1-1-2006

Binaural beats enhance alpha wave activity, memory, and *attention in healthy-aging seniors

Janice Colleen McMurray
University of Nevada, Las Vegas

BINAURAL BEATS ENHANCE ALPHA WAVE ACTIVITY, MEMORY,

AND ATTENTION IN HEALTHY AGING SENIORS

by

Janice Colleen McMurray

Bachelor of Arts
University of California, Northridge
2002

Master of Arts
University of California, Northridge
2004

A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy in Psychology
Department of Psychology
College of Liberal Arts

Graduate College
University of Nevada, Las Vegas
May 2006

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

Dissertation Approval
The Graduate College
University of Nevada, Las Vegas

April 20, 2006

The Dissertation prepared by

Janice Colleen McMurray

Entitled

Binaural Beats Enhance Alpha Wave Activity, Memory, and Attention in Healthy Aging Seniors

is approved in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Psychology

Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Examination Committee Member

Graduate College Faculty Representative

ABSTRACT

Binaural Beats Enhance Alpha Wave Activity, Memory, and Attention in Healthy Aging Seniors

by

Janice Colleen McMurray

Dr. Karen A. Kemtes, Examination Committee Chair
Professor of Psychology
University of Nevada, Las Vegas

Human aging will be one of the biggest challenges we face during this century and optimizing health for the rapidly growing older population is imperative to avoid end of life suffering. Uncovering stimuli and methods that may enhance memory and attentional focus in the aging brain has become a priority. Current research demonstrates a connection between neurocognitive decline in seniors over 65 years and deficits in alpha frequency brainwave activity. Studies indicate that specific auditory tones have a significant effect on our brainwaves and provide a positive influence. These tones have been defined as alpha-harmonic sound patterns and they are called binaural beats.

When tones of two different frequencies are presented separately to each ear, the superior olivary nuclei within the medulla of the brainstem synthesize the two sounds into a single, perceived, low frequency tone, the binaural beat. The binaural beat pulses with the overall frequency of the difference between the two original tones. If the difference matches a particular brainwave state, such as 7-11 Hertz (Hz), the alpha frequency range, then the overall brain activity will maintain that brainwave state. Research suggests that auditory beats within specific electroencephalograph (EEG) frequency ranges can enhance corresponding brainwave activity and may affect levels of neurocognition.

This study compared the effect of auditory binaural beats on measures of neurocognitive function and on brainwave activity in a sample of community-dwelling healthy aging seniors. Cognitive function task scores were significantly higher and a significant increase in alpha brainwave frequency was demonstrated during presentation of binaural beats. These results suggest that improvements in neurocognitive function were a consequence of enhanced levels of alpha frequency brainwave activity elicited by auditory binaural beats.

TABLE OF CONTENTS

ABSTRACT iii

LIST OF FIGURES vii

ACKNOWLEDGMENTS viii

CHAPTER 1 INTRODUCTION 1
Background upon Which the Study is Based 1

CHAPTER 2 REVIEW OF RELATED LITERATURE 3
The Aging Brain 3
Loss of Memory with Aging 6
Poor Attentional Focus with Aging 9
Interaction of Memory and Attention 11
Hope for Neurocognitive Function in Aging 12
Alpha Frequency Decreases with Age 13
Current Search for Neurocognitive Enhancement in Aging—Electroencephalography 14
Music and the Brain 15
Binaural Beats and the Manner in Which they Work 16
Focus of this Study 19

CHAPTER 3 METHODOLOGY 21
Participants 21
Materials 22
Mini Mental State Examination 22
Forward and Backward Digit Span Memory Tasks 24
Assessment of Attentional Focus in Aging 25
Electroencephalography 26
Binaural Beat Stimulation 27
Procedure 28

CHAPTER 4 RESULTS 31
Background Measures 31
Measurement of Attentional Focus 33
Measurement of Working Memory 34
Electroencephalography 35

