MUSIC AS A MEMORY ENHANCER IN HEALTHY, YOUNG ADULTS:

AN EVENT-RELATED POTENTIAL INVESTIGATION

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 Arts
with a Major in Psychological Research
August 2017

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ACKNOWLEDGEMENTS

I would like to thank my committee, especially Dr. Deason, for their support, patience, and insight throughout the entire process of obtaining my Masters. I would also like to thank Andrew Santana, Ilanna Tariff, Ruben Vela, and David Russel for assisting to make this research possible. I would also like to thank the Texas State University Graduate College for awarding me the Thesis Research Support Fellowship grant, which allowed me to pursue this project without fear of a financial restraint.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AD	Alzheimer’s disease
ANOVA	Analysis of Variance
AVLT	Auditory Verbal Learning Test
CR	Correct Rejections
EEG	Electroencephalography
EOG	Electrooculography
ERP	Event-related Potentials
FAR	False Alarm Rate
FN400	Early Anterior Negativity
Gold-MSI	Goldsmiths Musical Sophistication Index
HR	Hit Rate
LFE	Late Frontal Effect
LPC	Late Positive Component
LRS	Learning-related Synchronization
ROI	Region of Interest

ABSTRACT

Research examining the effectiveness of musical mnemonics as a memory enhancer has thus far been limited and somewhat contradictory. The present study was designed to add to this growing literature by establishing the benefit of music for memory in young adults (Experiment 1) and also to investigate the neural correlates of this benefit using event-related potentials (ERPs; Experiment 2). In the current experiments, each participant listened to 100 novel sets of lyrics, fifty spoken and fifty sung recordings. Following this study phase, the participant was presented with 200 pictures and asked to make an old/new recognition judgement. The "old" pictures referenced the general content of sets of lyrics studied whereas the "new" pictures did not refer back to the content of any of the recordings. It was predicted that participants would have better discrimination for the pictures referring to the sung lyrics than for the pictures referring to the spoken lyrics. In Experiment 1, pictures referring to sung recordings showed a higher discrimination rate than pictures referring to the spoken recordings as predicted. The behavioral results from Experiment 2 contradicted those found in Experiment 1, in fact, discrimination performance for the pictures referring to sung lyrics was significantly lower than for the pictures referring to spoken lyrics. Additionally, the ERP findings did not show a difference between the sung and spoken stimuli. Taken together, the data from the experiments provide evidence that musical mnemonics can benefit memory in some cases although is potentially more limited than previously thought, therefore continued research is needed to better understand the mechanisms and limitations of this effect.

I. INTRODUCTION

Popular belief embraces the idea that setting information, such as the alphabet or the bones of the human body, to a musical melody can enhance the recall of that information. The use of these musical mnemonics is commonly thought to enhance the learning of new information in children and adults as well as potentially in memory-impaired populations. Although, when the empirical literature is reviewed, the results are fairly limited and contradictory. Music has been shown to enhance memory for information in several studies (Calvert & Tart, 1993; McElhinney & Annett, 1996; Rainey & Larsen, 2002), but in others, there has been no enhancing effect (Kilgour, Jakobson, & Cuddy, 2000; Racette & Peretz, 2007). The benefits and limitations of musical mnemonics are not well understood, so investigations of what leads to a successful musical mnemonic will have vital implications in their uses for enhancing memory performance throughout the lifespan.

This chapter will present an overview of the current understanding of the relationship between music and memory including a basic discussion of different types of memory, a review of empirical studies of musical mnemonics and their applications, and the neural correlates of musical mnemonics. This review will set up the current experiments, which investigated the effectiveness of musical mnemonics as a memory enhancer in young adults (Experiment 1) and the neural correlates of musical mnemonics (Experiment 2).

Types of Memory

Prior to investigating the ability of music to enhance memory, one needs to have a basic knowledge of memory. There are two main types of long-term memory: implicit and explicit memory (Tulving, 1972). Implicit memory is defined as memory without conscious awareness; previous experiences influence behavior without conscious awareness (Roediger & McDermott, 1993). Explicit memory is a conscious or intentional retrieval of a past experience (Squire, 1992). Explicit memory can be divided into episodic and semantic memory. Episodic memory is remembering past life events, whereas semantic memory is remembering facts and concepts (Tulving, 1972). The current investigation focused on episodic memory.

Episodic memory can be measured by both recall and recognition memory tests. In recall tests, participants are presented with stimuli and then, after a delay, are asked to remember as many of the stimuli as possible. On the other hand, a recognition memory test normally involves being presented with either a word or picture and then, after an interval, the participant is presented with the same item again and is asked to judge whether they had seen the item previously (Tulving, 1993). Many prior studies examining the potential benefit of music for memory have used recall rather than recognition tests (Foster & Valentine, 2001).

Recognition memory judgments are thought to potentially involve two processes, recollection and familiarity (Yonelinas, 2002). Recollection signifies the retrieval of specific context-derived material about a particular item or event. While, familiarity is normally defined as a more general, non-specific sense of an item or event that has been previously experienced. Familiarity and recollection are commonly experienced in everyday life (Ally, Gold, & Budson, 2008). For example, the unexpected sight of a woman in a grocery store may bring about an immediate feeling of knowing her without being able to produce any specific details about who she is or how you know her. After a few minutes of thinking, the details may come into mind about the woman's identity- say, the hostess at a restaurant you had visited a few days ago- becomes apparent. In the example situation, the initial feeling of knowing the woman without being certain of how you know her is familiarity. The act of remembering the specific context and details of her identity and how you know her is considered recollection. In the current set of experiments, I examined how recognition memory, both recollection and familiarity, may be enhanced by musical encoding.

Musical Mnemonics

The idea that musical mnemonics may serve as a technique for learning new verbal information has a long history. Musical mnemonics, techniques used to enhance the learning of new information via music, are commonly used to help children and adults learn new information. When the past empirical literature is examined, music has been shown to increase memory for information in several studies (Calvert & Tart, 1993; McElhinney & Annett, 1996; Rainey & Larsen, 2002), but others have found no memory-enhancing effect (Kilgour et al., 2000; Racette & Peretz, 2007).

Several studies have found music to have a positive effect on memory (Calvert & Tart, 1993; McElhinney & Annett, 1996; Rainey & Larsen, 2002). Calvert and Tart (1993) studied the role of singing/music in students' recall of the Preamble to the Constitution. They studied the short-term, long-term, and very-long-term verbatim recall of college students using an educational television program, School House Rock, that aired from 1976-1979. Short-term verbatim recall was tested immediately following the initial exposure, long-term verbatim recall was tested five weeks following the initial exposure, and very-long-term verbatim recall was memory examined ten years following initial exposure. In one of their 2-3-minute cartoon vignettes, the program taught their audience the words to the Preamble of the Constitution (Wright & Huston, 1983). First, Calvert and Tart (1993) tested the very-long-term verbatim recall for the Preamble of college students who had watched that episode of School House Rock when it originally aired. Then, they tested the short-term and long-term verbatim recall using the same School House Rock cartoon. The participants were exposed to the Preamble vignette with either sung or spoken lyrics, once or repeatedly. Both the experimental and naturalistic data demonstrated the beneficial effects of songs as mnemonic memory aids for verbal material. Calvert and Tart (1993) found that increased exposure correlated with increased recall, and they suggested that repeated exposure to songs can lead to automatic rehearsal of those lyrics. They concluded presenting content in a musical form can be memorable for years, which provides students with an effective encoding, rehearsal, and retrieval strategy that improved verbatim recall.

McElhinney and Annett (1996) examined the effect of musical mnemonics on recall of verbal material. Each participant was presented with words either sung or spoken. The results showed that the sung presentation led to better recall of words as well as a greater chunking of recall, meaning that words were more likely to be grouped together in the sung condition compared to the spoken condition. The results of the McElhinney and Annett (1996) study on young healthy adults support the efficacy of musical mnemonics.

Additionally, Rainey and Larsen (2002) also found that music aided the learning of new information. They examined whether music, presented in the form of a familiar melody, can be an effective mnemonic device. In their experiments, participants learned a list of words that were heard either spoken or sung to a familiar melody ("Pop Goes the Weasel", "Yankee Doodle"). They measured the number of trials it took to learn the list initially and the number of trials it took to relearn the list a week later. In two experiments, Rainey and Larsen (2002) found that there was no advantage in the initial learning for the participants that learned the names to musical accompaniment. But, in both experiments, participants who heard the sung version required fewer trials to relearn the list of names a week later than those who heard the spoken version (Rainey & Larsen, 2002). This relearning advantage supported the idea that the musical encoding phase enhanced memory for the new information.

