiological Procedure

After completing consent, participants were setup for EEG recording. For both study and test phases of the experiment, EEG data was recorded using an ActiveTwo biopotential measurement system. The system uses an assembly of 64 active electrodes connected to a cap in the standard international 10-20 positions and additional electrodes placed above and below the left eye as well as on the outer canthus of both eyes. The electrical activity is amplified with a bandwidth of 0.03-30 Hz with a sampling rate of 512 Hz. Recordings were referenced to a common average reference in order to reduce the effects of reference-site activity. EEG signals were recorded with respect to a common mode sense active electrode placed between the PO3 and POz channels, then re-referenced offline to the average of that reference (Murray, Brunet, & Michel, 2008). The range of the signal offsets for all participants were within +/- 25mV.

Using the EMSE Software Suite from Source Signal Imaging, EEG data from the test phase was processed and corrected for excessive eye movement activity. Artifact data are manually identified using the empirical EMSE Ocular Artifact Correction tool, which creates a ratio of clean to artifact data for use as an algorithm to remove activity related to ocular artifacts. Trials were removed from analyses if they have baseline drift or movement greater than 90 μV. Using the EMSE spatial interpolation filter, bad channels were manually identified and corrected.

After the EEG data was sufficiently cleaned, ERP averages were created for each condition. The epoch analyzed began 200 ms before each presented word (used for the baseline) and the cutoff for the end of the epoch was at 1 second after the onset of the word. The mean amplitudes for the FN400 and late positive component (LPC) were averaged at 300-500 ms and 500-800 ms, respectively. The regions of interest (ROI) for the FN400 consist of the left anterior (ROI1) and right anterior (ROI2) part of the brain, and the ROI for the LPC consist of posterior region (ROI3) of the brain. ROI1 consisted of 15 electrodes, ROI2 consisted of 15, and ROI3 contained 19 electrodes. The exact electrodes used for each of the defined ROIs can be found in Figure 1. The analyses compared the subtraction of CR from Hits (Hits-CR) for each of these components in the sung and spoken conditions. A repeated measures ANOVA was used to analyze the mean amplitude for ROIs associated with FN400 (ROI1 and ROI2). A paired samples *t*-test will also be used to compare the mean amplitude of the LPC (ROI3) across the two conditions. As is typical with ERP analyses, the Greenhouse-Geiser correction was applied to correct the degrees of freedom to account for potential sphericity assumption violation.

<u>Behavioral Analyses</u>

Memory performance was measured by subtracting the false alarm rate (FAR; proportion of inaccurate old responses) from the hit rate (HR; proportion of accurate old responses), which is known as Pr (HR-FAR; Snodgrass & Corwin, 1988). Response bias was examined by calculating Br [FAR/(1-PR); Snodgrass & Corwin, 1988]. Once Pr and Br are obtained, two separate paired samples (sung vs. spoken) t-tests were conducted to examine memory performance and response bias respectively, with a significance level of $p < .05$. Paired-samples *t*-tests were used to compare the differences in judgment responses (like or dislike) and conditions (sung or spoken). To further analyze accuracy, a repeated-measures ANOVA was performed to compare how accuracy was effected in relation to condition (sung vs spoken) and judgment scores (like vs dislike) with paired-samples *t*-tests following any interactions. For the judgment repeated measures ANOVA and subsequent paired-samples *t*-test, one participant was excluded due to not having any misses in the spoken condition, which inhibits analysis of spoken hit judgment scores.

Responses to the Gold-MSI questionnaire were aggregated into six different variables, consisting of a person's active engagement when interacting with music, perceptual abilities, musical training, emotions toward music, singing abilities, and general sophistication related to music. In order to analyze the relationship between these variables and the participants' memory for the sung and spoken stimuli, a new variable was computed to determine the benefits of music (Sung Pr – Spoken Pr). Bivariate correlations were then used to determine the relationship between the aggregated variables from the survey with the new musical benefit variable, with a significance of $p < .05$.