CHAPTER 5 DISCUSSION 38
Support of Previous Studies 38
Future Directions 40

REFERENCES 43

VITA 59

LIST OF FIGURES

Figure 1 Tissue Loss and Widening of Sulci with Aging 4
Figure 2 The Superior Olivary Complex Acts as a Crossover Site for Spatially Oriented Auditory Information 17
Figure 3 Seven Experimental Phases 29
Figure 4 Alpha Power Means Comparisons (Phase II $M = 78.963$, Phase V $M = 82.323$) 32
Figure 5 Significant Difference in d′ Measures of CPT Performance During Phase VI 33
Figure 6 Significant Differences in Forward & Backward Digit Span Scores During Phase VII 34
Figure 7 Significant Difference in Alpha Frequency Power during Phase V 36
Figure 8 No Significant Difference in Alpha Frequency Power upon Presentation of Music during Phase II 37
Figure 9 Participants on Medications 23

ACKNOWLEDGMENTS

This dissertation is dedicated to my wonderful mother, F. Jean McMurray, in heartfelt gratefulness for her never-ending support. I am also thankful for the continuous encouragement of my brother and sister-in-law, Stephen T. and Cheryl A. McMurray; of my Advisor, Dr. Karen A. Kemtes; and of my precious friends, Dr. Gary S. Katz, Shaida S. Jetha, and Christine A. Zahka. Much appreciation is extended to everyone for their patience with my continued absence at special events and functions. Most of all, I am grateful for the grace of God and for the prayers and good wishes of family and friends, which supported me throughout this process.

CHAPTER 1

INTRODUCTION

Background upon Which the Study is Based

Recent theories regarding stages of life during aging support the proposal that humans are experiencing longer lifespans (Allen, Bruss, & Damasio, 2005; Finch & Stanford, 2004; Hawkes, 2003; Lee, 2003; Prvulovic, Van de Ven, Sack, et al., 2005). Worldwide, lifespan has been consistently increasing in a significantly positive fashion with no indication of leveling out. Lifespan for humans is currently estimated to be 70+ years in developed countries (Westendorp, 2006). If longevity continues along its current course of growth, we may realistically expect increasingly healthy mental aging to be an important aspect of this process.

Geesaman (2006) points out that aging is not a passive activity; rather it is an actively regulated metabolic process. Along with the discovery of specific genes that control aging, lifespan is also influenced by positive behavioral modifications and pharmacological advancements in medical science. Human aging will be one of the biggest challenges we face during this century (Westendorp, 2006) and optimizing health for the rapidly growing older population is imperative to avoid end of life suffering. An increase in longevity necessitates maintenance of the high levels of neurocognitive function associated with systems such as memory and attention.

New neurocognitive findings oppose prior views that healthy aging is typified by inevitable and advancing loss and decline. The term "healthy aging" will be used here to refer to characteristic neurocognitive patterns not due to dementia or disease. Biological and genetic studies undertaken using advanced imaging techniques are providing dynamic and precise classification of healthy aging.

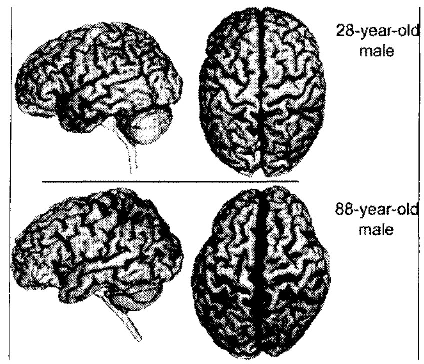
CHAPTER 2

REVIEW OF RELATED LITERATURE

The Aging Brain

Healthy aging produces a variety of well-documented changes in the brain's anatomy. Although research demonstrates a global loss of brain tissue volume in healthy aging (Allen et al, 2005; Kaasinen, Maguire, Kurki, Bruck, & Rinne, 2005; Raz et al., 2005), loss is not necessarily accompanied by moderate or severe deficits in cognitive function. The pattern of gray matter loss with age is reported to be relatively linear, whereas white matter volume changes tend to be more variable (Riello et al., 2005). White matter volume demonstrates a peak around the age of 50 years with a steep decline after the age of 60, and eventually decreases to approximately 20% of what existed in earlier adulthood (Allen et al.). Interestingly, Raz et al., (2004) found that the single gray matter structure that follows the path of slower white matter decline is the hippocampus, vital for memory function. Corresponding to tissue loss, the sulci widen (Figure 1). Brain shrinkage in healthy aging is accompanied by gradual loss of synapses, pruning of dendritic trees, glial loss, and impaired angiogenesis (Kelly et al., 2006; Trejo, Carro, Lopez-Lopez, & Torres-Aleman, 2004). The outcome of anatomical loss is decline in neurocognitive processes especially those of memory and attention throughout the aging years.