The studies by Calvert and Tart (1993), McElhinney and Annett (1996), and Rainey and Larsen (2002) provided evidence that music can serve as an effective mnemonic device, but there have been other studies that have not found this effect (Kilgour et al., 2000; Racette & Peretz, 2007). First, Kilgour et al. (2000) examined whether presentation rate was the driving factor behind the benefit of music as opposed to the melody. In their first experiment, they found that sung lyrics were better recalled than spoken lyrics. Kilgour et al. (2000) believed this could have been the result of a longer duration time for the sung lyrics. Therefore, in subsequent experiments, the presentation rates were manipulated so the duration for the sung and spoken material was equal. With the equated durations, there was no difference in memory performance seen between the sung and spoken material (Kilgour et al., 2000). Potentially, these findings suggested that the benefit of music found in prior studies was due to duration differences between the stimuli.

Racette and Peretz (2007) also investigated the effectiveness of learning verbal information through song and found little benefit. In their first experiment, participants learned an unfamiliar song in one of three conditions: sung-sung, sung-spoken, and spoken-spoken. In the sung-sung condition, the song to be learned was presented sung, and the participant's response was sung as well. In the sung-spoken condition, the response was spoken and, in the spoken-spoken condition, both the presented lyrics and the response were spoken. They found that fewer words were recalled when participants had been asked to sing than when they spoke the lyrics, and the mode of presentation, sung or spoken, had no effect on the lyric recall. Racette and Peretz (2007) concluded that, at least in initial learning, the text and the melody of a song have independent representations in memory, which would make singing a dual task to perform and thus more difficult.

In summary, although the above-mentioned results from the past research on the effectiveness of musical mnemonics are contradictory, they provide us with a framework to build upon for the current experiments. The research studies discussed have shown that musical encoding can be an effective method to enhance memory (Calvert & Tart, 1993; McElhinney & Annett, 1996; Rainey & Larsen, 2002), yet other studies have shown no effect (Kilgour et al., 2000; Racette & Peretz, 2007). The current experiments further explore the effectiveness of musical mnemonics on memory in young, healthy adults.

Applications of Musical Mnemonics

In recent years, research studies have investigated the effect of musical mnemonics on patients with Alzheimer's disease (AD) (Simmons-Stern et al., 2010; Simmons-Stern et al., 2012; Moussard et al., 2014). Alzheimer's disease is characterized by the progressive deterioration of cognitive function, and one of the first symptoms is often impaired episodic memory (Crystal, Grober, & Masur, 1989). This cognitive decline can greatly affect an individual's daily life. Patients with AD have demonstrated a decreased ability to learn and retain new information, which can impair patients' ability to live independently. Researchers are focused on studying the use of musical mnemonics in this population to minimize the decline in quality of life for the affected patients (Schlölzel-Dorenbos, van der Steen, Engels, & Olde Rikkert, 2007) and the burden to the caregivers (Razani et al., 2007).

Simmons-Stern et al. (2010) performed the first experiment examining the effectiveness of musical mnemonics on patients with AD and healthy older adults. Participants studied simple sets of lyrics accompanied either by a sung or spoken recording and subsequently had their memory tested. They were presented with the sets of lyrics (with no auditory accompaniment) and asked to judge whether they were old or new. Patients with AD performed better on this recognition memory test for the lyrics that had been musically encoded compared to the lyrics that had been accompanied by a spoken recording. Healthy older adults did not show this same benefit of music. Simmons-Stern et al. (2010) suggested that there may be a difference in the way music benefits memory between AD patients and healthy older adults.

Simmons-Stern and colleagues (2012) followed up on their earlier study to investigate the effect of musical stimuli on memory in patients with AD by making the to-be-learned information relevant to activities of daily living. They tested their memory for general content information and specific content information. All of the participants were visually presented with novel song lyrics that were accompanied by either a sung or spoken recording. Following the introduction of all 40 recordings, each participant was asked a general content question (e.g., “Did you hear song lyrics about pills?”), then a specific content question (e.g., “According to the lyrics, what should you do with your pills?). The results demonstrated that healthy older adults and Alzheimer’s patients performed better on the general content, or “gist”, questions referring to the sung lyrics than on the questions referring to the spoken lyrics. However, when it came to the memory recall of specific lyric content, both sets of participants performed just as well on the spoken as the sung lyrics (Simmons-Stern et al., 2012). They concluded that the mnemonic benefit of musical encoding only extends to general content, or familiarity, of the lyrics, but it may not extend to more specific information like that involved in recollection.

Moussard and colleagues (2014) also examined the benefit of music on memory in healthy older adults and patients with mild AD. All of the participants were instructed to learn and memorize lyrics presented either sung or spoken and were asked to recall the lyrics immediately and ten minutes after presentation. They found that the sung condition did not improve immediate recall, but it did increase delayed recall in the healthy older adults and AD participants compared to the spoken condition. Additionally, after a four-week delay, the patients with AD showed better memory for lyrics of the sung condition compared to spoken condition. Moussard et al. (2014) suspected that the initial encoding of the sung stimuli may increase the load of learning, but it increases long-term retention of the new verbal information.

These studies indicate the potential promise of musical mnemonics for both healthy older adults and patients with AD. With more research, the knowledge of how and why musical mnemonics appear to enhance memory can be better understood. The investigation of musical mnemonics could help develop new methods of improving memory and thus the daily life of patients with AD.

Neural Correlates of Music and Memory

As previously discussed, there is anecdotal and limited empirical evidence supporting the theory that musical mnemonics enhances memory and learning. However, there is also little research on the mechanisms by which music influences memory. The current study investigated the neural correlates of musical mnemonics. One method used to investigate these neural correlates is by electroencephalography (EEG). EEG measures the electric potential ("voltage") changes across the scalp due to current flow within the brain. The EEG signals primarily arise from cortical post-synaptic activity (Marder, 1998). Two previous studies (Thaut, Peterson, & McIntosh, 2005; Peterson & Thaut, 2007) have examined EEG data to examine the neural correlates of musical mnemonics.

Thaut, Peterson, and McIntosh (2005) conducted one of the first studies to investigate the effect of musical mnemonics on learning and memory and the subsequent plasticity of oscillatory neural networks. They used Rey's Auditory Verbal Learning Test (AVLT), a verbal learning and memory test used in neuropsychological evaluations that employs repeated study/test learning. The AVLT consists of a single standardized list of 15 words that, in the study, participants heard either in spoken or sung form depending on their group assignment. Following the learning trials, there was an immediate recall memory test and a second memory test 20 minutes later. EEG analysis was used to determine differences between verbal learning in the sung compared to the spoken conditions. In their first experiment, they found no behavioral difference between the learning and recall performance of sung vs. spoken word lists. However, a significant difference between spoken and sung conditions was seen in the scalp distribution of learning-related synchronization (LRS) in the theta (3-5 Hz), low alpha (7-9 Hz), high alpha (10-12 Hz), and gamma frequency bands (35-50 Hz). Thaut et al. (2005) defined LRS as the percent change in EEG spectral power from the initial encoding of the word to the average of the succeeding word encoding trials. Spectral power shows the strength of the EEG oscillations, or energy, as a function of frequency. Essentially, it shows at which frequency variations are strong and at which they are weak. During the spoken learning condition, the theta LRS was strongest in right central and posterior regions, whereas during the sung learning condition, maximal theta LRS was seen in the right prefrontal and left occipital regions. Low-alpha for the sung condition was slightly more bilateral in the midline central posterior regions than in the spoken condition. High-alpha LRS for the sung condition was strongest in central prefrontal and left posterior regions, while the spoken condition showed strongest high-alpha in the central posterior and right frontal regions. Gamma LRS was the highest for the sung condition in the central bilateral regions, whereas for the spoken condition, it was highest in the left hemisphere. Thaut et al. (2005) did not find a behavioral difference between the sung and spoken conditions, but they did observe that the sung and spoken conditions accessed different oscillatory brain networks. In their second experiment, the design and task were the same as the first experiment, but in this experiment, they analyzed the EEG spectral power during learning that led to subsequent successful memory recall. Again, the behavioral results did not show a difference between the conditions at test, but there were informative EEG differences between conditions during encoding. They studied the network synchronization by measuring the change in phase-locked oscillations among three electrodes within four quadrants. During the short-term recall (approximately 1-minute delay), learning-related network coherence showed an increase in low-alpha coherence only in the sung condition. For quantitative comparisons, Thaut et al. (2005) computed local coherence, which is the coherence within each of the four quadrants, and the network coherence between them. They also computed the global coherence, which shows the coherence across the whole cortex. Local network coherence was seen in the right anterior and right posterior networks and globally between right posterior and left anterior networks. In the long-term recall (20-minute delay) test, the sung condition showed increased local network coherence in the gamma band in the right anterior and posterior networks, while the global network coherence in the low-alpha band shifted to bilateral posterior regions. The results showed no behavioral difference between the sung and spoken conditions for both trials, but there was difference in the network coherence, such that only the sung condition was associated with increased neural synchronization. Therefore, increases in coherence in alpha and gamma bands in specific lateral and global brain networks predicted memory retention for words in the sung condition but not in the spoken condition.

