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The Effect of Visual Search and Audio-Visual Entrainment on Episodic Memory

Holly Anne Westfall
University of South Florida, hwestfall@mail.usf.edu

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by

Holly A. Westfall

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Department of Psychology
College of Arts and Sciences
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Major Professor: Kenneth Malmberg, Ph.D.
Emanuel Donchin, Ph.D.
Geoffrey Potts, Ph.D.

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Abstract

Previous research suggests that larger context effects are observed when participants are required to search a scene in order to find the to-be-remembered stimuli. Similarly, animal research on brain oscillations has shown theta wave activation when animals are searching their environment. These theta wave oscillations are positively correlated with learning. However, theta activation can also occur in response to sensory stimulation, for example, auditory stimulation with binaural beats or visual stimulation with a checkerboard pattern reversal. The results of several studies suggest that while a visual search task seems to reliably improve free recall performance, the effects of passive sensory stimulation on memory are less consistent. Implications and suggestions for future research are discussed.

Chapter 1:

Introduction

Research on context-dependent memory suggests that these effects are stronger when participants are required to search the study environment for the to-be-remembered items. This type of exploratory activity is associated with hippocampal theta oscillations in rodents (Vanderwolf, 1969) and these same hippocampal oscillations are correlated with enhanced learning (e.g. Berry & Thompson, 1978). Human studies have found cortical theta to be associated with navigation and learning (Caplan et al., 2003; Kahana, Sekuler, Caplan, Kirschen, & Madsen, 1999; Sederberg, Kahana, Howard, Donner, & Madsen, 2003). Inspired by this research, we developed a memory procedure which involves a visual search task combined with auditory and visual stimuli that has been shown in EEG studies to entrain to theta frequencies. We hypothesized that presenting visual and auditory stimuli at the theta frequency during completion of a visual search task would result in an enhancement of human episodic memory.

Here I begin by reviewing the literature on context-dependent memory, human and animal studies on theta oscillations, and entrainment with auditory and visual stimuli. Then I discuss the results of several experiments investigating the relationship between visual search and sensory stimulation on human memory performance. We found the effect of visual search to be quite robust, but obtained mixed results with the entrainment stimuli. Finally, I discuss practical applications for these findings and suggestions for future research.

Context-dependent Memory

Context-dependent memory can be described as improved memory performance when the context present at study matches the context present at test (Smith & Vela, 2001). Context itself can include physiological states, mood states, and a person's external environment. For example, Goodwin and colleagues manipulated the physiological state of their participants by having half of them drink 8-10 oz. of alcohol prior to completing a memorization task. The next day, all participants completed a free recall task in either the same state of sobriety as study or the opposite. They found that regardless of the state of sobriety at study, performance was best when the state at study matched the state at test (Goodwin, Powell, Bremer, Hoine, & Stern, 1969). Context can also be manipulated in terms of mood, as in Eich and Metcalfe's (1989) study in which they played happy or sad music for their participants. Similarly, they found that performance on a free recall task was best when mood at study matched mood at test. Godden and Baddeley (1975) performed an experiment with scuba divers, asking them to study two lists of words, one on land and one underwater. Then they were tested for both lists either on land or underwater. Again, performance was best when test location matched study location. These studies illustrate memory retrieval facilitation when the context at test matches the context that is already stored in memory.

While context dependent memory effects are frequently found in free recall tasks, they are less frequently observed in recognition tasks (Smith, 1988), and there is still much to learn about the means by which they operate. In fact, we find that in recognition memory, context-dependent memory findings vary widely. For example, Murnane, Phelps, and Malmberg (1999) consistently found very small context effects, while more recently Hockley (2008) found very large context effects using a similar procedure. However, when looking at the details of the experimental designs, one can see that the encoding sequences differed in the amount the participant was required to search the study environment for the to-be-remembered item. The studies in which participants had to more actively search the study environment saw much larger context effects. Whereas the studies in which it was easy to distinguish between the study item and context saw very small context effects. Perhaps memory is enhanced when people are actively engaged in exploring their surroundings.

Spatial Navigation

There is evidence from animal literature which suggests this may be true. Spatial navigation depends on intact hippocampal function and exploratory activities in rodents are associated with hippocampal theta oscillations (Jung, Weiner, & McNaughton, 1994; Mizumori, 1994; Tort et al., 2008). Theta ranges from 2-8 Hz and is generated by two areas of the brain: the cortex and the hippocampus (Buzsáki, 2002). In rodents, hippocampal theta is active when they are exploring their environment. Purposeful movements such as walking, rearing, climbing, or exploratory head movements are associated with theta activation, whereas automatic, repetitive activities like eating, drinking, or grooming are not (Vanderwolf, 1969).

Human studies have found similar correlations between theta power and spatial navigation. In a study using invasive readings, intracranial electroencephalogram (iEEG) recordings were made while participants virtually navigated a 3D environment to complete both searching and goal-seeking tasks. Researchers found greater theta activity during both kinds of tasks compared to remaining motionless in the virtual environment (Caplan et al., 2003). In a similar experiment, participants learned to navigate a 3D computer-generated maze guided by arrows. Following this “study mode” they completed a “test mode” in which they had to recall their way to a goal point. iEEG recordings revealed that cortical theta activity occurred during both study and test modes (Kahana et al., 1999). In addition, animal studies have found these theta oscillations to be correlated with enhanced learning.

Theta and Learning

Berry and Thompson (1978) found that the rate of acquisition of classical eye blink conditioning can be predicted by hippocampal theta activity before training even begins. Electrical brain activity taken two minutes before training demonstrated that hippocampal oscillations in the theta range of 2-8 Hz predicted faster rates of learning than oscillations in the non-theta 8-22 Hz range. Seager, Johnson, Chabot, Asaka, and Berry (2002) experimented with eye blink classical conditioning in rabbits contingent on the presence or absence of theta. Those rabbits trained only during theta frequencies learned conditioning to criterion in half as many trials as those trained only during non-theta frequencies. These findings are true for both a delay conditioning procedure (Seager at al., 2002) and a trace paradigm (Griffin, Asaka, Darling, & Berry, 2004).