Figure 1: Tissue Loss and Widening of Sulci with Aging



Although evidence shows overall gray matter shrinkage, loss appears more dramatic in the some areas than in others. Especially affected are the lateral prefrontal cortex, hippocampus, cerebellum, and caudate nucleus—areas particularly important for memory and attentional focus (Hedden & Gabrieli, 2005; Kelly et al., 2006; Reuter-Lorenz & Lustig, 2005). Volumetric studies have confirmed that a greater amount of normal age-related shrinkage takes place in the prefrontal cortex than in any other cortical region (Fera et al., 2005; Hedden & Gabrieli, 2005) and that shrinkage increases with age. White matter loss is highest in the prefrontal cortex (Reuter-Lorenz & Lustig). Imaging studies consistently show that neural circuits contained in the prefrontal cortex control functions such as interference, choices among responses, multitasking, and encoding and retrieval of memories (Hedden & Gabrieli; Johnson, Mitchell, Raye, & Greene, 2004; Wager, Jonides, & Reading, 2004). Raz et al. (2005) report that although volumetric changes in the striatum are found, decline is minimal. The striatum is housed within the basal ganglia and thereby has significant influence on relay systems linking dopaminergic neurons to the prefrontal cortex. Any striatal loss, however minimal, has important implications.

Accompanying volumetric declines in the prefrontal cortex and the striatum are associated changes in neurotransmission circuitry underpinning these regions. The neurotransmitters most affected by the aging process, dopamine and choline, are directly linked with memory and attentional function (Hess, 2005; Prvulovic et al., 2004; Raz et al., 2005). Marschner et al. (2005) report that both serotonergic and dopaminergic structures undergo losses during healthy aging. They hypothesize that losses in these systems result in deficits in reward processing that may lead to cognitive inflexibility. Through enhancement of neuronal plasticity and survival, Mattson, Maudsley, and Martin (2004) found that insulin and insulin-like growth factors, brain-derived neurotrophic factor, and serotonin serve as relay stations acting to protect against age-related neurocognitive disorders influencing attention and memory. In a study of the use of physostigmine to boost cholinergic system function in older humans, Freo et al. (2005) showed that cholinergic enhancement significantly improved neural activity in prefrontal cortical areas.

Healthy aging is also characterized by changes in the basal ganglia and Hedden and Gabrieli (2005) have shown these changes to correspond with deficits in memory, attention, and other executive functions. Surprisingly, the small amount of hippocampal volume losses with healthy aging have *not* been shown to be correlated with memory function (Rand-Giovannetti et al., 2005; Rodrigue & Raz, 2004). Instead, basal ganglia related decreases in medial temporal lobe activation were documented during the study as correlated factors.

Of major importance to healthy neurocognitive aging are recent reports of what is expected to represent compensation and functional reorganization in the aging brain (Hedden & Gabrieli, 2005; Reuter-Lorenz & Lustig, 2005). Anatomically, additional and higher levels of activity are found cross-hemispherically, in lateral and prefrontal sites during tasks involving memory, encoding, and inhibition (Prvulovic et al., 2005; Rajah & D'Esposito, 2005; Reuter-Lorenz & Lustig, 2005). These findings provide solid support for the theory that the prefrontal cortex is capable of compensating for decline in other regions of the aging brain.

Neurocognitive function also benefits from adhering to practices of good cardiovascular health and a low-calorie diet. According to Bruce-Keller, Umberger, McFall, and Mattson (1999), food restriction is a reliable method by which to maintain and even return to youthful states of brain and behavior. Their research demonstrates that the largest benefits are seen in behavior related to the executive functions including memory and attention, which normally suffer the most during healthy aging. Hess (2005) posits that any health issue involving the nervous system will heavily influence the course and severity of memory change in aging. Diet also influences peripheral glucose regulation, which is linked to cognitive decline and a despondent mood particularly in aging adults (Hendrickx, McEwen, & van der Ouderaa, 2005).