Peterson and Thaut (2007) further examined EEG coherence during the learning phase associated with successful recall following short- and long-delays. Similar to their earlier study, the AVLT was used, and the participants either heard the spoken or sung version of the word lists. Peterson and Thaut (2007) focused on differences during learning in the prefrontal and medial temporal cortical regions, because prior research suggested these areas are important to verbal encoding (Buckner, Logan, Donaldson, & Wheeler, 2000). They studied the effect of music on learning and memory by comparing the learning-related changes in EEG coherence during encoding when the word was subsequently recalled or subsequently forgotten. Participants in the sung condition showed a greater increase in theta coherence between hemispheres and an increase in right alpha coherence for both short- and long-delay learning. Participants in the spoken condition showed a decrease in right alpha coherence for both short- and long-delay learning. For gamma coherence, participants in the sung condition showed increased coherence for long-delay learning, whereas the spoken group showed a decrease. The authors concluded that verbal learning paired with music strengthens coherent oscillations in the frontal cortical networks, which are associated with verbal learning.

The experiments by Thaut et al. (2005) and Peterson and Thaut (2007) provided the first evidence that music can influence neuronal activity, even without the presence of an obvious cognitive difference.

Current Study: Hypotheses and Rationale

The current experiments were designed to investigate the potential benefit of pairing information with music in order to enhance memory in healthy young adults. Both of the current experiments had an encoding phase and test phase. During the encoding phase, each participant was presented with 100 recordings, 50 sung (with melody accompaniment) recordings and 50 spoken recordings. Following each recording, the participant made a ‘like/dislike’ judgment. During the subsequent test phase, the participant viewed 200 pictures and was asked to decide whether they had heard a sung or spoken recording about the object in the picture (“old”) or had not heard a sung or spoken recording about the object in the picture (“new”). In Experiment 1, it was predicted that, when presented with a picture referring to the sung and spoken lyrics, the young, healthy adults would recognize the pictures related to the sung stimuli more often than the pictures related to the spoken stimuli. In Experiment 2, it was, also, hypothesized that participants would better remember new information that was studied with a sung recording than information studied with a spoken recording. In addition, it was predicted that there would be an enhancement of ERP components, related to memory, during the recognition test phase of the experiment for the sung recordings.

Prior research (Simmons-Stern et al., 2012) has shown that music potentially enhances general content information, that requires a familiarity-based memory, whereas specific content information, that requires a recollection-based memory, was not further enhanced by musical encoding. The current experiments used a paradigm which encouraged familiarity-based recognition. The use of pictures in the test, with no perceptual overlap between study and test phase, was used to determine whether true abstraction of the general information of the audio clip was occurring. Since none of the studies reviewed used pictures, it was also novel and beneficial to observe how this modality change effected the expected results.

In addition to examining behavioral results, the event-related potentials (ERPs), which reflect averaged stimulus- or response-locked EEG activity, were investigated in Experiment 2. There has been extensive research examining memory processes using ERPs. Specifically, ERPs have been useful in understanding recognition memory (Rugg, 1995). ERPs show a distinction between the items correctly identified as previously studied (“old”/hit) and the items correctly identified as not having been studied (“new”/correct rejection), with the “old” items/hits eliciting a more positive ERP waveform than the “new”/correct rejection items (Freedman & Johnson, 2000). This *old/new effect* is found in several ERP components. The first component that reflects this *old/new effect* usually occurs at bilateral frontal electrode sites between 300 and 500 ms, which typically precede the controlled attempt to retrieve information. This effect has been referred to as the FN400 component, and it has been associated with familiarity (Curran, 2000; although see Voss, Lucas, & Paller, 2012, for alternative views). The second component occurs maximally at parietal electrodes sites, between 500 and 800 ms, and is commonly referred to as the LPC (late positive component). Past research has determined this effect, the parietal *old/new effect*, to be less sensitive to familiarity and more related to the context-rich recollection type of memory (Woodruff, Hayama, & Rugg, 2006). The last component demonstrating an *old/new effect* occurs around 800-1200 ms over the frontal electrodes site, with predominance in the right hemisphere. This late frontal effect (LFE) is associated with the post-retrieval verification and checking processes, particularly when evaluating details and features (Wilding & Rugg, 1996). Research in neuroimaging has suggested that this LFE could be reflecting the executive control function of the prefrontal cortex while retrieving a memory (Buckner, Raichle, Miezin, & Petersen, 1996).

In summation, Experiment 1 investigated the effect of musical mnemonics. It was predicted that the pictures related to the sung lyrics would be more often recognized than the pictures related to the spoken lyrics. Experiment 2 investigated both behavioral and ERP effects of musical mnemonics. It was again predicted that the pictures relating to the sung lyrics would be more often recognized than the pictures relating to the spoken lyrics. In addition, the ERP components related to memory were investigated. The FN400, the LPC, and the LFE *old/new ERP effects* were examined to determine whether there was an enhancement of these effects for information that been studied with music compared with information studied with a spoken recording.

II. EXPERIMENT 1: RESEARCH METHODS AND DESIGN

Participants

A total of 24 individuals were recruited to participate. They were between the ages of 18-30 years old, and all the individuals that participated had normal/correct-to-normal vision and hearing. They were compensated for participation in form of course credit for an introductory-level Psychology course via the Texas State Psychology Department's online human subjects pool or extra credit at the professor's discretion.

Materials and Stimuli

The stimuli consisted of 150 4-line sets of lyrics, each having a spoken and sung version, which resulted in 300 auditory stimuli. Each song was recorded and equalized on Logic Pro 8 (Version 8.0.2; Apple Inc.). A female vocalist from Texas State University with extensive musical and voice training was recruited to sing and speak all lyrics. The spoken excerpts were recorded with normal vocal inflection at the same speed as their corresponding sung counterpart. Each of the 150 sets of lyrics was designed to have a picture paired with it that relates to the meaning of the song. For example, if during the encoding phase, the participant heard the lyrics, "It keeps you from getting lost, under the sun or in the frost. A compass tells you where to go, in the desert or in the snow." during the test phase, they would see a picture of a compass and asked whether they had heard a set of lyrics referring to this picture in the study phase. All the pictures were color photographs of objects related to each set of lyrics. They were found via an internet search engine. Pictures were sized to 450 pixels x 450 pixels and presented on a white background.

There were 3 lists of 50 lyrics/pictures counterbalanced across subjects for total number of words, duration, beats per minute (bpm), and major/minor key. The average length of the recording was 18.3 seconds (equated for spoken and sung) and the average word count for each recording was 23 words. These lists were rotated across subjects so that each lyric/picture appeared an equal number of times in each condition. Along with these lists, there were an additional set of 50 filler pictures presented in the test phase to equate the number of old/new items in the recognition memory test.

Behavioral Procedures

This experiment utilized a within-subjects design. Each participant completed a one-hour session, which consisted of an encoding phase and a test phase (see Figure 1). During the encoding phase, participants listened to 100 audio recordings: 50 spoken and 50 sung with musical accompaniment randomly intermixed. Participants were presented the auditory stimuli through headphones (Audio Technica ATH-M30). Prior to the encoding phase, the volume was set to a comfortable level for each participant. While the auditory stimuli played, the lyrics appeared on the computer screen, which was done in order to equate the comprehensibility of the sung and spoken stimuli. After each presentation, the participants were to make a judgement on the auditory stimuli by pressing one of two buttons on a button box that corresponded to “like” or “dislike”, which was done in order to maintain attention.

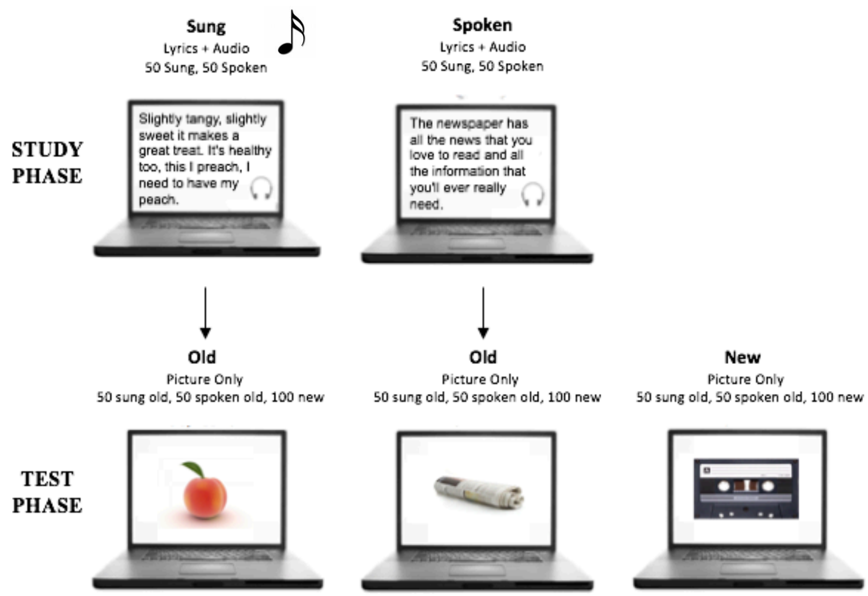

Figure 1: Behavioral method illustration. The musical note denotes the audio clip that is sung with musical accompaniment. The picture on the bottom right (cassette tape) signifies the pictures that do not relate to any of the audio clips.