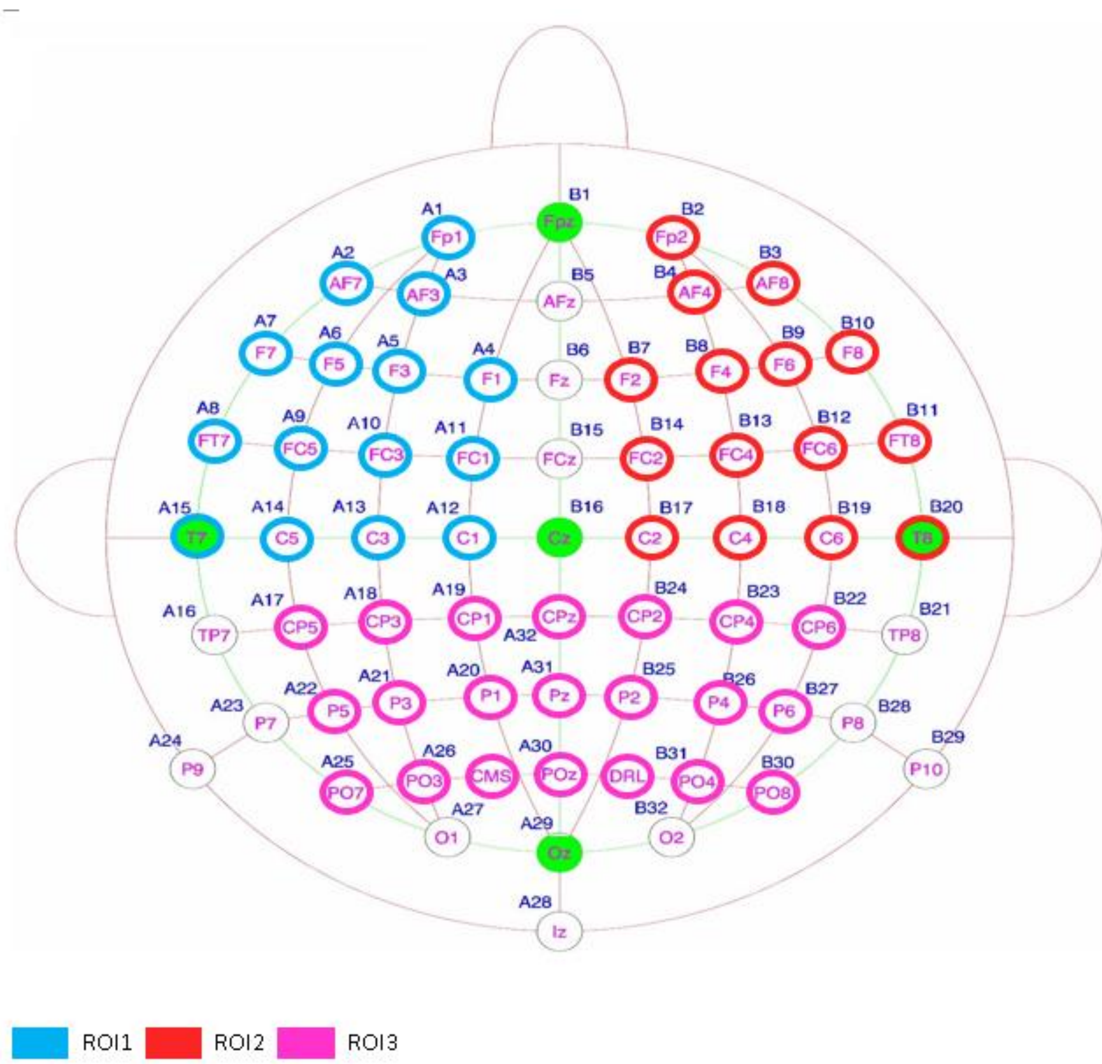

Figure 1. Map of Electrode Placement on Scalp with Designation of ROIs for Analysis. Please note that the colors of the legend correspond with the designated ROIs of the scalp and that designation of ROI is as follows: ROI1, Left Anterior; ROI2, Right Anterior; ROI3, Parietal.

IV. RESULTS

Behavioral Results

Memory performance (Pr) for sung trials (*M* = .53, *SD* = .21) and spoken trials (*M* = .53, *SD* = .22) were not significantly different (*t*(14) = 0, *p* = 1). Similarly, the response bias (Br) for the sung trials (*M* = .68, *SD* = .17) and the spoken trials (*M* = .68, *SD* = .19) also did not differ, (*t*(14) = -.362, *p* =.723). The paired-samples *t*-test comparing the sung hits (*M* =.85, *SD* = .08) and spoken hits (*M* = .85, *SD* = .08) also showed no significant difference between accuracy and conditions, *t*(14) = .00, *p* = 1.0.

The paired-samples *t*-tests comparing like and dislike judgment scores across conditions showed that sung song were liked (*M* = 23.93, *SD* = 12.17) significantly more than spoken (*M* = 18.93, *SD* = 12.42, *t*(14) = 2.44, *p* =.029. There was no significant difference between the sung "like" and the sung "dislike" (*M* = 26.1, *SD* = 12.17) (*t*(14) = -.340, *p* = .739) nor was there any significant difference between responses averages to the spoken "like" and spoken "dislike"(*M* = 31.1, *SD* =12.42), *t*(14) = -1.89, *p* = .079. The repeated measures ANOVA comparing the effect of condition and judgment on accuracy showed that there was no significant effect for condition (*F*(1, 12) = .13, *p* = .727), a significant effect for judgment scores (*F*(1, 12) = 8.45, *p* = .013), but no interaction effect between condition and judgment scores, *F*(1, 12) = .01, *p* = .906. The significance for the accuracy difference across judgment scores showed that accuracy for the "like" responses (*M* = .89, *SD* = .08) was significantly higher than accuracy for "dislike" responses (*M* = .82, *SD* = .10).