Other studies further tested this idea by impeding the natural occurrence of theta (Berry & Thompson, 1979; Asaka, Griffin, & Berry, 2002; Asaka, Seager, Griffin, & Berry, 2000) or artificially inducing theta (Berry and Swain, 1989; Deupree, Coppock, and Willer, 1982). They found that reducing the amount of theta activity caused animals to take significantly longer to learn conditioning to criterion while increasing theta decreased the number of training trials by half.

Theta activity can be predictive of learning in human studies as well. In an iEEG study, epileptic participants completed a memory task in which they studied lists of high-frequency nouns followed by a delayed free recall task. Theta and gamma activity during study were predictive of words later recalled (Sederberg et al., 2003). These studies show that theta is correlated with enhanced learning and may also be related to encoding new memories.

Theta activity in animals is clearly correlated with spatial navigation and learning individually, but the relationship between exploratory activity and learning is less clear. Recently, in a set of behavioral experiments, we attempted to relate spatial navigation and memory performance by manipulating participant exploratory activity (Westfall & Malmberg, in press). For each experiment, participants were presented with a list of words, which they had to type into a computer. Half of the participants were presented with words that were always displayed in the center of the screen, while the other half were presented with words that were displayed in a random location on the computer monitor. We found that participants who were required to search for the study words outperformed those who did not in a test of free recall. This effect remained reliable even when the location of the word was pre-cued, implying that simply being in “search mode” serves to enhance free recall regardless of the difficulty of the search itself.

Our results are consistent with the hypothesis that a visual search task would enhance episodic encoding. By putting participants into a state of exploration, we speculated that theta activity may be induced in the brain in a similar manner to studies such as Caplan et al., subsequently resulting in an improvement in memory performance. While such speculation is not ruled out by our findings, we cannot at this point conclude that theta is induced via visual search. To do so would require proper measurements of oscillatory activity in the brain (e.g., via EEG data). Nevertheless, we think it is prudent, given these results, to explore other manipulations in the present behavioral paradigm that have been found to induce theta grounded in physiological evidence. For instance, prior research has found it is possible to induce theta in humans via passive sensory stimulation.

Entrainment

Binaural beats. When two slightly difference pitches are played at the same time, the perceived pitch, or base frequency, is halfway between the two tones. Perhaps more interestingly, a beat is also perceived as a fluctuation in volume with a frequency of the difference between the two tones (Oster, 1973). For example, if a 300 Hz tone and a 310 Hz tone are played at the same time, the resulting pitch will be perceived as 305 Hz and the beats will occur at a frequency of 10 Hz. This phenomenon can be observed when tuning an instrument, for example. One may adjust an instrument to match the tone of a pitch pipe until the resulting beats disappear. These beats are referred to as monaural beats, because they can be heard with only one ear. However, one has a very different experience when each tone is presented to each ear via stereo headphones. Beats perceived in this way are called binaural beats and they are particularly interesting, because by presenting each tone to only one ear, the interaction of the two sounds does not occur in the physical world, and the perception of the beats occurs solely in the brain (Lane, Kasian, Owens, and Marsh, 1998). There is research which suggests that steady state responses in humans can be recorded as a response to the amplitude or frequency modulation of a tone (Picton, Skinner, Champagne, Kellett, & Maiste, 1987). Lane and colleagues (1998) found that participants had higher hit rates and fewer false alarms in a vigilance task and had overall higher moods when listening to binaural beats at the beta frequency (16 and 24 Hz) compared to those listening to binaural beats at the delta/theta frequency (1.5 and 4 Hz).

Checkerboard pattern reversal. Evoked potentials and brain oscillations can also be influenced by visual stimulation. A reversed checkerboard pattern stimulation is commonly used to test for neurological abnormalities due to drug abuse (Brandt, 1997); Alzheimer's disease and dementia (Orwin, Wright, Harding, Rowan, & Rolfe, 1986); epilepsy (Willoughby et al., 2003); and schizophrenia (Jibiki, Takizawa, & Yamaguchi, 1991). This same technique has also been used to induce brain oscillations of varying frequencies in healthy human participants (Fitzgibbon, Pope, Mackenzie, Clark, & Willoughby, 2004; Hoffmann, Skrandies, Lehmann, Witte, & Strobel, 1996; Mast & Victor, 1991). In light of these findings, we are interested in examining changes in task performance mediated by these types of passive sensory stimulation.

Chapter 2:

Pilot Experiment 1

An internet search for binaural beats will return a flood of videos and sound files which claim to aid the user with anything from concentration to relaxation. However, there is little scientific research investigating the validity of these claims. In a pilot experiment, we attempted to replicate our previous findings on the effect of visual search on memory in addition to assessing the effects of binaural beats on free recall.

The results of several experiments on the effect of search on memory performance revealed that we see improvements in memory performance when memory is tested via free recall, but not when memory is tested via recognition memory (Westfall & Malmberg, in press). When memory is tested with an old-new recognition procedure, we found a large bias for participants to respond “old” to both targets and foils when they were in the search condition. However, when memory was tested with a two-alternative forced-choice (2AFC) procedure, we found no discernible difference in memory performance. We might expect to see results such as these if the search procedure resulted in an increase in context storage, but not an increase in the strength with which the items themselves are stored. If this is true, we might expect to find that participants are better able to recall specific context associated with the study words when they are required to search for them. We decided to investigate this idea in the following experiment by asking participants specific questions about the context of each word as they were recalled, to see which type of context, if any, is stored more accurately.

Method

Participants. Fifty-seven undergraduates at the University of South Florida participated in the experiment in exchange for course credit.

Materials.

Word lists. All word stimuli were nouns with normative frequencies of 20-50/million (Francis & Kucera, 1982). For each participant, 48 words were randomly selected and divided into four study lists of 12 words each.