Loss of Memory with Aging

Because of research into age-related cognitive challenges with memory, progress is being made toward defining and classifying its neural basis. According to Qiu and Fratinglioni (2003), although healthy seniors show decline in global cognition, memory function in particular is impacted. Looking through the eye of the neuroimaging lens, recent studies have demonstrated that age-related deficits in working and episodic memory are associated with various changes in prefrontal cortical function. In a meta-analysis of these studies, Rajah and D'Esposito (2005) found that in normal aging, different prefrontal areas showed different patterns of change in different participants. This indication of individually based functional change in some areas of the brain offers great hope that functional compensation or re-organization in other brain areas is occurring. Evidence of cortical adaptability in normally aging adults requires development of systems and stimuli that will encourage and stimulate neural compensation.

Over the years, emphasis has been placed on uncovering stimuli and methods that may enhance memory and attentional focus during the senior years. In an interesting 2004 study, Johnson et al., assessed the ability of healthy older adults to re-think of an item they had just viewed, in other words to *refresh* just-activated information. They found that not only do older adults gain less long-term memory benefit from refreshing learned material, but they also demonstrate lower levels of neural activity in the prefrontal cortex during the refreshing process. Not only does this support evidence already cited regarding the relationship between deficits in prefrontal activity and poorer cognitive memory processes but it also suggests poorer performance for seniors on a range of executive functions subserved by the prefrontal cortex.

Through functional Magnetic Resonance Imaging (fMRI) research Rand-Giovannetti et al. (2006), on the other hand, have found regionally specific neural responses to memory-enhancing repeated encoding tasks in healthy older participants. Their results demonstrate that hippocampal regions were activated *only* during the initial encoding trial and that subsequent trials showed activation in multiple cortical areas with no activity in the hippocampus. These findings indicate that successful attempts to encode new information may be a result of changes in the cortical attention network instead of the medial temporal lobe system.

Bialystok, Craik, Klein, and Viswanathan (2004) found that bilingual seniors who speak, comprehend, and process across two languages, show smaller age-related performance declines than individuals who speak a single language. These researchers report that bilingual participants also had faster reaction times in conditions that placed larger loads on working memory. The results of this study suggest that bilingualism may mitigate some of the negative influences on neurocognitive process during aging.

Freo et al. (2005) designed a positron emission tomography (PET) study assessing the pharmacological modulation of prefrontal cortical activity during a visual discrimination working memory test comparing younger and older adults. Their results indicate that cholinergic enhancement made no structural impact within prefrontal cortical regions in either group. For the older adults, however, cholinergic treatment did enhance neural activity levels in the anterior and ventral prefrontal regions. The fact that different prefrontal cortical areas are selectively recruited in young and older subjects, suggests that studies are needed looking at specific areas of neurocognitive age-related change rather than the more commonly considered universal pattern of memory loss. In fact, Clark et al. (2004) report that spectral alpha frequency brainwave power is predictive of performance on memory tasks and is associated with an age-related decrease.

Poor Attentional Focus with Aging

Attention includes a combination of processes including sustained attention, selective attention (inhibiting responses to competing information), and the ability to shift attention during multiple tasks (Riccio, Reynolds, Lowe, & Moore, 2002). Sustained attention is related to the timespan over which one can remain vigilant and alert and the ability to separate relevant from irrelevant stimuli underpins selective attention. In a study examining the performance of healthy seniors on a continuous performance test, Mani, Bedwell, & Miller (2005) found age-related deficits in commission and omission errors. Haarmann, Ashling, Davelaar, and Usher (2005) also report deficits correlated to aging in a modified continuous performance task.

Age-related deficits in attentional focus suggest that inhibitory processes are particularly affected by aging. Townsend, Adamo, and Haist (2006) have found fMRI evidence that older adults demonstrate significantly increased activation during both focused and shifting attention. These data suggest that the increase in activity may reflect processing of both task-relevant and task-irrelevant information indicating an age-related loss of attentional selectivity. Moreover, older adults may be less capable of inhibiting intrusions involving personally relevant information, which contributes to interference of attentional focus (Zacks, Radvansky, & Hasher, 1996). Deficits in paying attention have a multi-pronged effect and result in delays in encoding and subsequent retrieval, increased distraction, and poorer memory.