Bivariate correlations between the benefit of music and the responses to the Gold-MSI survey were ran (see Table 1 for descriptions/means of the variables from the Gold-

MSI). No significant correlations were found between any of the pairings (see Table 2 for correlations).

Electrophysiological Results

A repeated measures ANOVA was conducted using a within subject factors of condition (sung vs. spoken) and region of interest (ROI1 vs. ROI2) to examine the Hits-CR amplitude differences for the FN400 component (300-500 ms). The results indicate there was no main effect for condition for the FN400 Hits-CR, $F(1,14) = .409$, $p = .51$. There was also no main effect for ROI ($F(1,14) = 1.02$, $p = .33$) or an interaction between condition and ROI, $F(1, 14) = .916$, $p = .36$. A paired samples *t*-test was conducted to compare the Hits-CR amplitude difference in ROI3 between the sung and spoken condition for the LPC (500-800 ms). There was a marginal effect of condition, with the Hits-CR amplitude across the sung condition ($M = .62$, $SD = .80$) being more positive than the spoken condition ($M = .20$, $SD = .95$; $t(14) = -1.87$, p = ..078).

In order to gain further insight into the difference between the correct rejections and hits for both conditions, topographic maps were made using the mean amplitude of electrodes after subtracting the correct rejections from the hits (Hits-CR). These topographic maps are averaged across the time span of 300-500ms after the onset of stimuli to depict the FN400 component (See figure 2). The Hits-CR for the sung and spoken condition are also mapped out topographically to examine the LPC (500-800 ms; see Figure 3). A visual comparison of these two topographic maps shows the same pattern of results, with minimal difference between the two conditions for the FN400, but an increased difference for the sung condition in the LPC. Figures 4, 5, and 6 show variations in waveforms for the sung hits, spoken hits, and CR at representative electrodes of each ROI (1, 2, and 3, respectively).

Table 1. Descriptive Statistics for Pearson Correlations in Table 2.

Variable	Mean	Standard Deviation
Musical Benefit (Sung Pr- Sp Pr)	0.00	.08
Perceptual Abilities	42.87	5.00
Active Engagement	34.67	9.48
Musical Training	21.93	12.40
Emotions	32.07	4.04
Singing Abilities	25.53	8.64
General Sophistication	67.93	21.08

Note. Musical Benefit variable created by subtracting Spoken Discrimination scores from Sung Discrimination scores (Sung Pr – Spoken Pr).

Table 2. Pearson Correlations between Musical Benefit and Aggregated Variables from Gold-MSI.

	Perceptual Abilities	Active Engagement	Musical Training	Emotions	Singing Abilities	General Sophistication
Musical Benefit (Sung Pr – Sp Pr)	-.042 (.44)	-.077 (.40)	.218 (.22)	-.375 (.08)	.058 (.42)	.053 (.43)

Note. Top row are Pearson correlation coefficients and bottom row are the corresponding *p*-values.