When the participants completed the encoding phase, they were given a break of approximately 5 minutes. In the test phase, participants were presented with 200 pictures (half referring to lyrics presented in the study phase, half unrelated). Each picture was presented in the center of the screen and remained on the screen until the participant responded “old” if the picture was related to lyrics heard before or “new” which indicated the word was not related to previously heard lyrics. The picture would remain on the screen until the participant responded. Participants made “old” or “new” responses by pressing one of two buttons on a button box. After each response, a blank screen appeared for 1.5 seconds prior to the appearance of a fixation cross that remained on the screen for 1.5 seconds, which was then followed by the next picture. The encoding and test phases of the experiment was conducted using the experiment presentation program E-Prime (Psychology Software Tools, Pittsburgh, PA).

Following the completion of the experiment, the participants completed the Goldsmiths Musical Sophistication Index (Gold-MSI), v1.0 (Appendix A), which determined each participant's musical ability (Müllensienfen, Gingras, Musil, & Stewart, 2014).

Analytic Strategies

Memory discrimination performance was measured by subtracting the false alarm rate (FAR), which is the proportion of incorrect old responses to new items, from the hit rate (HR), which is the proportion of accurate old responses. This produces a measure of Pr (HR-FAR; Snodgrass & Corwin, 1988). Pr was used to measure memory discrimination so that the results would be comparable to prior related experiments (Simmons-Stern et al., 2010; 2012). Paired samples (sung vs. spoken) *t*-tests were conducted to examine memory discrimination, with a significance level of $p < .05$.

The responses to the Gold-MSI questionnaire were accumulated into six different variables, which consisted of active engagement, perceptual abilities, musical training, singing abilities, emotions, and general musical sophistication. In order to analyze the relationship between these variables and memory performance, a new variable was created in order to determine the benefit of music (SungPr – SpokenPr). Bivariate correlations were performed in order to determine the relationship between the accumulated variables from the Gold-MSI questionnaire with the new musical benefit variable, with a significance level of $p < .05$.

Behavioral Results

In Experiment 1, memory discrimination (Pr) for sung trials ($M = 0.47$, $SD = 0.19$) and spoken stimuli ($M = 0.43$, $SD = 0.22$) were significantly different (t (23) = -

2.206, $p = 0.038$; see Figure 3). The Pr was significantly greater for the sung condition than the spoken. The hit rate performance for sung trials ($M = 0.75$, $SD = 0.12$) and spoken trials ($M = 0.71$, $SD = 0.15$) were significantly different (t (23) = 2.206, p = 0.038). The average FAR ($M = 0.28$, $SD = 0.16$) was calculated, but it cannot be separated by condition. The like/dislike judgments were also analyzed. A repeated measures ANOVA comparing the liking percentage of condition (spoken vs. sung) and accuracy (hits vs. misses) showed there was no significant effect for condition (F (1, 23) = 1.703, $p = 0.205$), a significant effect for accuracy (F = (1, 23) = 11.810, $p = 0.002$), but there was no interaction between condition and accuracy (F (1, 23) = 0.001, p = 0.972). Comparing the hits and misses across conditions showed that hits had a higher liking percent ($M = 0.94$, $SD = 0.39$) than the misses ($M = 0.83$, $SD = 0.40$).

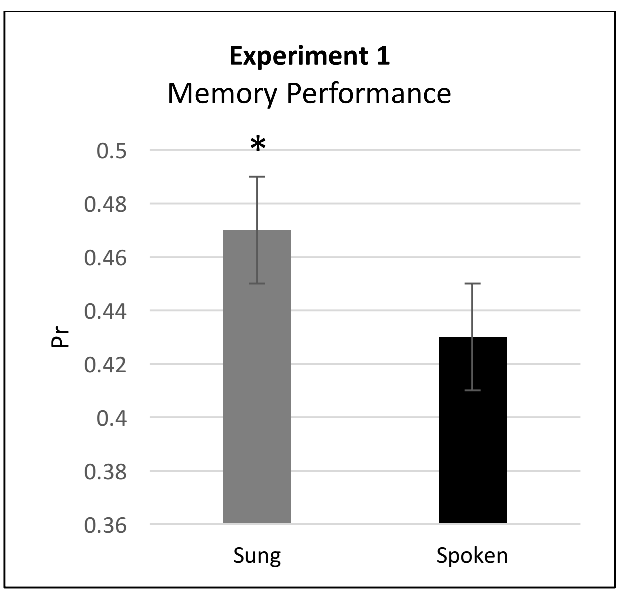

Figure 2: Discrimination performance (Pr). Bars indicate standard error of the mean.

Bivariate correlations between a calculation of the benefit of music (*Sung Pr – Spoken Pr*) and responses to the Gold-MSI questionnaire were conducted (see Table 1 for descriptions/mean of the variables from the Gold-MSI for Experiment 1). There were no significant correlations between any of the pairings (see Table 2 for correlations for Experiment 1).

Table 1. Experiment 1
Descriptive Statistics of the Gold-MSI Questionnaire

Variable	**Mean**	**Standard Deviation**
Active Engagement	37.33	9.16
Perceptual Abilities	45.08	6.86
Musical Training	20.79	11.45
Singing Abilities	29.21	6.35
Emotions	31.63	4.78
General Music Sophistication (GMS)	71.00	17.26
Musical Benefit	0.04	0.08

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

Table 2. Experiment 1
Pearson Correlations Between Musical Benefit and Aggregated Variables from Gold-MSI

	Active Engagement	*Perceptual Abilities*	*Musical Training*	*Singing Abilities*	*Emotions*	*GMS*
Musical Benefit	0.026 (0.903)	-0.219 (0.305)	-0.075 (0.726)	0.356 (0.088)	-0.009 (0.967)	0.099 (0.647)

Note. Musical Benefit is *Sung Pr – Spoken Pr.* Top row are Pearson correlation coefficients and corresponding *p*-values are below in parentheses.

III. EXPERIMENT 2: RESEARCH METHODS AND DESIGN

Participants

A total of thirty individuals were recruited as participants. They were between the ages of 18-30 years old, right-handed, no prior neurological issues, and had normal/corrected-to-normal vision and hearing. They were compensated for participation in the form of course credit for an introductory-level Psychology course via the Texas State Psychology Department's online human subject pool or payment of $10/hour. The Institutional Review Board at Texas State University approved procedures. Of the thirty participants, 25 had usable data for EEG analysis. The five excluded participants were excluded for various reasons. One participant's data were excluded because of a computer error and four participants' data were excluded because of inadequate bin sizes (less than 15 sung-hits, spoken-hits, or correct rejections).

Materials and Stimuli

The materials and stimuli were identical to those in Experiment 1.

Behavioral Procedures

The behavioral procedure was the same as Experiment 1, except the earphones used in Experiment 2 were specially designed to minimize interference with the EEG signals and the lyrics were only visually presented for 6 seconds prior to audio recording starting. The presentation of the lyrics on the screen was adjusted from the entire duration of the audio clip (Experiment 1) to only 6 seconds prior to the audio clip starting (Experiment 2) to reduce the contamination of eye-movement artifact from reading the lyrics on the screen. In the future, it would be beneficial to analyze the encoding EEG data, therefore all precautions were made to minimize artifacts throughout data collection.

Electrophysiological Procedures

Following the completion of the consent form, participants were setup for EEG recording. While the participant was getting setup for EEG recording, they completed the Gold-MSI (Müllensienfen et al., 2014). For both the encoding and test phases of the experiment, EEG data was recorded using a BioSemi ActiveTwo amplifier system. This particular system uses an assembly of 64 active electrodes connected to a cap in the standard international 5-10-20 positions. Additional electrodes were placed above and below the left eye as well as on the outer canthus of both eyes. EEG signals were recorded with a sampling rate of 512 Hz. Also, a time series filter zero-phase-shift IIR band-pass filter was applied to the whole recording from 0.03 – 30 Hz. The EEG signals were recorded with respect to a common mode sense active electrode placed between the PO3 and POz channels, which was re-referenced offline by way of the common average reference (Murray, Brunet, & Michel, 2008). The range of the half-cell potential offsets was within +/- 25 μV for all participants.

EEG data from the test phase, using the EMSE Software Suite from Source Signal Imaging (Source Signal Imaging, San Diego, CA), was processed and corrected for excessive eye movement activity. Using the EMSE Ocular Artifact Correction Tool, trials were corrected for excessive electrooculography (EOG) artifacts. The artifact data was distinguished from artifact-free data. Then, by using a covariance technique that concurrently models artifact and artifact-free data, a logarithmic ratio of artifact data to clean data is produced by EMSE. Lastly, the ocular artifacts are subtracted from the EEG recording where it is detected by the correction tool. If the baseline drifts or movement was greater than 90 μV, trials were removed from analyses. Bad channels were manually identified and corrected, using the EMSE spatial interpolation filter. On average, one channel was interpolated for each participant.