Sound files. Sound files were generated using Gnaural, an open source binaural beat audio generator. Binaural beats were created with a base frequency of 250 Hz and a beat frequency of 5 Hz. Isochronic tones with a base frequency of 250 HZ and a beat frequency of 5 Hz were used as a control. Isochronic tones are pulses of a single tone in contrast to the sinusoidal pulses of the binaural tones. Pink noise was included as a background noise and was set at an equal volume to the binaural and isochronic tones.

Design. This study was a 2 x 2 (tone x search) mixed factorial design with search manipulated within-subjects and tone manipulated between-subjects. Participants learned four lists of 12 words. During the study session of each list, the participant was exposed to one of two visual search conditions. In both conditions, words were displayed one at a time in 18-point Tahoma font on the white background of a computer monitor. Each word was randomly assigned to appear in light yellow font or light gray italicized font. The participant was required to locate each word and type it into a response box on the computer screen in order to move on to the next word. In the “no search” condition, words were always displayed in the center of the screen. In the “search” condition, words appeared in a random location on either the left third or the right third of the computer screen. Word lists were blocked by search condition and counterbalanced across participants. After all four study lists had been presented, there was one end of study free recall task. The participant was given an unlimited amount of time to recall as many words as possible in any order. For each word they recalled, they were asked to type the word into the computer and then answer a series of questions regarding the context of the word. They were asked on what third of the screen the word appeared (spatial context), on what study list the word appeared (temporal context), and what font color and style in which the word was printed (specific features of the word itself).

Procedure. Participants completed all portions of the experiment, including instructions and informed consent, in individual testing rooms on desktop PCs equipped with 15" LCD monitors. The study instructions informed the participant that their memory would be tested for the words they were about to see and emphasized the importance of maintaining good performance in the task. Participants listened to the auditory stimuli continuously throughout the entire task through stereo headphones with the volume adjusted to a comfortable level. They were told that the purpose of the sound playing through the headphones was to provide a monotonous background noise in order to eliminate extraneous sounds. Following each study list, the participant completed a 30 second distractor task in which they were required to mentally add a series of digits. After all study lists and distractor tasks had been presented, they then completed the free recall task.

Results and Discussion

Results are presented in Figure 1. A two-way analysis of variance revealed a main effect of search, $F(1,55) = 4.22$, $p < .05$, $\eta_p^2 = 0.071$, and a main effect of tone $F(1,55) = 5.41$, $p < .05$, $\eta_p^2 = 0.089$. Words presented in the search condition were more likely to be recalled than those presented in the no search condition, and participants listening to binaural beats outperformed participants listening to isochronic tones. The search x tone interaction was not reliable, $F < 1$.

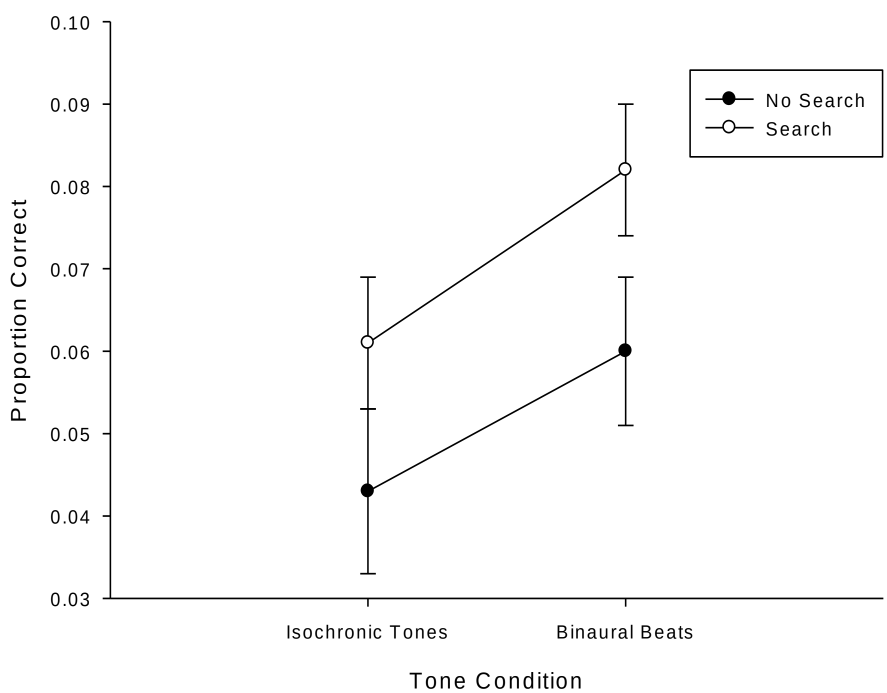

Figure 1. Proportion of words correctly recalled as a function of tone and search condition for Experiment 1.

Analysis of the data collected concerning the context questions showed the effects of search and tone to be less reliable. For screen location, there was no effect of search, $F(1,55) = 1.690$, $p=0.199$, $\eta_p^2 = 0.030$, tone, $F<1$, or the search x tone interaction, $F(1,55) = 1.334$, $p=0.253$, $\eta_p^2 = 0.024$. We found similar results for list number for search, $F(1,55) = 2.435$, $p = 0.125$, $\eta_p^2 = 0.046$, tone, $F(1,55) = 2.260$, $p = 0.139$, $\eta_p^2 = 0.043$, and interaction effects, $F<1$. Responses between conditions for font color were nearly identical as for each of search, tone, and the search x tone interaction, $F<1$. Overall, it seems that accuracy for context information did not vary as a function of our manipulations.

Chapter 3:

Pilot Experiment 2

Although we observed a positive effect of visual search and binaural beats on free recall in Experiment 1, there remained a number of issues to be resolved. First of all, though we found a main effect of tone, the effect size was very small. As the average accuracy rate was around five percent, we believed this effect would have been stronger if accuracy had been higher. In Experiment 2, we implemented shorter word lists and repeated each word on the study lists three times in an effort to increase recall accuracy.

In addition, there was a concern that asking the context questions as each word was recalled may have had an effect on the overall recall performance by increasing the retention interval. To address this concern, in Experiment 2, half of the participants answered the context questions during recall in the same manner as in Experiment 1 and half were only required to type in the recalled words without answering any context questions.