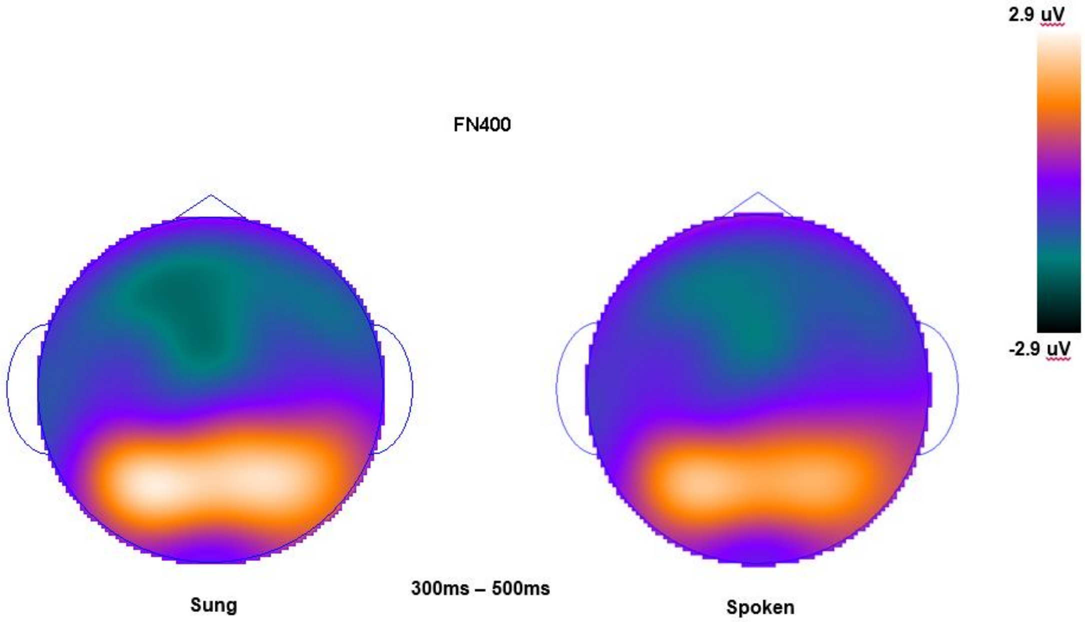

Figure 2. FN400: Average of Electrodes from 300ms to 500ms for Hits-CR. Neutral activity (purple) indicates no difference between hits and correct rejection. Positive activity (light colors) indicates more activity occurring for hits. Negative activity (dark colors) indicates more activity occurring for correct rejections.

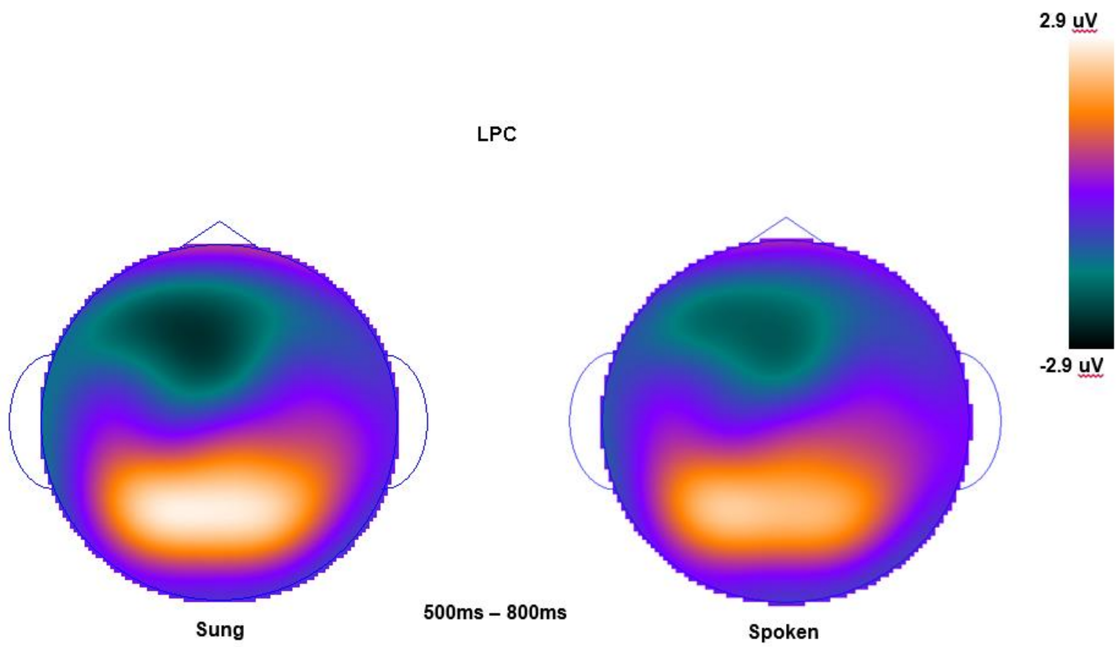

Figure 3. LPC: Average of Electrodes from 500ms to 800ms for Hits-CR. Neutral activity (purple) indicates no difference between hits and correct rejection. Positive activity (light colors) indicates more activity occurring for hits. Negative activity (dark colors) indicates more activity occurring for correct rejections.