Chaparro, Wood, and Carberry (2005) designed a study looking at the manner in which driving behavior of healthy older adults is affected by visual and auditory multitasking. Using a closed driving course, they demonstrated that for the cognitively aging population, divided attention while driving has a significant negative influence on performance. Their results indicate the importance of caution, particularly for seniors, regarding the use of cellular phones or engaging in conversations with passengers while driving. Fortunately, research shows that levels of cautiousness increase among older adults. Rush, Panek, and Russell (1987) report that cautiousness in seniors increased more as measured by rates of accuracy-of-response than by the actual speed-of-response. In a study assessing older adults' use of simultaneous multiple tasks, Rapp, Krampe, and Baltes (2006) found a preference among seniors to allocate limited attentional resources toward higher rated tasks. They report significant dual-task performance deficits when seniors were faced with a choice between an attention task and a postural control task.

Research involving emotional states in aging adults has demonstrated that higher levels of anxiety and depression are linked with deficits in cognitive attentional tasks (Bierman, Comijs, Jonker, & Beekman, 2005; Deptula, Singh, & Pomara, 1993; Paterniti, Dufouil, Bisserbe, & Alperovitch, 1999). When considering anxious states without depression, a study of the cognitively intact elderly demonstrated that anxiety negatively affects attentional focus (Rankin, Gilner, Gfeller, & Katz, 1994). Hogan (2003) found that the negative emotional state of anxiety was correlated with diminished attentional function, but did not affect motor function in normal older adults. A 1993 study examining aging, emotional states, and memory found that even in healthy aging adults without clinical levels of depression, negative affect interfered with memory function (Deptula et al.). Their elderly participants were found to have significant connections between scores on verbal recall tasks and their ratings of negative affect.

Interaction of Memory and Attention

It may not be appropriate to tease apart the two neurocognitive systems of memory and attention although many studies are designed with this in mind. Gazzaley, Cooney, Rissman, and D'Esposito (2005) have shown that healthy seniors present with deficits in suppression of task-irrelevant representations and that this is manifested as excess cortical activity. They found that poorer suppression capability resulted in attention deficits and impaired working memory. In a study considering adult age differences on a false recall task, Smith, Lozito, and Bayen (2005) found that when detecting differences among similar stimuli, healthy older adults do not perform better when additional study time is added to encourage better distinctive processing. Smith et al. interpreted these results as evidence of a reduction in distinction processing on the part of older adults. When assessing inhibitory changes after age 60, Persad, Abeles, Zacks, and Denbury (2002) concluded that inhibition abilities decline with age, affecting several neurocognitive systems including memory and attention. These researchers posit that inhibition has a major impact on cognitive decline in age-related performance.

Another project assessing the neurocognitive processes of attention and memory as mutually dependent found that attentional focus is necessary to regulate the contents of capacity-limited memory networks in normal aging (Gazzaley et al., 2005). These researchers showed that curtailing task irrelevant input increased successful memory performance to the extent that a subgroup of their participants actually tested at the same level as the younger participants who demonstrated intact working memory. More studies are called for that combine tasks involving interaction effects of attention and memory function rather than the general approach of studying the two in isolation.

Hope for Neurocognitive Function in Aging

Although healthy aging is characterized by progressive cognitive loss and decline, new and effective interventions offer hope for neural reorganization and compensation. Reuter-Lorenz & Lustig (2005) report evidence of cortical overactivation in the aging brain that is now well documented and has positive implications for executive functions, motor control, and working memory. Complementary studies indicate that neural overactivation suggests compensation. The application of genetic analyses to the study of aging processes has uncovered a mutant gene (age-1) that increases life span and may slow the rate of aging (Johnson, 2005). As methods of postponing human aging advance, a premium will be placed on processes designed to maintain cognitive function.

Measures supporting neurocognitive function during the senior years are improving. Studies show that maintaining good cardiovascular health (Qiu & D'Esposito, 2003), following a low fat/low calorie diet (Bruce-Keller et al., 1999), keeping ones mind active (Hendricks, McEwen, & Ouderaa, 2005), making use of pharmacological advances to supplement low levels of neurotransmitters (Emmerling et al., 1994; Freo et al., 2005), and using caution while multitasking (Castel & Craik, 2003), have all been shown to benefit memory and attentional function in healthy aging. New methods, such as techniques that enhance brainwave function may provide an optimizing process in promoting successful aging of the mind. Brainwave function and its enhancement are considered below.