Originally, the isochronic tones were created and used as a control condition for the binaural beats. However, there is evidence that oscillations may be entrained with exposure to pulses of a single tone, similar to the isochronic stimuli used in Experiment 1 (Pantev, Makeig, Hoke, Galambos, Hampson, & Gallen, 1991). Therefore, in a second pilot experiment, half of the participants were exposed to the binaural tones and half were not exposed to any auditory stimulus.

Method

Participants. Thirty-six undergraduates at the University of South Florida participated in the experiment in exchange for course credit.

Materials, design, and procedure. The materials, design, and procedure for Experiment 2 were identical to Experiment 1 with the following exceptions: This study was a 2 x 2 x 2 (tone x question x search) mixed factorial design with search manipulated within-subjects, and tone and context questions manipulated between-subjects. For each participant, 16 words were randomly selected and divided into four study lists. Each word on the study list was repeated three times so that the participant was exposed to 12 words on each study list, only four of which were unique. We also decided to increase the beat frequency in this study relative to the prior study so that it was more clearly in the theta range of 2-8 Hz and more discernible from the delta range of 0-4 Hz, which is associated with deep sleep and may cause a decrease in attention (Lane et al., 1998). Half of the participants listened to a 7 Hz binaural beat embedded in pink noise, whereas the other half of the participants had no auditory stimulus. Lastly, half of the participants were required to answer questions regarding screen location, list number, and font color as each word was recalled during a free recall task, while the other half was asked to complete the recall task without answering context questions.

Results and Discussion

A 3-way analysis of variance revealed no significant differences in the number of words recalled for participants in the context question condition compared to those in the no question condition, $F < 1$. Asking context questions as each word is recalled seems to have no effect on the proportion of words correctly recalled by participants. There was no main effect of search, $F(1,32) = 1.947$, $p = .17$, or tone, $F(1,32) = 1.185$, $p = .285$, however the non-significant trend for search was in the predicted direction. None of the interaction effects were reliable, $F < 1$.

Table 1
Means and Standard Errors for Experiment 2

		No Search		Search	
		M	*SE*	*M*	*SE*
Binaural Beats	No Questions	0.170	0.047	0.232	0.042
	Questions	0.200	0.039	0.231	0.035
Isochronic Tones	No Questions	0.201	0.041	0.271	0.037
	Questions	0.244	0.039	0.238	0.035

There are several possible explanations for why we did not see any effect of the binaural beats in this experiment, the most obvious that we altered the beat frequency of the sound files. Yet, the results of our two pilot experiments are intriguing. The following experiments further investigate the mechanisms by which binaural beats impact episodic memory in addition to assessing the effects of a commonly used visual stimulus, the checkerboard pattern reversal.

Chapter 4:

Experiment 3

For the following two experiments, I performed manipulations of visual search, auditory stimuli, and visual stimuli in an attempt to observe changes in task performance mediated by sensory stimulation. Prior studies have shown changes in oscillatory activity in the brain within the theta frequency band as a result of exposure to binaural stimulation (Galambos, 1982; Lane et al., 1998; Picton et al., 1987) and checkerboard reversal stimulation (Fitzgibbon et al., 2004). The following studies do not measure such oscillatory activity, and I will not be able to conclude that my presentation of either sensory stimulation induced theta oscillations. Rather the goal is to explore the effect of other variables on episodic memory that prior research has shown to induce theta activity in humans.

Though the initial investigations of context storage were not as expected, we were also interested in further consideration of the effect of the timing of the context questions on recall. Therefore, in Experiment 3, we included the context question manipulation and varied the timing of the questions to occur during the free recall task as each word is recalled or after the free recall task has been completed.

Method

Participants. Forty undergraduates at the University of South Florida participated in the experiment in exchange for course credit.

Materials, design, and procedure. The materials, design, and procedure for this experiment were identical to those in Experiment 2 with the following exceptions: We returned our focus to binaural beats with a beat frequency of 5 Hz as in Experiment 1. This study was a 2 x 2 x 2 (Search x Tone x Question) mixed factorial design with search and tone manipulated within-subjects and question timing manipulated between-subjects. For each participant, 48 words were randomly selected and divided into four study lists of 12 words each. Each word on the study list was repeated 3 times so that the participant was exposed to 36 words per study list, only 12 of which were unique. Instead of having one test session at the very end of the experiment, each study list was followed by the distractor task and a free recall task. By following each study session with a test session, it seemed illogical to ask participants about the list number on which the word appeared as well as the screen location of each word, since screen location necessarily varied with search condition. Therefore, participants were only asked about the font color of the words on the study lists. Half of the participants were asked the context question as they entered each word into the computer at recall, as in Experiments 1 and 2. The other half of the participants were first asked to recall as many words as possible in any order. Following this free recall task, they were shown each word they recalled, one at a time, and answered the context question.

Results and Discussion

Results are presented in Figure 2. We found no effect of the timing of the context question, $F<1$. Asking participants about the font color of each word during recall or after did not have any effect on the proportion of words correctly recalled. We found a main effect of Search, $F(1,39)=9.405$, $p<.05$, $\eta_p^2= .331$. However there was no effect of tone,

$F(1,39)=1.754$, $p = .201$, $\eta_p^2=.085$, and the search x tone interaction was not significant, $F<1$.