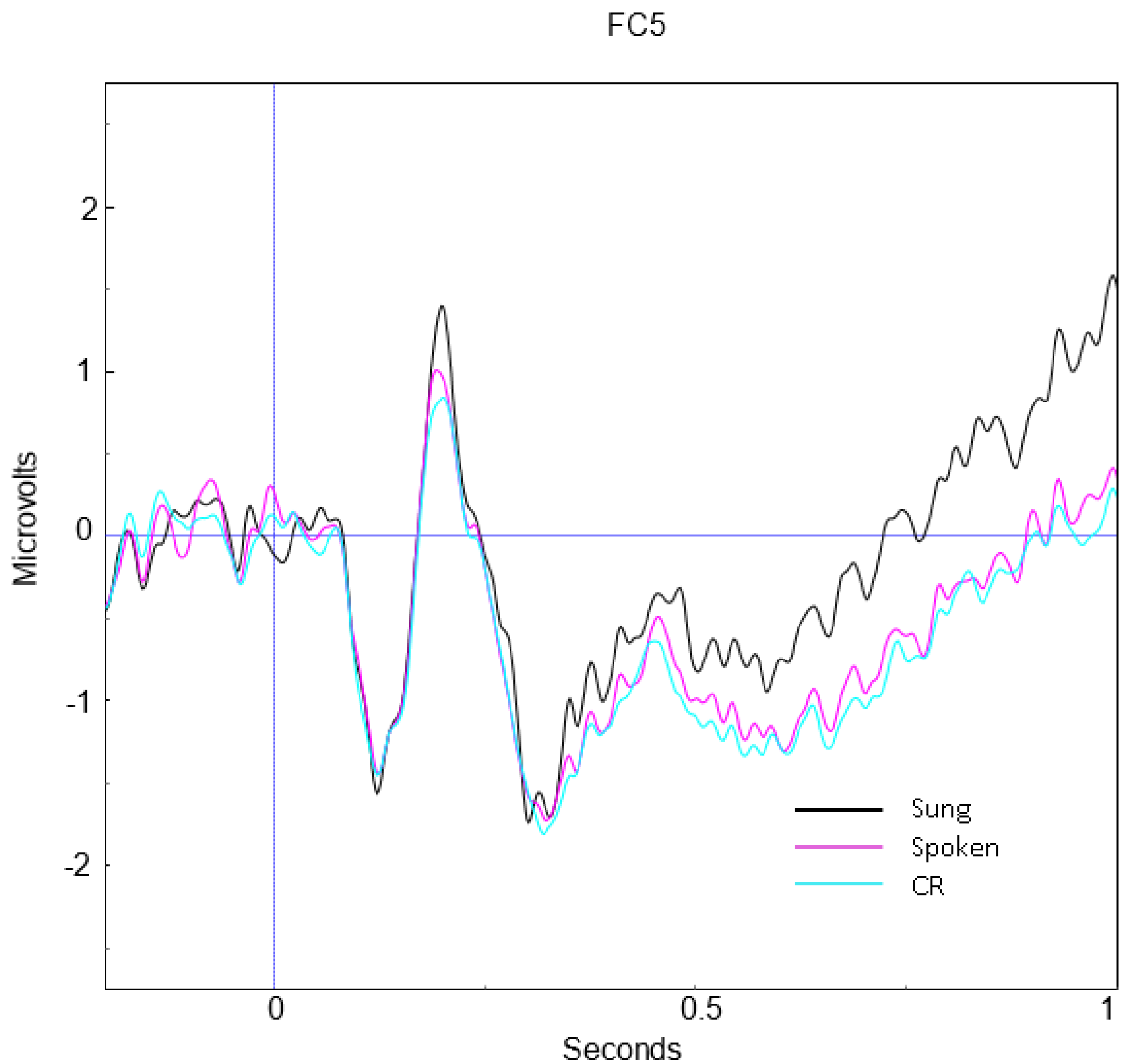

Figure 4. Representative Electrode for FN400: ROI1, Left Anterior Region of the Cortex. Waveform activity for electrode FC5 from onset of stimuli to 1000ms. The legend details the coloration of sung hits, spoken hits, and correct rejections.