Alpha Frequency Decreases with Age

Aging, as defined by Christian (1984), constitutes a biological process rather than a disease and the resulting functional decline in neurotransmitter metabolism lies at the root of lower than normal EEG power. An important characteristic of the EEG in healthy aging adults is a slowing of alpha frequency brainwaves. According to Samson-Dollfus, Delapierre, Do Marcolino, and Blondeau (1997), alpha frequency brainwaves show a steady decrease in seniors. Lubar (2003) describes alpha frequency in infants as 2-4 Hz, at 4-years as 6 Hz, at 8-years as 8 Hz, with stabilization around 12 Hz at 13-14-years. Mean alpha frequency in older adulthood is 10 Hz with progressive slowing as we age. Mean alpha frequency below 7 Hz after age 70 is predictive of the onset of Alzheimer's disease (AD). Low alpha power correlates with neurocognitive decline. A series of EEG studies by Roubicek (1977) demonstrated that the decrease in alpha frequency brainwaves during the aging process is characterized by a downward shift in lower alpha frequency within the range from 9 Hz to 7 Hz. When alpha brainwaves become inhibited at the lower end of their frequency range, active input of vital brain nuclei cannot efficiently occur (Lubar, 2003). Excesses of inhibitory alpha are most problematic in the frontal lobes, which are intricately involved with executive functions. Brainwave activity within the alpha frequency range has been correlated with alertness, attention, inhibitory processes, working memory, perceptual abilities, and processing speed (Bryan & Luszcz, 1996; Clark et al., 2004; Faubert & Bellefuille, 2002; Hedden & Park, 2001; Jenkins, Myerson, Joerding, & Hale, 2000; McEvoy, Pellouchoud, Smith & Gevins, 2001; Persad et al., 2002).

Current Search for Neurocognitive Enhancement in Aging—Electroencephalography

Ninety-seven percent of the activity that occurs in the brain is integrated at the cortical level (Lubar, 1997; Nunez, 2000; Sibson et al., 1998). Electrical changes in the brain's cellular membrane polarization and inhibitory and excitatory potentials create voltage that is carried throughout the brain. The voltage travels toward the cortex and may be measured from the scalp as microvolts. Electrical current from the brain is recorded from nuclei systems producing a great enough amount of activity to be recordable at the cortex; electrical signaling of individual cells is too weak to be recorded using EEG. The advantage of EEG measurement is good temporal resolution despite relatively poor localization.

Precisely which neurons populate these neuronal assemblies remains mostly unknown. Gomez, Kanneworff, Budelli, and Grant (2005) found, in a study of the medium ganglionic (MG) layer neurons of mormyrid fish, that,

> … spike timing-dependent plasticity in the apical dendrites… and the broad spikes of MG cells originate in the soma and propagate through the molecular layer in the apical dendritic tree, and suggest the possibility that this backpropagation may contribute to 'boosting' of the synaptic response in distal apical dendrites (p. 141).

Dendritic spines are small mushroom-like appendages with an excitable membrane found on neurons in the central nervous system (Coombes, 2001). Event Related Potential (ERP) measurements record electrical firings generated in the brain stem, while EEG recorded alpha waves are the result of the summation of gray matter dendrite potentials particularly on the main dendritic shaft (Schmitt, 1987; Thompson et al., 2004).

Much work remains to be done, however, on the local network firing that is the main source of EEG measured at the scalp.

Research using EEG measures of brain activity indicates that elderly individuals have difficulty maintaining the high levels of cortical arousal associated with working memory and attention (Fingelkurts et al., 2003; Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004; Klimesch, Doppelmayr, Pachinger, & Russegger, 1997; Kliimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999). Specifically, age-related lower than normal levels of coordinated hemispheric brainwave patterns especially within alpha frequency brainwaves is common in healthy seniors. Basar, Basar-Eroglu, Karakas, & Schurmann, (2001) have shown that specific alpha oscillations serve as resonant communication networks throughout the brain and play a major role in memory and integrative functions. In a series of EEG studies, Pierce, Watson, King, Kelly, and Pribrain (2003) found that the brain's electrical activity demonstrates a more varied and complicated pattern across electrode sites as people age. Their recordings showed significantly less synchronous overall cortical activity activation of more electrode sites in older adults than in younger adults. Schürmann, Demiralp, Basar, and Eroglu (2000) posit the concept of selectively distributed alpha systems, which they view as correlates of the selectively distributed processing taking place in neurocognitive networks.