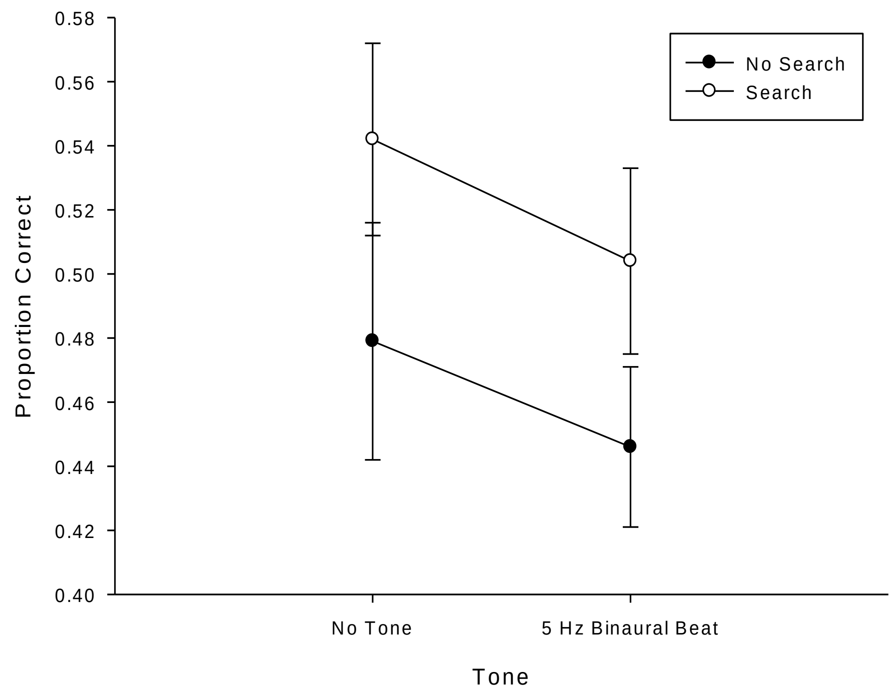

Figure 2. Proportion of words correctly recalled collapsed across question condition as a function of tone and search conditions for Experiment 3.

While being in a state of search seems to enhance free recall, listening to binaural beats at a 5 Hz frequency does not seem to provide any advantage over having no auditory stimuli on recall. Though this effect was not significant, it was in the opposite of the predicted direction and, if anything, listening to the binaural beats seemed to hinder memory performance. It is possible that the added stimulus is distracting to participants and our results in Experiment 1 may simply show that some stimuli are less distracting or are less harmful to memory than others.

Chapter 5:

Experiment 4

In a final experiment, we examined the effects of visual stimulation on human episodic memory in the form of a checkerboard pattern reversal. Generally, checkerboard reversal stimulation is been presented by asking participants to stare at a fixation point without requiring the participants to engage in any other simultaneous task (e.g. Mast & Victor, 1991). Since we are also interested in the effect of visual search, we were faced with the obstacle of how to present the visual stimulation while still enabling participants to perform a visual search task. As a result, we created several within-subject conditions to see which method might be most effective and appropriate for further investigation.

Method

Participants. Thirty participants at the University of South Florida completed this experiment in exchange for course credit.

Materials and procedure. The materials and procedure were identical to those used in Experiment 3 with the following exceptions: Participants were required to learn six word lists and were not required to answer context questions nor were they exposed to any auditory stimuli.

Design. This was a 3 x 2 (Stimulus location x Stimulus reversal) within subjects design. There were three methods of visual stimulus presentation. Participants were required to learn two lists of words in each stimulus presentation condition described below and each condition had two manners of stimulus reversal. For one word list, the checkerboard stimulus reversed at a rate of 5 Hz, or 10 reversals per second. For the other word list, the checkerboard pattern remained static. Word lists were blocked by stimulus presentation and counterbalanced across participants. The checkerboard stimulation was composed of 2 cm x 2 cm checks. Dark squares had a luminance of 0 and light squares had a luminance of 240. The contrast between the two shades was set at 100%.

Full screen checkerboard, no search. In this presentation condition, the checkerboard pattern filled the entire screen of a 15” LCD computer monitor. Words were displayed one at a time in the center of the screen in a 4 cm x 4 cm text box.

Perimeter checkerboard, no search. The checkerboard pattern was only presented in a 4 cm perimeter around the computer monitor. The remaining 30 cm x 22 cm space in the middle of the screen was similar to the no search task described in Experiment 1, with words presented one at a time in the center of the screen.

Perimeter checkerboard, search**.** This condition was similar to the perimeter checkerboard condition, except participants engaged in a visual search task in which the words were presented in a random location on either the left third or the right third of the remaining space.

Results and Discussion

Results are presented in Figure 3. We found no effect of pattern reversal, $F(1,29)=.879$, $p = .356$, $\eta_p^2 = .029$. We found a main effect of screen condition, $F(2,58)=3.547$, $p<.05$, $\eta_p^2 = .109$, but no significant interaction between the two, $F<1$. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the full screen, no search condition (M=0.50, SD=0.17) was significantly different than the perimeter, search condition (*M*=0.56, *SD*=0.17), p<.05. However, the perimeter, no search condition (*M*=0.54, *SD*=0.17) did not significantly differ from the full screen, no search and perimeter, search conditions.

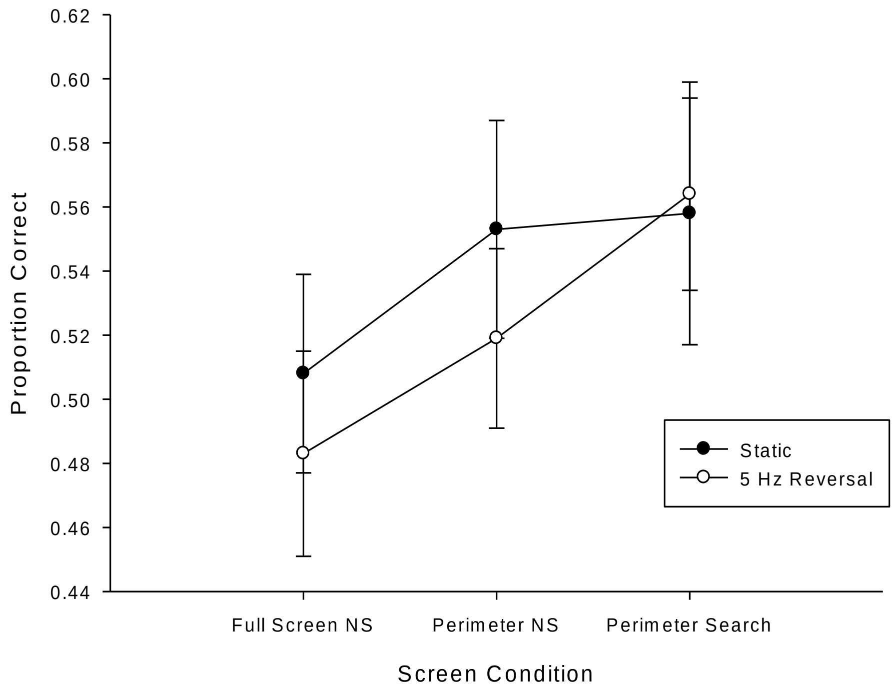

Figure 3. Proportion of words correctly recalled as a function of screen and reversal conditions for Experiment 4.