Analytic Strategies

For Experiment 2, both behavioral and ERP data were analyzed. The analysis of the behavioral data was identical to Experiment 1. First the EEG data was artifact-scored, then ERP averages were created for each condition (average number of trials in each condition: sung = 27.81; spoken = 29.74; correct rejection = 23.41). The epochs ranged from -200 ms before each presented picture to 1.8 seconds following the onset of the picture. All ERPs were baseline-corrected to the average of the -200 to 0 ms pre-stimulus interval. The mean amplitudes for the FN400, late positive component (LPC), and late frontal effect (LFE) were averaged at 300-500 ms, 500-800 ms, and 800-1200 ms, respectfully. The regions of interest (ROI) for the FN400 and LFE focused on the anterior electrodes, i.e. left anterior (ROI 1), central anterior (ROI 2), and right anterior (ROI 3). The ROI for the LPC focused on central and posterior electrodes, i.e. left posterior (ROI 4), central posterior (ROI 5), and right posterior (ROI 6). ROI 1 consisted of 8 electrodes, ROI 2 consisted of 8 electrodes, ROI 3 consisted of 8 electrodes, ROI 4 consisted of 12 electrodes, ROI 5 consisted of 14 electrodes, and ROI 6 consisted of 12 electrodes. Each set of electrodes, in a given ROI, was averaged together to create a single waveform. The particular electrodes located in each ROI are illustrated in Figure 2. 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 performed to analyze the mean waveform amplitude for ROIs associated with each component. The Greenhouse-

Geisser correction, which is normally used with ERP analyses, was applied to correct the degrees of freedom to account for potential violations of the sphericity assumption. The Bonferroni correction was applied to the post-hoc tests, in order to correct for multiple comparisons.

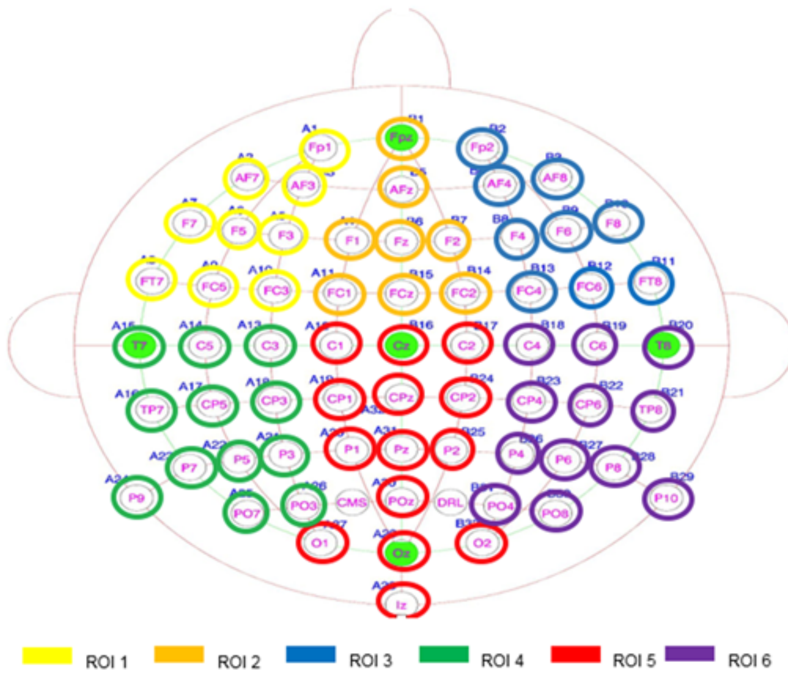

Figure 3: Map Electrode Placement on Scalp with Designation of ROIs for Analysis.

Behavioral Results

In Experiment 2, memory discrimination performance (Pr) for sung trials (M = 0.33, SD = 0.16) and spoken trials (M = 0.37, SD = 0.18) were significantly different (t (26) = -3.63, p = 0.001; see Figure 3). The Pr was significantly greater for the spoken condition than the sung. The hit rate performance sung trials (M = 0.67, SD = 0.72) and spoken trials (M = 0.72, SD = 0.14) were significantly different (t (24) = -3.64, p = 0.001). The FAR (M = 0.33, SD = 0.14) was calculated, but the conditions cannot be separated. A repeated measures ANOVA comparing the liking percentage of condition (spoken vs. sung) and accuracy (hits vs. misses) showed there was a significant effect for condition (F (1, 24) = 12.839, p = 0.001), no significant effect for accuracy (F = (1, 24) = 0.008, p = 0.932), but there was no interaction between condition and accuracy (F (1, 24) = 0.342, p = 0.564). Comparing the conditions on preference judgment (combining across hits and misses) showed that the sung condition had a higher liking percent (M = 0.94, SD = 0.39) than the spoken condition (M = 0.83, SD = 0.40).

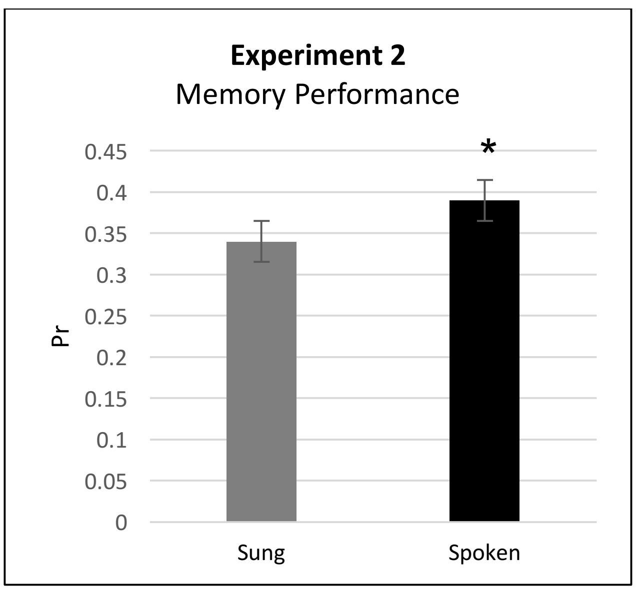

Figure 4: Discrimination performance (Pr)). Bars indicate standard error of the mean.

Bivariate correlations between a calculation of the benefit of music (*Sung Pr – Spoken Pr*) and responses to the Gold-MSI questionnaire were conducted (see Table 3 for descriptions/mean of the variables from the Gold-MSI for Experiment 2). There were no significant correlations between any of the pairings (see Table 4 for correlations for Experiment 2).

Table 3. Experiment 2
Descriptive Statistics of the Gold-MSI Questionnaire

Variable	**Mean**	**Standard Deviation**
Active Engagement	37.44	9.39
Perceptual Abilities	43.96	7.38
Musical Training	19.52	19.23
Singing Abilities	29.04	6.62
Emotions	36.78	4.64
General Music Sophistication (GMS)	72.96	26.21
Musical Benefit	-0.04	0.06

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

Table 4. Experiment 2
Pearson Correlations Between Musical Benefit and Aggregated Variables from Gold-MSI

	Active Engagement	*Perceptual Abilities*	*Musical Training*	*Singing Abilities*	*Emotions*	*GMS*
Musical Benefit	-0.225 (0.259)	0.110 (0.586)	0.320 (0.111)	0.285 (0.150)	-0.250 (0.209)	0.279 (0.158)

Note. Musical Benefit is *Sung Pr – Spoken Pr.* Top row are Pearson correlations coefficients and corresponding *p*-value are below in parentheses.

Electrophysiological Results

ERPs elicited by pictures (old and new) in the recognition test were investigated by examining old/new waveform differences in three components: FN400 (300-500 ms), LPC (500-800 ms), and LFE (800-1200 ms). Individually for the FN400 (300-500ms) and LFE (800-1200ms) components, a 2 x 3 repeated-measures ANOVA was conducted using within subject factors of condition (sung vs. spoken) and region of interest (ROI 1 vs. ROI 2 vs. ROI 3) to investigate Hits-CR mean amplitude difference. For the LPC component (500-800ms), a 2 x 3 repeated measures ANOVA was conducted using within subject factors of condition (sung vs. spoken) and region of interest (ROI4 vs. ROI5 vs. ROI6) to investigate Hits-CR mean amplitude difference[*].

Sung Hits – CR vs. Spoken Hits - CR

For the FN400 component, there were no main effects of condition (F (1, 24) = 0.538, p = 0.470) nor ROI (F (1.396, 33.492) = 0.688, p = 0.459). There was an interaction between condition and ROI (F (1.715, 41.160) = 3.555, p = 0.044). The paired samples t-tests revealed no significant differences between sung and spoken at ROI 1 (t (24) = 1.109, p = 0.278), ROI 2 (t (24) = -1.066, p = 0.297), nor ROI 3 (t (24) = -1.414, p = 0.170). Two repeated measures ANOVAs were conducted separately for the sung and spoken conditions at ROI 1, ROI 2, and ROI 3. There was no significant difference between the ROIs for the sung condition, F (1.420, 34.086) = 0.022, p = 0.944. For the spoken condition, there was a trend toward a significant difference between ROIs, F (1.461, 35.053) = 2.466, p = 0.113. Follow-up paired samples t-tests were conducted on the spoken condition at ROI 1, ROI 2, and ROI 3. There was not a significant difference seen between ROI 2 and ROI 3 (t (24) = -0.109, p = 0.914) nor ROI 1 and ROI 3 (t (24) = 1.551, p = 0.134). However, ROI 2 had a significantly higher amplitude than ROI 1, t (24) = -2.227, p = 0.036. For the LPC component, there was no main effect of condition

[*] Variations in reaction time were likely not contributing to differences seen. Differences in reaction time was controlled for by averaging each item type (sung hits, spoken hits, and correct rejections) and ensuring there was no significant difference between any of the three by trimming outliers from the analyses. When controlling for reaction time, the results were all the same except for the interaction between condition and ROI at LFE in the Spoken-Hits vs. CR (F (1.473, 35.341) = 2.591, p = 0.103) was not seen.