Music and the Brain

In an effort to raise deficient brainwaves to a more normal level, researchers have looked to other disciplines for answers. A particularly interesting effect has been noted by neurologist, Dr. Oliver Sacks. In 1966, after working with stroke and encephalic patients, Dr. Sacks discovered that by merely listening to classical music his patients briefly returned to an alert and active state after being literally frozen by the effects of their disease. For reasons not yet understood, patients who are unable to use words in speech are still able to sing those words (Sacks, 1998). Investigating EEGs of his patients' neural electrical signals during this transformation, Dr. Sacks found that their overall EEG power had been positively influenced after presentation of classical music.

Further studies demonstrate that certain beats within classical music may affect brainwaves. Sornson (1999) found that beta-harmonic sound patterns enhance the absolute power of waveforms as measured objectively between baseline control conditions and experimental binaural beat conditions. An improvement in vigilance, performance, and mood was found in a study by Lane, Kasian, Owens, and Marsh (1998, p. 252), during which "binaural beat auditory stimulation significantly influenced affective processes even when people were unaware that such signals were being presented." It seems that music containing binaural harmonic frequencies may help synchronize brain activity and elicit improved ability to maintain cognitive function.

Binaural Beats and the Manner in Which they Work

In 1839 Howard William Dove, a 20-year-old German researcher, discovered the phenomenon of binaural beats. Binaural beats are auditory processing artifacts, the perception of which occurs within the brain independent of physical stimuli (Borisyuk, Semple, & Rinzet, 2002; Oster, 1973; Sams, 1995). The auditory effect of binaural beats occurs when tones of two slightly different frequencies are presented separately to each ear. Each ear receives a separate frequency but the brain perceives the difference between the frequencies as a "middle" frequency. This perception is related to internal processing within the nervous system rather than in the external presentation of sound frequencies. Evidence suggests that the binaural beats originate in the superior olivary nucleus of the brainstem (Figure 2) where the hemispheric assimilation of the auditory system begins (Borisyuk et al.; BTG Technology, 2004).

Figure 2: The Superior Olivary Complex Acts as a Crossover Site for Spatially Oriented Auditory Information

Atwater (1988) found that a binaural beat generates two amplitude-modulated standing waves, (Irvine, Park, & McCormick, 2001; Rosenzweig, 1961; Turecek & Trussell, 2002). Accordingly, when a binaural beat is perceived there are actually two standing waves of equal amplitude and frequency present, one in each hemisphere (Borisyuk et al.). Both hemispheres work together to synthesize the two sounds into a single tone. The single meshed tone will "beat" with an overall frequency of the difference between the two original tones due to in-phase and out-of-phase disparate yet similar interference within waveforms (BTG Technology). These binaural beats entrain both hemispheres to the same frequency, resulting in equivalent electromagnetic environments and maximizing interhemispheric neural communication. This electrical activity is then conducted to the cortex where it may be recorded by electrodes and displayed as waveforms showing electrical activity in the form of amplitude of voltage spread over time (Ruskin, 1995). If the difference between tones matches a particular brainwave state, such as the 4-6 Hz theta range, the 7-11 Hz alpha range, or the 12-24 Hz beta range, then the overall brain activity will maintain that brainwave state (Lane et al., 1998; Sornson, 1999).

The pathways within the brain that transmit the binaural beats to the cortex for processing must be considered, as well. According to Swann, Bosanko, Cohen, Midgley, and Seed (1982), the reticular activating system (RAS), a large net-like region in the brainstem that plays a major role in filtering sensory input and focusing attention and awareness, is strongly involved in the cortical processing of binaural beats. Studies indicate that the binaural signals are processed in the RAS (Atwater, 1997; Hiew, 1995; Kennerly, 1996; Swingle, 1996).