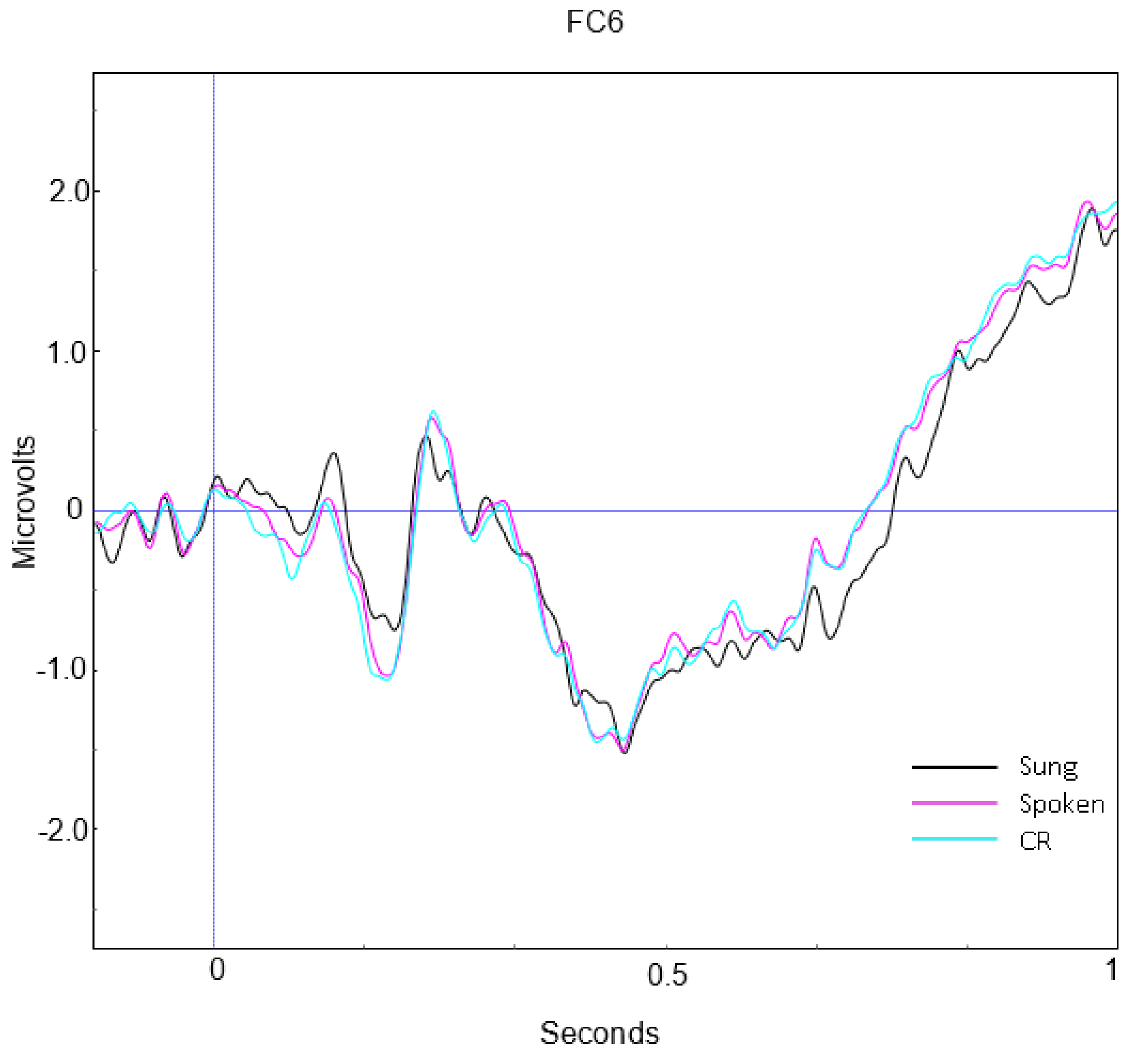

Figure 5. Representative Electrode Activity for FN400: ROI2, Right Anterior Region of the Cortex. Waveform activity for electrode FC6 from onset of stimuli to 1000ms.