Chapter 6:

General Discussion

The results of several studies indicate that when participants are required to complete a visual search task during study, memory performance is enhanced. When participants are additionally presented with auditory stimuli, we found that those listening to binaural beats with a beat frequency of 5 Hz outperform participants listening to isochronic tones with the same beat frequency. However, when compared to no auditory stimuli, binaural beats at 7 Hz or 5 Hz do not produce improvements in free recall performance. In fact, performance was in the opposite of the predicted direction; listening to any auditory stimuli may be harmful to study. We also investigated the effect of a visual checkerboard reversal stimulus and found that it did not matter if the background was reversing at a frequency within the theta range or not. Again, though results were not significant, conditions in which the background reversed were slightly less accurate than those in which the background remained static. Performance was best for the screen condition in which the visual stimulus was present only around the perimeter of the screen and the participant was required to search for the to-be-remembered item in the remaining space. In contrast to our prior studies, there was no effect of search between the two perimeter conditions. One possible explanation for this particular finding is that since the space in which the participant was required to search was smaller in Experiment 4, the search task itself may have been less difficult and therefore produced less of an effect. This explanation seems unlikely based on the results of a previous study in which we found the effect of search to be reliable regardless of the difficulty of the task. In that study, we pre-cued each word during study which directed the participant's attention to the stimulus, facilitating the search process. There we again found a main effect of search suggesting that simply being in "search mode" serves to enhance free recall regardless of the difficulty of the search itself (Westfall & Malmberg, in press). The other possible explanation is that the visual stimulus was simply distracting and made study more difficult. This could also explain why we saw an advantage to binaural beats over isochronic tones, but no advantage to binaural beats over no visual stimuli. It is possible that binaural beats do not necessarily enhance memory, rather they are less harmful or distracting than the isochronic tones.

Future research in this area may be quite relevant in applied settings. There is a certain amount of cognitive decline that comes with age (Schaie, 1994) and it seems that theta can help alleviate some of these "age-related learning deficits," at least in animals. Asaka, Mauldin, Griffin, Seager, Shurell, & Berry (2005) performed a similar experiment to Griffin and colleagues (2004) including age as an additional independent variable. They found that older rabbits trained during the presence of theta, as measured by electrodes implanted in the hippocampus, learned eye blink conditioning in just as many trials as the young yolked control group. The age-related learning deficits were nearly eliminated. These results are provocative insofar as they may have implications for the treatment of age-related cognitive disorders without the use of drugs.

Though there is a natural decline in hearing ability with age, older adults tend to be able to perceive binaural beats almost as well as younger adults (Oster, 1973) and the brain has not yet shown to adapt to the stimuli over time (Picton et al., 1987). It is also worth investigating other methods which may be useful in improving human memory. Methods such as entrainment or varying the rate of presentation of stimuli are attractive, because users need no training to be able to perceive them or reap their benefits. The same may be said for the visual search task. Though we do not yet fully understand the mechanisms by which this manipulation operates, the results are quite robust and one may be able to develop a procedure which may be applied to education settings. For example, our lab is currently developing an incidental learning task which incorporates this visual search procedure

The next logical step in this line of research is to follow up with physiological measurements of electrical brain activity. None of these studies included any measurements of oscillatory activity in the brain and therefore we cannot make any claims about entrainment of frequencies in response to the exposure to binaural beats, visual stimuli, or visual search. EEG studies could be used to examine examining more thoroughly how binaural beats and visual search affect episodic memory and to determine if the manipulations used here can be used to entrain specific oscillatory frequencies.

Chapter 7:

Conclusions

Through a series of experiments we found that a visual search task during study enhances free recall performance. Participants presented with binaural beats within the theta frequency outperformed those listening to isochronic tones at the same frequency, but did not show enhanced memory recall compared to controls with no auditory stimuli. When presented with a visual stimulus during the search task, participants did not correctly recall a greater proportion of words when the visual stimulus was reversing at a rate of 5 Hz compared to a static background. These experiments did not include physiological measurements of oscillatory activity, but the manipulations were inspired by EEG studies such as Caplan et al. with the goal of improved episodic memory performance. Though the results here were inconsistent, these data justify more extensive research in the measuring the effects of visual search and audio-visual entrainment on both episodic memory and brain oscillations.

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Appendices

Appendix A: Additional Analyses

Experiment 3.

Serial position analysis. Figure 4 shows free recall performance in Experiment 3 as a function of serial position at study. An analysis of variance revealed a main effect of search condition, $F(1,39) = 10.301$, $p < .05$, $\eta_p^2 = .352$. Words participants were required to search for were more likely to be recalled than words for which they were not required to search. We also found a main effect of serial position, $F(35,665) = 2.592$, $p <. 001$, $\eta_p^2 = .120$. Pairwise comparisons showed words in serial position 36 to be significantly different from words in serial positions 6, 14, and 19, p < .05. These results suggest recency effects in free recall performance. However, there was no effect of tone, $F(1,39) = 1.834$, p = .192, $\eta_p^2 = .088$, or question timing, $F < 1$, and no significant interaction effects.