(F (1, 24) = 0.671, p = 0.421), ROI (F (1.898, 45.548) = 1.197, p = 0.310), nor an interaction between condition and ROI (F (1.565, 37.571) = 0.859, p = 0.407). For the LFE component, there were no main effect of condition (F (1, 24) = 0.531, p = 0.473), ROI (F (1.501, 36.019) = 1.705, p = 0.201), nor an interaction between condition and ROI (F (1.344, 32.255) = 1.054, p = 0.334).

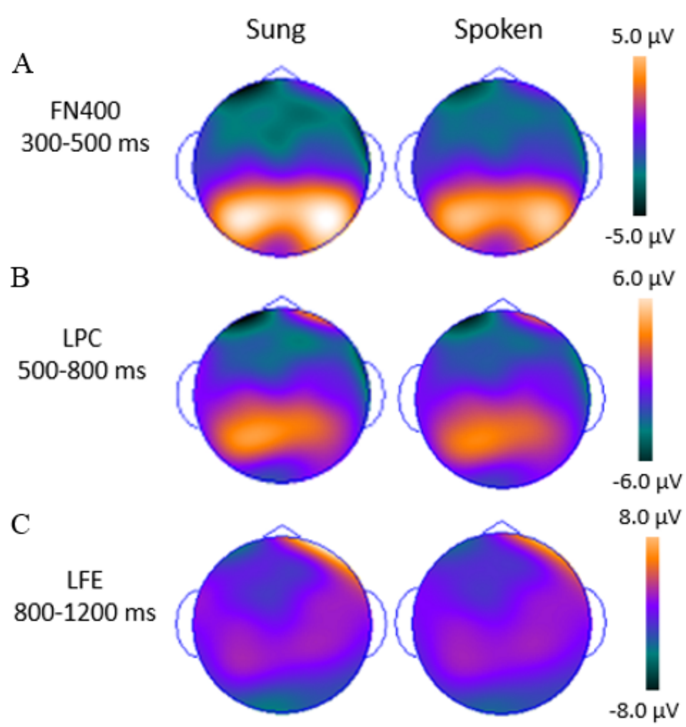

Figure 5: FN400: Average of Electrodes from 300ms to 500ms post stimuli for Hits-CR (A); LPC: Average of Electrodes from 500ms to 800ms post stimuli for Hits-CR (B); LFE: Average of Electrodes from 800ms to 1200ms post stimuli for Hits-CR (C)

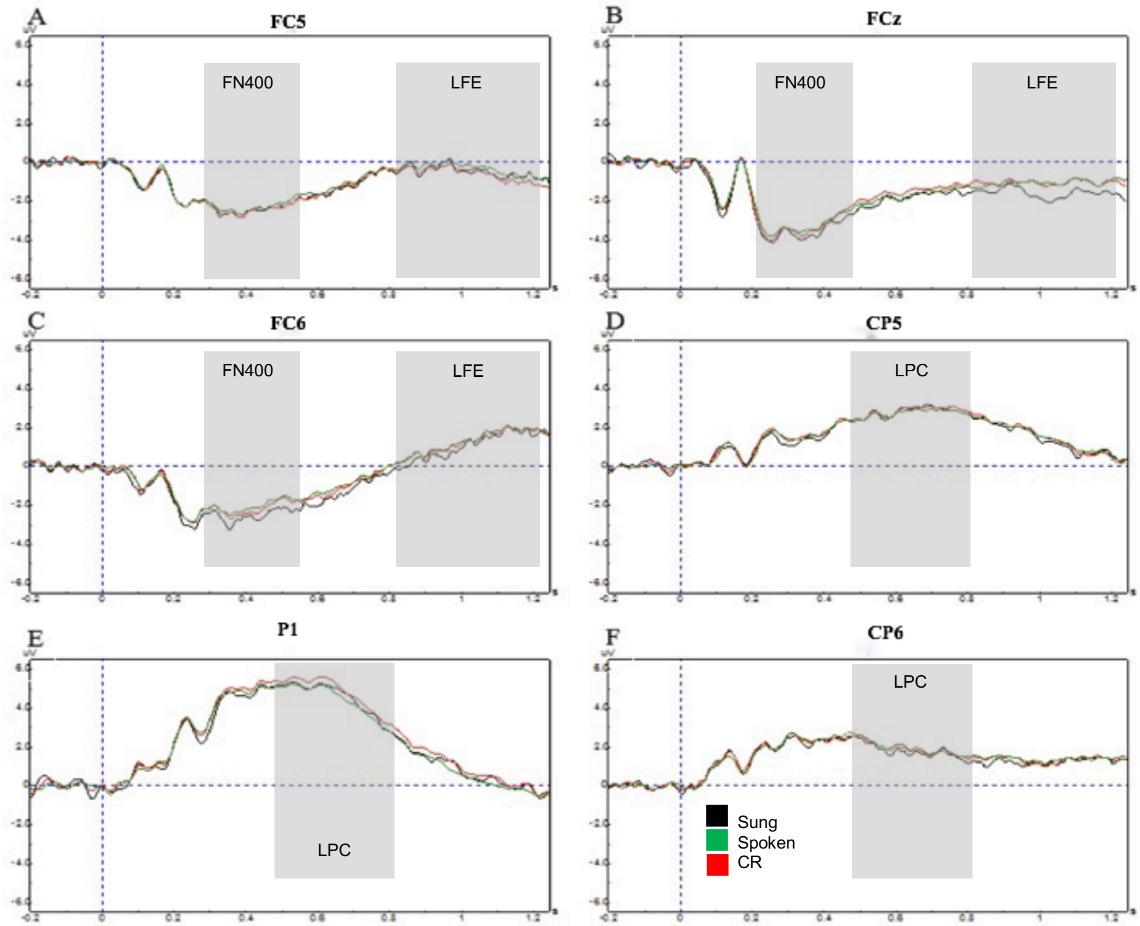

Figure 6: (A) Representative Electrode for FN400 and LFE: ROI 1, Left Anterior Region of the Cortex; (B) Representative Electrode for FN400 and LFE, Central Anterior Region of Cortex; (C) Representative Electrode for FN400 and LFE: ROI 3, Right Anterior Region of Cortex; (D) Representative Electrode for LPC: ROI 4, Left Parietal Region of the Cortex; (E) Representative Electrode Activity for LPC: ROI 5, Central Parietal Region of the Cortex; (F) Representative Electrode for LPC: ROI 6, Left Parietal Region of the Cortex.

Sung Hits vs. CR

We examined the typical *old/new ERP effect* for each condition separately to see if this provided any further information. Two 2 x 3 repeated measures ANOVAs were conducted for FN400 (300-500ms) and LFE (800-1200ms) components, respectively using within subject factors of item type (Sung-Hits vs. CR) and region of interest (ROI 1 vs. ROI 2 vs. ROI 3) to investigate the typical *old/new ERP effect*. An ANOVA was conducted for LPC (500-800 ms) but using appropriate ROIs (ROI 4 vs. ROI 5 vs. ROI

6). For the FN400 component, there was no main effect of item type (F (1, 24) = 2.469, p = 0.129), ROI (F (1.634, 39.226) = 0.719, p = 0.467), or an interaction between item type and ROI (F (1.420, 34.084) = 0.022, p = 0.944). For the LPC component, there was no main effect of item type (F (1, 24) = 0.650, p = 0.428) nor an interaction between item type and ROI (F (1.714, 41.145) = 1.543, p = 0.227). There was a main effect of ROI, F (1.912, 45.891) = 3.623, p = 0.036. Paired samples t-tests were conducted to find the differences in the ROI for the LPC. This was done by collapsing across the item type (sung hits and CR) for each ROI. There was not a significant difference between ROI 4 and ROI 5, t (24) = 1.840, p = 0.078 nor ROI 5 and ROI 6, t (24) = 0.752, p = 0.459. There was a significant difference between ROI 4 and ROI 6, t (24) = -2.450, p = 0.022. ROI 4 had a higher mean amplitude than ROI 6. For the LFE component, there was a trend toward a main effect of item type (F (1, 24) = 3.692, p = 0.067), a main effect of ROI (F (1.305, 31.331) = 6.306, p = 0.012), but no interaction between item type and ROI (F (1.432, 34.361) = 0.653, p = 0.478). Correct rejections showed a higher mean amplitude than sung stimuli. Also, paired samples t-tests were conducted to discover the differences between ROIs for the LFE. Again, the item types were collapsed across ROIs. There was a trend toward a significant difference between ROI 1 and ROI 2 (t (24) = 2.278, p = 0.032), where ROI 1 had higher mean amplitude than ROI 2. Also, there was a significant difference between ROI 2 and ROI 3 (t (24) = -4.070, p = 0.001), where ROI 3 showed higher mean amplitude than ROI 2. There was not a significant difference between ROI 3 and ROI 1 (t (24) = 1.450, p = 0.160).