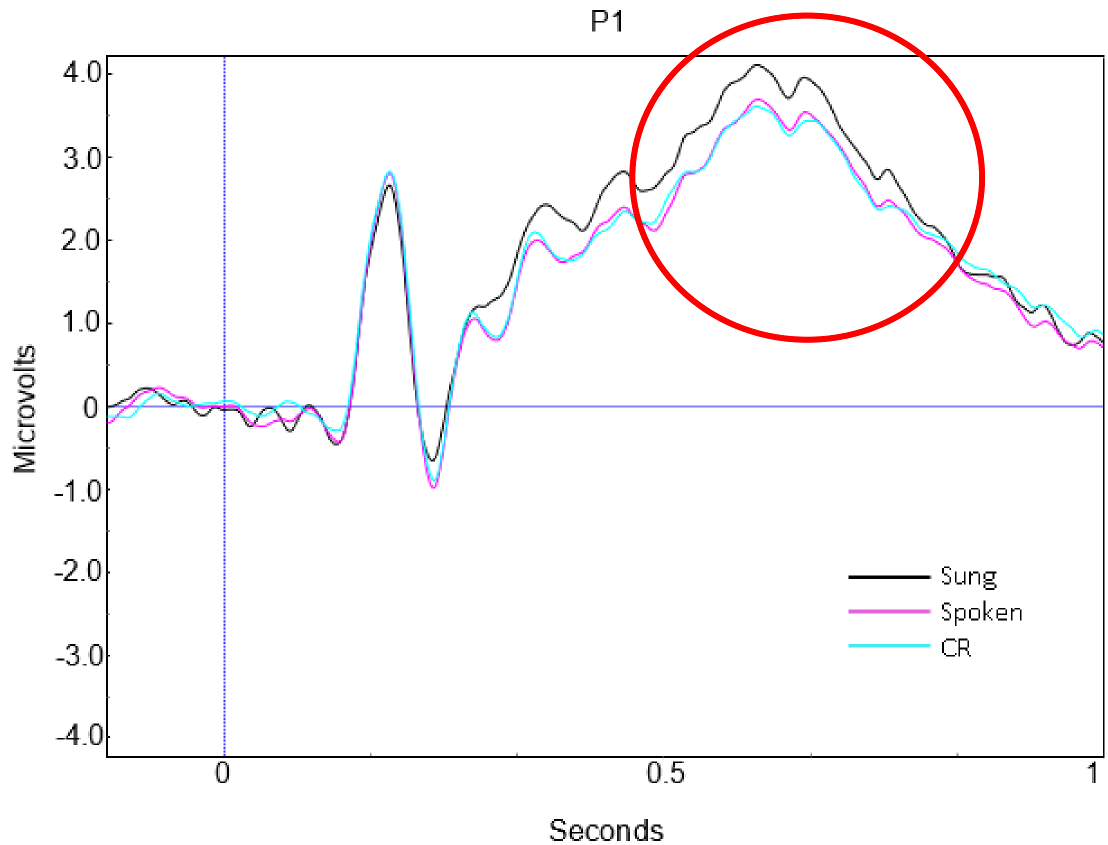

Figure 6. Representative Electrode Activity for LPC: ROI3, Parietal Region of the Cortex. Waveform activity for electrode P1 from onset of stimuli to 1000ms. Red circle denotes LPC time frame in which marginal increase in positive potential was present for spoken condition.

V. DISCUSSION

This study assessed three hypotheses. The first hypothesis is that recognition of a word will improve if the lyrics associated with the word are presented with a sung vs a spoken recording when initially studied. The second hypothesis was that recognition of a word would reveal differences in ERP components associated with recognition memory, specifically the presence of enhanced FN400 and LPC components, if that word was encoded in the sung versus the spoken condition. The data from this study did not fully support any of these hypotheses. Memory performance showed no benefit for the sung over spoken condition, contrary to the findings of Simmons-Stern et al. (2012), but the electrophysiological measures did show a marginal enhancement of the LPC old/new ERP effect for items that had been musically encoded.

This study is the first to examine the neural activity associated with recognition of sung and spoken lyrics by means of EEG. We predicted we would see an enhanced old/new ERP effect for the sung condition in the anterior regions related to the FN400 at 300-500 ms and in the parietal area of the cortex related to LPC at 500-800ms. The FN400 component has been shown to be associated with the process of familiarity (Ally & Budson, 2007; Curran, 2000; Rugg & Curran, 2007; Wolk, Schacter, Lyzigos, Sen, Holcomb, Daffner, & Budson, 2006). The results of the current study revealed no significant differences across conditions for the ROIs associated with the FN400. For the LPC component, there was an increased old/new amplitude difference for the sung condition compared to the spoken condition. This marginal effect could be a result of low power, as the sample size of the current study was relatively small. Potentially running a larger number of subjects would increase the power of the study leading to a significant old/new LPC effect. However, if the trend in the current data persisted, this old/new effect would be independent of improved memory, as there was no significant difference in accuracy performance for the sung and spoken conditions.

The lack of an effect on the amplitude of the FN400 component, but slight increase in positive amplitude for the LPC in the sung condition could be the result of the single exposure to the stimuli. The prior study by Simmons-Stern et al. (2012) used repeated exposures and found significant improvement in memory for the sung condition. If the current study had found the same improvement, it would logically follow that the FN400 component, associated with familiarity, might have shown decreased negative amplitude, and the LPC, associated with having previously experienced stimuli, would have had an increase in positive amplitude. The lack of significance in memory between conditions in the current study is in line with the lack of an FN400 effect, as familiarity did not differ between conditions. The presence of a marginal increase in positive amplitude of the LPC may indicate that there was an effect of having presented the stimuli in the sung condition, but perhaps this effect resulted from the words related to the sung condition eliciting richer, more detailed memory than the memories elicited by the spoken condition. This may not have been enough of a difference to impact overall memory performance, but it could have resulted in a subjectively richer memorial experience for those stimuli that had been musically encoded.

In addition to small sample size, there are other potential limitations to our study. A behavioral paradigm using the same stimuli created for this study found that memory for the sung lyrics improved when the lyrics remained on the screen during the recordings. However, eye artifacts were a concern for the EEG data collection, and having the lyrics on the screen during the audio recordings increases the likelihood of these eye artifacts. This comprehension problem could have counteracted the positive effects music has on memory, as the lyrics only appeared for a period of 4 seconds, which some participants stated was too short of a time to read the entirety of the song. In order to determine if this is the case, a follow up study exploring this issue is necessary.

The differences in the results found in this study and the prior studies by Simmons-Stern et al (2010, 2012) could be a result of several factors. The current study nearly doubled the number of stimuli used so it is possible that the lack of effect comes from the increased difficulty of the experiment due to the larger number of lyrics presented. Also, in the Simmons-Stern work, both the sung and spoken recordings were played twice compared to only once in this study. As other studies have shown, the benefit of music as a mnemonic device may not take effect until the exposure is repeated (Calvert & Tart, 1993). The single exposure in the current study, like the one in Calvert and Tart (1993), had no significant effect on behavioral memory performance. Adding a repetition of the audio recording to the encoding phase could allow for music to have a benefit. Additionally, it could be that the original set of stimuli had a quality that the newly added set does not. The previous stimuli used single line or double line melodies, while the new recordings were more intricate, in that they had more layers of melody. This increase in complexity could have minimized the efficiency of integration that music has been shown to have. In any case, it is important that we do not overlook these possibilities as further research using these stimuli is conducted.