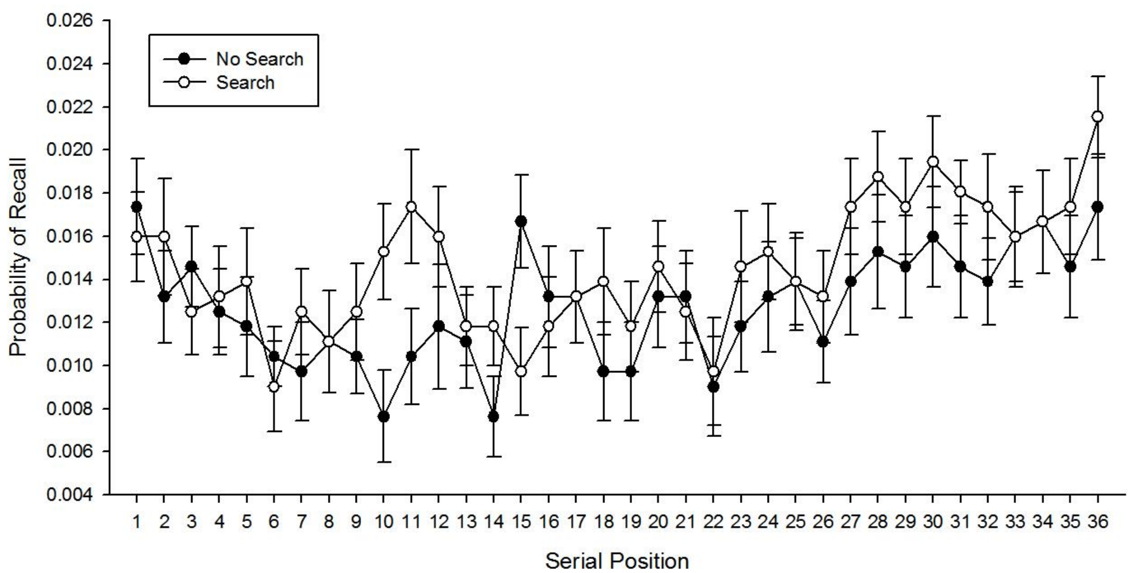

Figure A1. Free recall performance in Experiment 3 as a function of study position.

Probability of first recall. Figure 5 shows the function for probability of first recall. An analysis of variance revealed a main effect of serial position on probability of first recall, $F(35,665) = 2.146$, $p < .001$, $\eta_p^2 = .101$. Pairwise comparisons showed words in serial position 36 to be significantly different from words in serial positions 9, 19, and 26, p < .05, illustrating that participants were more likely to begin the free recall task with items at the end of the study lists. However, there was no significant effect of search condition, $F(1,39) = 3.142$, $p = .092$, $\eta_p^2 = .142$, tone, $F(1,39) = 3.723$, $p = .069$, $\eta_p^2 =$ .164, and no effect of question timing, $F < 1$. No interaction effects reached significance.

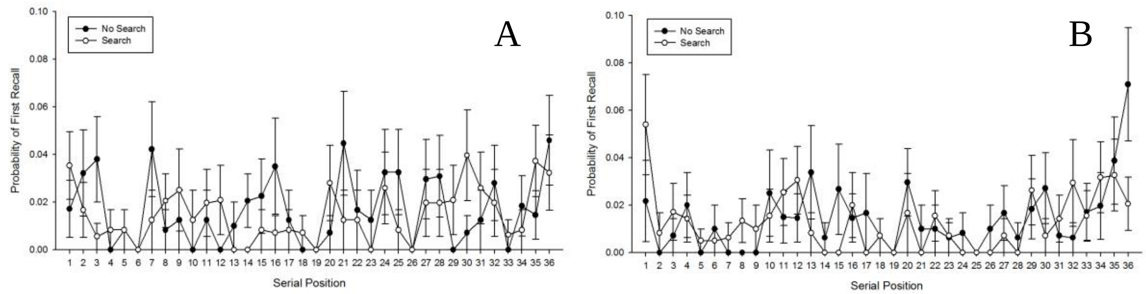

Figure A2. Probability of first recall for no tone and 5 Hz binaural beat conditions. Panel A shows the data for the no tone condition. Panel B shows the data for the 5 Hz binaural beat condition.

Experiment 4.

Serial position analysis. Figure 6 shows free recall performance in Experiment 4 as a function of serial position at study. A 3-way ANOVA revealed a main effect of screen condition, $F(2,58) = 3.544$, $p < .05$, $\eta_p^2 = .109$, and a main effect of serial position, $F(35,1015) = 3.901$, $p <. 001$, $\eta_p^2 = .110$. Pairwise comparisons showed words in serial position 35 to be significantly different from serial positions 13 and 18, p < .05. Words in serial position 36 were significantly different from words in serial positions 2, 6-18, 20-24, and 26-28, again illustrating recency effects in free recall performance. However, there was no effect of reversal, $F < 1$, and no significant interaction effects.

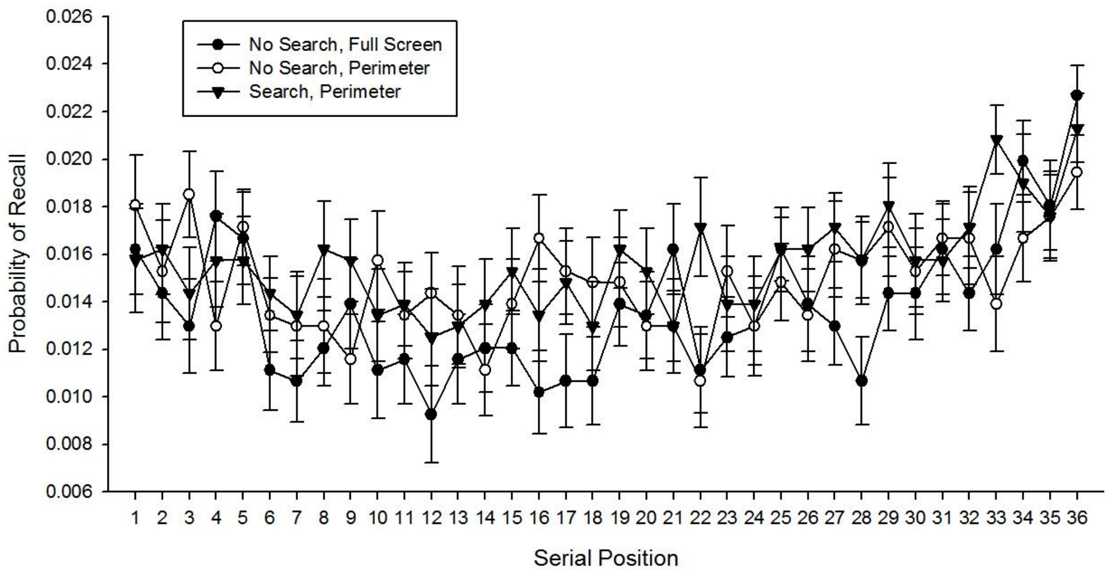

Figure A3. Free recall performance in Experiment 4 as a function of study position.