Spoken Hits vs. CR

The *old/new ERP effect* was examined separately for the spoken condition. Two 2 x 3 repeated measures ANOVAs were conducted for FN400 (300-500ms) and LFE (800-1200ms) components, respectively using within subject factors of item type (Spoken-Hits vs. CR) and region of interest (ROI 1 vs. ROI 2 vs. ROI 3) to investigate the typical *old/new ERP effect*. An ANOVA was conducted for LPC (500-800 ms) but using appropriate ROIs (ROI 4 vs. ROI 5 vs. ROI 6). For the FN400 component, there was no main effect of item type (F (1, 24) = 0.364, p = 0.552), ROI (F (1.510, 36.236) = 0.516, p = 0.551), or interaction between item type and ROI (F (1.460, 35.050) = 2.465, p = 0.113). For the LPC component, there was no main effect of ROI (F (1.821, 43.693) = 2.467, p = 0.101) or an interaction between item type and ROI (F (1.858, 44.592) = 0.800, p = 0.447). There was a trend toward a main effect of item type, F (1, 24) = 4.184, p = 0.052. The spoken item type showed a higher mean amplitude than correct rejections. For the LFE component, there was a main effect of item type (F (1, 24) = 9.628, p = 0.005), ROI (F (1.490, 35.758) = 6.141, p = 0.009), and a trend toward an interaction between item type and ROI (F (1.480, 35.530) = 2.670, p = 0.097). The correct rejections showed higher mean amplitude than the spoken item type. Follow-up paired samples *t*-tests were conducted to explore the main effect of ROI and the item type x ROI interaction. The ROIs were collapsed across item type. The paired samples *t*-tests revealed a significant difference between ROI 2 and ROI 3 (t (24) = -3.854, p = 0.001) and a trend to significance between ROI 3 and ROI 1 (t (24) = 2.026, p = 0.054). In both cases, ROI3 showed higher mean amplitude than ROI2 and ROI1. There was no significant difference between ROI 1 and ROI 2 (t (24) = 0.997, p = 0.329). The paired samples *t*-tests showed a significant difference between spoken and CR at ROI 1 (F (24) = -2.978, p = 0.007), but there was not a significant difference between spoken and CR at

ROI 2 (*F* (24) = -0.980, *p* = 337) nor between spoken and CR at ROI 3 (*F* (24) = -1.524, *p* = 0.141). At ROI 1, the CR had significantly higher amplitude than the spoken.

To gain more insight into the differences between the correct rejections and hits for both conditions, topographic maps were created for the subtraction of correct rejections from hits (Hits – CR). These topographic maps were averaged across the time span of 300-500 ms after the onset of the stimuli to depict the FN400 component. The Hits-CR for both conditions are also mapped out topographically in order to examine LPC (500-800 ms) and LFE (800–1200 ms). A visual representation of the three topographic maps shows a similar pattern of results (illustrated in Figure 4). There appear to be only minimal differences between the sung and spoken conditions. Waveforms for the sung hits, spoken hits, and correct rejections at representative electrodes for each ROI were also plotted (see Figure 5).

IV. GENERAL DISCUSSION

The current experiments investigated whether musical mnemonics were successful in enhancing the memory of young, healthy adults. It was hypothesized that memory performance recognition of pictures of sung stimuli would be greater than for pictures of spoken stimuli. It was also hypothesized that recognition of a picture related to the sung and spoken audio stimuli would reveal differences between ERP components associated with recognition memory.

Prior literature had shown mixed results of the usefulness of musical mnemonics. In Experiment 1, a benefit for musically encoded information was seen, whereas, in Experiment 2, this benefit was not seen. In both experiments, there was a significant difference between the sung and spoken condition, but this difference was opposite in direction. In Experiment 1, the pictures related to sung lyrics were more often successfully recognized than the pictures related to spoken lyrics. In Experiment 2, the pictures related to spoken lyrics were more often successfully recognized than the pictures related to sung lyrics, which is contrary to the finding of Simmons-Stern et al. (2012). These results could be due to a few factors. In Experiment 1, the lyrics remained on the screen for the duration of the audio, while in Experiment 2, the lyrics only appeared on the screen for 6 seconds prior to the audio clip starting. This modification was made for the ERP experiment as the eye movements during the reading of the lyrics while the audio clip was playing would lead to noise in the EEG recording. The longer exposure of the lyrics on the screen in Experiment 1 may have allowed the participants to encode the lyrics more fully than the participants in Experiment 2 by following along with the lyrics on the screen while they were being said or sung. This difference may have led to better discrimination of the pictures related to the sung encoding condition. Also, prior literature had suggested that learning novel lyrics (sung) with a melody is more difficult that learning novel lyrics (spoken) without a melody because of an increased workload (Korenman & Peynircioglu, 2004; Purnell-Webb & Speelman, 2008). Additionally, in Experiment 2, the participants were connected to EEG equipment while they completed the experiment, which could influence their performance. In future studies, these factors should be equated to investigate the enhancing effect of music on memory.

In addition to the lack of a benefit of music to behavioral memory performance in Experiment 2, the electrophysiological measures did not reveal any important differences between the effects of sung versus spoken encoding on test memory performance. The present experiment is one of the first to investigate the effect of music on memory with an electrophysiological component. It was predicted that there would be an enhanced *old/new ERP effect* for the sung condition in the anterior regions associated with the FN400 at 300 – 500 ms post stimuli, the parietal regions associated with the LPC at 500 – 800 ms post stimuli, and potentially the anterior regions associated with the LFE at 800 – 1200 ms post stimuli. The results of the study revealed no significant differences between the sung and spoken conditions for the FN400, LPC, or LFE *old/new effects*.

The standard *old/new effect*, which compares the hits to the correct rejections, for each component was examined to replicate typical memory experiment findings separately for the sung and spoken conditions. For Spoken-Hits vs. CR at LPC, the Spoken-Hits showed a trend toward an increased amplitude compared to CR. This effect was expected, since the Spoken-Hits were previously experienced and the CR were not.

This pattern is typically seen in the *old/new effect*. For Sung-Hits vs. CR at LFE, the CR showed a trend toward increased amplitude compared to the Sung-Hits. Also, for Spoken-Hits vs. CR at LFE, the CR had a significantly higher amplitude than Spoken-Hits. Typically, the hits would produce a higher amplitude than the CR in the LFE *old/new effect*, which is thought to relate to post-retrieval verification and checking processes (Wilding & Rugg, 1996). The LFE is associated with the continuing evaluation and monitoring of the result of the retrieval attempt, and it has been suggested that the activity may index retrieval efforts or controlled processes related to directing additional attempts when initial retrieval attempts have failed (Ally & Budson, 2007; Ally, Waring, Beth, McKeever, Milberg, and Budson, 2008). It may be that the participants had more difficulty making old/new decisions for the "new" items (correct rejections) than the "old" items (hits), therefore the participants required less post-retrieval processes for the "old" items than the "new" items. Expanding the analyses to examine ERPs to false alarms and misses might provide more information about these effects.

The ERP results did not show a difference between conditions. This may be due to the fact that encoding (verbal/auditory) and test (visual/picture) are occurring at different levels of cognitive representation. The participants had to extrapolate the general meaning of the audio clip, then they had to make a judgement on a picture depicting the object described in the lyrics. In the Simmons-Stern et al. (2010; 2012), the participants made a recognition judgement on lyrics or a repeated word/phrase. In all of these experiments, the encoding and test phase involved words, which required no form change. A past experiment in our lab used the same paradigm but with a word recognition task (Santana, 2016; Mooney, Santana, & Deason, 2017). The results of this study also showed no behavioral differences between the sung and spoken conditions. There was marginal enhancement of the LPC for the sung compared to the spoken encoding condition, which was thought to reflect recollection. These results may suggest that the words relating to the sung condition elicited stronger, more detailed memory than those of the spoken condition. This effect may not have produced enough of a difference to alter the behavioral results, but it may have resulted in a subjectively stronger memorial experience for the stimuli that was sung with musical accompaniment (Santana, 2016; Mooney et al., 2017).