One of the main differences between our current study and the Simmons-Stern work is the population under study. The demographic of the previous research consisted of healthy older adults and patients with AD. Considering episodic memory declines with age (Brickman & Stern, 2009), older adults' memory may differ from the young adults in this study. In addition to the reduction in episodic memory in healthy aging, the memory deficits in AD impair memory more drastically. Simmons-Stern et al. (2010, 2012) suggested that music may allow for better encoding of information as music activates a widely distributed area of brain regions, some of which may be more preserved in AD. Since the younger participants have yet to experience this decline in memory performance, they may not need to rely on these compensating mechanisms when making recognition memory judgments.

Another interesting finding is the lack of relationship between the benefit of music on memory to musical training or training in music theory. As one study using the musical sophistication index (Gold-SMI) found, age does play a role in self-reporting levels of musical sophistication (Müllensiefen, Gingras, Musil, & Stewart, 2014). It is possible that younger individuals are in closer proximity to musical environments, and more active in areas related to music, especially as technology has become more widely available. This study also assessed memory for melodies, which showed age to be a positive factor, with younger participants performing more poorly than the older participants on melody recall. While pertaining to music, and not lyrics, this could explain why there was an effect for music in the older populations from Simmons-Stern et al. (2012), and not in the present study. Since the melody is a pertinent part of the stimuli within this experiment, the lack of integration found in the current study could be a result of the younger population remembering the melody less, but further research would be necessary to determine this interaction. These age differences, both in the previous studies by Simmons-Stern et al. (2010, 2012), Deason et al. (2012), and Müllensiefen (2014) give motivation to want to compare these populations. It is for that reason that future studies should compare these separate populations in order to determine if the effect music has on memory is mediated by factors associated with aging.

As reviewed in the Introduction, prior work by Thaut, Peterson, and McIntosh (2005) and Peterson and Thaut (2007) showed that sung words, while not necessarily better remembered than words that had been spoken, still induced different electrophysiological activity. However, these researchers focused specifically on synchronization of wave bands during the encoding process. While data was collected during encoding, the current study assessed only ERP and behavioral correlates at test. It is possible that this increased synchrony during encoding was present in our paradigm as well, but further analysis is necessary to answer this question.

On the topic of encoding data, the current study looked into judgments toward the lyrics, the sung condition was liked (48%) significantly more than the spoken (38%), with these percentages also reflecting that a majority of the stimuli were disliked. Upon analyzing the relationship between judgment responses in relation to accuracy across conditions, there was no effect for condition, but there was an effect for judgments toward stimuli, with higher levels accuracy for the “likes” than “dislikes.” This coincides with previous findings of a study on memory for music that showed increased liking ratings during encoding was associated with improved accuracy at test (Stalinski, 2014).

The negative response toward the stimuli may have an unseen effect on the outcome of the present findings, specifically with the ERP data. One study showed that emotional context during encoding impacted the amplitude of components associated with the old/new effect (Zhang, Liu, An, Yang, and Wang, 2015). This study used stimuli associated with positive and negative emotions at encoding, then compared these data to the FN400 and LPC. The results showed that the old/new effect found in the LPC was minimized as a result of exposure to stimuli with high levels of negative emotional arousal during encoding. Along with this, there was an old/new FN400 effect for every level of arousal, except the highly negative condition. Although in the current study judgment responses do not directly relate to emotional arousal, they do indicate an individual's perspective toward the stimuli. As most of the sung and spoken lyrics in the current study were viewed negatively it is possible that the stimuli induced a negative state of emotion diminished both old/new ERP effects. In order to determine if there is a possible emotional effect on recognition and ERP components, future studies would need to manipulate conditions to include music and lyrics associated with high and low levels of positive and negative affect. Doing so would allow researchers to determine if the relationship between memory and music differ across varying levels of emotional arousal.

In addition to further EEG/ERP analyses, there are other analyses that could provide further insight into our study. The current study only looked into hits and correct rejections for EEG analysis, but it might also be interesting to examine false alarms, which occur when participants inaccurately respond "old" to a new item. There is also the possibility that liking or disliking lyrics during encoding influenced the outcome.

As reviewed previously, studies on music and memory are rare within the scientific literature, and studies using electrophysiological or other measures of neural activity are even more of a rarity. In spite of the equivocal findings, this study is an important addition to understanding the interactions between music and memory. This study is the first to assess recognition of a single word associated with lyrical content using EEG analyses, and Further research using this method is necessary to understand why there was no improvement in memory performance for sung lyrics in this younger population, especially considering that those with AD have benefited from a similar application.

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