Probability of first recall. Figure 7 shows the function for probability of first recall. A 3-way ANOVA revealed a main effect of serial position on probability of first recall, $F(35, 1015) = 3.185$, $p <.001$, $\eta_p^2 = .099$. Pairwise comparisons showed words in serial positions 1 and 36 to be significantly different from words in serial positions 11 and 13, p < .05, demonstrating participants tendency to begin recall with items at the beginning or the end of the list. However, there was no significant effect of screen condition, $F(2,58) = 1.450$, $p < .243$, $\eta_p^2 = .048$, and no effect of reversal, $F < 1$. There was a significant 3-way interaction (screen condition x reversal x serial position),

$F(70,2030) = 1.363$, $p = .05$, $\eta_p^2 = .045$, however no 2-way interactions reached significance.

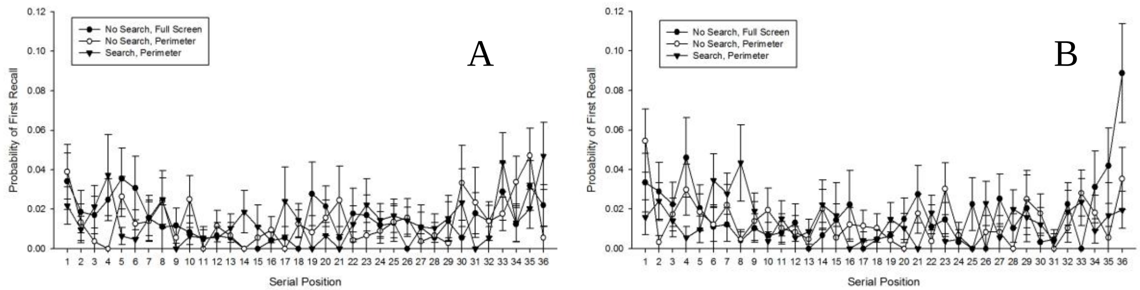

Figure A4. Probability of first recall for no reversal and 5 Hz reversal conditions. Panel A shows the data for the no reversal condition. Panel B shows the data for the 5 Hz reversal condition.

Discussion. When memory is tested via free recall, the frequency with which words are remembered is correlated with the order in which they are presented at study. Participants most frequently recall the most recently presented words, known as the recency effect, the words presented at the beginning of the list tend to be recalled next most frequently, known as the primacy effect, and the words presented in the middle of the list are recalled least frequently (Deese & Kaufman, 1957). When probability of recall is plotted as a function of serial position at study, the result is a u-shaped serial position curve.

The probability of first recall (PFR) curve is a serial position curve for only the very first item recalled (Hogan, 1975). The recency effect and probability of first recall go hand in hand. Not only is the frequency with which items are recalled correlated with serial position at study, but it is also correlated with the order in which items are recalled. Participants tend to begin recall with the most recent words on the study list, followed by the words presented at the beginning of the list, followed by the words presented at the middle of the list (Deese & Kaufman, 1957). PFR is also an important indicator of how participants begin free recall in terms of context reinstatement (Kahana, Howard, Zaromb, & Wingfield, 2002). In a free recall task, participants are given a limited amount of information with which to probe their memory. All that is available to them is the context present at test. Since the temporal context of words presented at the end of the list will be most similar to the test context, it follows that more recently presented words would be recalled first and most frequently.

In Experiments 3 and 4, we see representative patterns of primacy, recency, and PFR. The u-shaped curve seen in Figures 4 and 6 are typical of a delayed free recall task with a subdued effect of recency (Glanzer & Cunitz, 1966). However, these analyses are not applicable for the type of data we have for these experiments. In both Experiment 3 and Experiment 4, study lists are 12 words long and each word is repeated three times per list, making each study list 36 items long. In addition, the presentation order of all 36 words is randomly determined. Therefore, it is inappropriate to interpret the serial position data separately for each item, as each word has three serial or study positions and only one recall or output position. While it is interesting to note that these data conform to typical findings, because of our manipulations, any interpretation of serial position at study, recall order at test, or context reinstatement would be entirely improper.

Appendix B: IRB Approval

USF UNIVERSITY OF SOUTH FLORIDA

DIVISION OF RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-5618

August 31, 2012

Holly Westfall
Psychology
4202 East Fowler Ave., PCD4118G
Tampa, FL 3320

RE: **Expedited Approval** for Initial Review
IRB#: Pro00009377
Title: Behavioral effects of visual search and audio-visual entrainment

Dear Ms. Westfall:

On 8/24/2012 the Institutional Review Board (IRB) reviewed and **APPROVED** the above referenced protocol. Please note that your approval for this study will expire on 8/24/2013.

Approved Items:
Protocol Document(s):
Study Protocol

Consent/Assent Documents:
Informed Consent.pdf

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110 and 21 CFR 56.110. The research proposed in this study is categorized under the following expedited review category:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

Please note, the informed consent/assent documents are valid during the period indicated by the official, IRB-Approval stamp located on the form. Valid consent must be documented on a copy of the most recently IRB-approved consent form.

As the principal investigator of this study, it is your responsibility to conduct this study in accordance with IRB policies and procedures and as approved by the IRB. Any changes to the approved research must be submitted to the IRB for review and approval by an amendment.

We appreciate your dedication to the ethical conduct of human subject research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John A. Schinka, Ph.D.

John Schinka, Ph.D., Chairperson
USF Institutional Review Board