Another factor leading to differences between Experiment 2 and the prior research could be the number of stimuli exposures. In both experiments, the participants were only exposed to the audio clips once. Past experiments, including Simmons-Stern et al. (2010, 2012), have had multiple exposures. Calvert and Tart (1993) found that increased exposure of musical stimuli relates to increased recall. They suggest that repeated exposure to musical stimuli can lead to automatic rehearsal of those lyrics, which would explain why music can be remembered for years. It is possible that, if the audio stimuli were played more than once, the benefit for musical mnemonics would be present.

The delay between the encoding phase and the test phase may also be a factor in the effectiveness of the musical benefit. Moussard and colleagues (2014) found that after a four-week delay, the lyrics of the sung condition were better remembered than the spoken condition. They believed that the initial encoding of the sung stimuli could increase the load of learning, but it also may increase long-term retention of the new information. They believed this because their results were consistent with the hypothesis of dual representations in memory for lyrics and melody (Racette & Peretz, 2007). Due to this dual representation, it can slow the learning process, but it can produce a stronger memory trace that can facilitate retrieval over time (Moussard et al., 2014). If the present study had a delay of at least a day between the encoding and test phase, the benefit of the sung condition over the spoken condition may have been present. Future studies should evaluate the different delays, such as 24 hours, 1 week, or 4 weeks between study and test. Potentially, with an increasing delay, the sung stimuli would show more and more of a beneficial effect.

In the encoding phase of the current experiments, a ‘like/dislike’ judgment was made for each audio stimulus. Emotions experienced during encoding can influence memory performance, if participants like a stimulus it may increase the chance of recalling that stimulus during the test phase (Stalinski, 2014). In Experiment 1, it was discovered hits had a higher liking rate than the misses. Whereas, Experiment 2 found that sung audio clips were more likely to be “liked” than spoken audio clips. The results of Experiment 1 support the idea that the emotional reaction or “liking” a stimulus will increase the chances of remembering that stimulus later.

As reviewed in the Introduction, Thaut et al. (2005) and Peterson and Thaut (2007) proposed that musical mnemonics induce oscillatory synchrony in the neural networks related to memory and verbal learning. They concluded that verbal learning paired with music enhanced coherent oscillations in the frontal cortical network. While the current experiment only investigated the ERP and behavioral correlates during the test phase, by examining the oscillatory activity, it would help more fully understand the results.

In summary, the research on the relationship between music and memory is limited and mixed. These experiments provided a novel look at the relationship between musical mnemonics and recognition memory. A significant difference between sung and spoken conditions was found in both experiments but these results contradicted each other. In Experiment 1, the results indicated that musical encoding led to enhanced memory performance compared to spoken encoding. In Experiment 2, the results indicated that musical encoding led to worse memory performance compared to spoken encoding. Additionally, the ERP results did not reveal any important distinctions between the effects of sung versus spoken encoding on test memory performance. These results suggest that more research on musical mnemonics and its potential usefulness is necessary.

APPENDIX SECTION

APPENDIX A: GOLDSMITHS MUSICAL SOPHISTICATION INDEX

The Goldsmiths Musical Sophistication Index, v1.0

October 11, 2012

Please circle the most appropriate category:	**1** Completely Disagree	**2** Strongly Disagree	**3** Disagree	**4** Neither Agree nor Disagree	**5** Agree	**6** Strongly Agree	**7** Completely Agree
1. I spend a lot of my free time doing music-related activities.	1	2	3	4	5	6	7
2. I sometimes choose music that can trigger shivers down my spine.	1	2	3	4	5	6	7
3. I enjoy writing about music, for example on blogs and forums.	1	2	3	4	5	6	7
4. If somebody starts singing a song I don't know, I can usually join in.	1	2	3	4	5	6	7
5. I am able to judge whether someone is a good singer or not.	1	2	3	4	5	6	7
6. I usually know when I'm hearing a song for the first time.	1	2	3	4	5	6	7
7. I can sing or play music from memory.	1	2	3	4	5	6	7
8. I'm intrigued by musical styles I'm not familiar with and want to find out more.	1	2	3	4	5	6	7
9. Pieces of music rarely evoke emotions for me.	1	2	3	4	5	6	7
10. I am able to hit the right notes when I sing along with a recording.	1	2	3	4	5	6	7

Please circle the most appropriate category:	**1 Completely Disagree**	**2 Strongly Disagree**	**3 Disagree**	**4 Neither Agree nor Disagree**	**5 Agree**	**6 Strongly Agree**	**7 Completely Agree**
11. I find it difficult to spot mistakes in a performance of a song even if I know the tune.	1	2	3	4	5	6	7
12. I can compare and discuss differences between two performances or versions of the same piece of music.	1	2	3	4	5	6	7
13. I have trouble recognizing a familiar song when played in a different way or by a different performer.	1	2	3	4	5	6	7
14. I have never been complimented for my talents as a musical performer.	1	2	3	4	5	6	7
15. I often read or search the internet for things related to music.	1	2	3	4	5	6	7
16. I often pick certain music to motivate or excite me.	1	2	3	4	5	6	7
17. I am not able to sing in harmony when somebody is singing a familiar tune.	1	2	3	4	5	6	7
18. I can tell when people sing or play out of time with the beat.	1	2	3	4	5	6	7
19. I am able to identify what is special about a given musical piece.	1	2	3	4	5	6	7
20. I am able to talk about the emotions that a piece of music evokes for me.	1	2	3	4	5	6	7

Please circle the most appropriate category:	**1 Completely Disagree**	**2 Strongly Disagree**	**3 Disagree**	**4 Neither Agree nor Disagree**	**5 Agree**	**6 Strongly Agree**	**7 Completely Agree**
21. I don't spend much of my disposable income on music.	1	2	3	4	5	6	7
22. I can tell when people sing or play out of tune.	1	2	3	4	5	6	7
23. When I sing, I have no idea whether I'm in tune or not.	1	2	3	4	5	6	7
24. Music is kind of an addiction for me - I couldn't live without it.	1	2	3	4	5	6	7
25. I don't like singing in public because I'm afraid that I would sing wrong notes.	1	2	3	4	5	6	7
26. When I hear a piece of music I can usually identify its genre.	1	2	3	4	5	6	7
27. I would not consider myself a musician.	1	2	3	4	5	6	7
28. I keep track of new music that I come across (e.g. new artists or recordings).	1	2	3	4	5	6	7
29. After hearing a new song two or three times, I can usually sing it by myself.	1	2	3	4	5	6	7
30. I only need to hear a new tune once and I can sing it back hours later.	1	2	3	4	5	6	7
31. Music can evoke my memories of past people and places.	1	2	3	4	5	6	7

Please circle the most appropriate category:

32. I engaged in regular, daily practice of a musical instrument (including voice) for **0 / 1 / 2 / 3 / 4-5 / 6-9 / 10 or more** years.
33. At the peak of my interest, I practiced **0 / 0.5 / 1 / 1.5 / 2 / 3-4 / 5 or more** hours per day on my primary instrument.
34. I have attended **0 / 1 / 2 / 3 / 4-6 / 7-10 / 11 or more** live music events as an audience member in the past twelve months.
35. I have had formal training in music theory for **0 / 0.5 / 1 / 2 / 3 / 4-6 / 7 or more** years.
36. I have had **0 / 0.5 / 1 / 2 / 3-5 / 6-9 / 10 or more** years of formal training on a musical instrument (including voice) during my lifetime.
37. I can play **0 / 1 / 2 / 3 / 4 / 5 / 6 or more** musical instruments.
38. I listen attentively to music for 0-15 min / 15-30 min / 30-60 min / 60-90 min / 2 hrs / 2-3 hrs / 4 hrs or more per day.
39. The instrument I play best (including voice) is ____

Please tick one of the following:
Occupational status

- ☐ Still at School
- ☐ At University
- ☐ In Full-time employment
- ☐ In Part-time employment
- ☐ Self-employed
- ☐ Homemaker/full time parent
- ☐ Unemployed
- ☐ Retired

What is the musical genre you mainly listen to?
(tick only one box)

- ☐ Rock/Pop
- ☐ Jazz
- ☐ Classical Music

What is the Highest educational qualification you have attained?

☐ Did not complete any school qualification

☐ Completed first school qualification at about 16 years (e.g. GCSE/Junior High School)

☐ Completed Second qualification (e.g A levels/ High School)

☐ Undergraduate degree or professional qualification

☐ Postgraduate degree

☐ I am still in education

If you are still in education, what is the highest qualification you expect to obtain?

☐ First school qualification (e.g. GCSE / Junior High School)

☐ Post-16 vocational course

☐ Second school qualification (e.g. A-levels / High School)

☐ Undergraduate degree or professional qualification

☐ Postgraduate degree

☐ Not applicable

Anonymous ID:________
(please write down the last three letters of your surname, the day you were born (2 digits) and todays day (8 digits). Example: Adam Smith, born 13.02.1982, taken the test 05.03.2011 and Anonymous ID: ith1305032011)

Your age : _____ years.

Gender: **Female / Male**

Nationality:

Country in which you spent the formative years of your childhood and youth:

Country of current residency:

Email address (permanent email address, optional): ____________________

Name (optional): ____________________

☐ Please tick the box only if you dont want to be contacted about this project again in the future.

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