Because many researchers believe that different brainwaves correspond to the production of specific neurochemicals in the brain (Ostrander & Schroeder, 1991; Schroeder & Barr, 2001; Patterson, Krupitsky, Flood, & Baker, 1994; Southworth, 1999), the positive effect of auditory binaural beats at the neurological level may be twofold. It is possible that a positive effect on frequencies within the brain may, in turn, trigger balanced production of neurotransmitters that are under-produced. Several neurological studies suggest that a primary function of the RAS is to adjust levels of the neurotransmitter acetylcholine and that this activity manages cortical-arousal states (Ernst et al., 2003; Southworth, 1999). It is hypothesized by Kaya et al. (2002) that this regulation may occur when cholinergic neurons adjust to binaural beat stimulation and thereby maintain production and transport of acetylcholine to the cortex. Cortical areas respond by increasing levels of sustained alertness. Acetylcholine has also been associated with higher intelligence test scores, which coincide with one's ability to maintain alertness (Halliwell, 1989; Hutchison, 1994; Wess, 1995).

Focus of this Study

We may be able to offer a more optimistic view of healthy neurocognitive function during the senior years and Hess (2005) concludes that a more multidimensional approach to the study of aging, memory, and attentional function is warranted. This study is designed to assess the application of binaural beat stimulation, in the alpha frequency range, as an adjunctive, non-pharmacological intervention for the enhancement of attentional focus and working memory in healthy, active community-dwelling adults over the age of 65 years. Binaural beat stimulation uses special patterned auditory signals presented via compact disc (CD) over stereo headphones at normal listening levels. This stimulation is thought to elicit patterned changes in EEG activity and produce changes in central nervous system arousal that could be beneficial to seniors experiencing age-related neurocognitive decline. If we can influence the frequency of alpha brainwave activity, we should be able to improve the function of healthy aging adults who often experience challenges when attempting to concentrate, remember information, and remain focused.

CHAPTER 3

METHODOLOGY

Participants

Twenty healthy active community-dwelling adults over the age of 65 (aged 67 to 80 years) were recruited from the University of Nevada, Las Vegas Cognition in Aging Laboratory's pool of senior participants. Participants were free from past closed head injury and seizure disorder (injuries of this sort result in abnormal brainwave patterns [Lubar, 1997]). A prior study (Lane et al., 1998) found that a subject with tinnitus reported annoyance when presented with music containing binaural beats so people with tinnitus were screened out of this study. Each individual received a remuneration of twenty dollars for their participation.

During testing, all participants remained on their regular, prescribed medications. Studies of the effects of medication on EEG recordings are infrequent and offer disparate results. In some cases, no significant changes in EEG due to stimulants are documented (Lubar, White, Swartwood, & Swartwood, 1999; Swartwood et al., 1998). This was attributed to evidence that stimulants act in subcortical areas of the brain and do not influence brainwaves recorded at the cortical surface. A study by Loo, Teale, and Reite (1999) noted that a normalization of EEG due to medication occurred in good responders only and that changes occurred in the theta frequency band. While some normalization was found, complete normalization was not. In a case study of Alzheimer's disease patients taking Galantamine, Memantine, Nicotine, and Revastigmine, quantitative EEG changes were measured in the relative theta power band (Sneddon et al., 2006).

The participants in the current study remained on their medications because of the University of Nevada, Las Vegas (UNLV) Institutional Review Board requirements and reported, on the Pre-Test Screening Questionnaire, any medications they had taken the day of testing. Fifty-five percent of the participants were taking drugs prescribed by their medical doctors. Examples of drugs reported were medications prescribed for anti-anxiety, hormone supplementation, high blood pressure, hypothyroidism, glucose adjustment, arthritis, and acid reflux (see Figure 9). EEG recordings of individuals taking medications were further analyzed for lesser (or greater) improvement after presentation of binaural beat stimulation. It is beyond the scope of this project to undertake the pioneering imaging work required to determine the precise interaction of drugs and brainwaves.

Materials

Mini Mental State Examination (MMSE)

First published in 1975, The MMSE represents a brief, standardized method by which to rate cognitive mental function. The exam assesses orientation, attention, immediate and short-term recall, language, and the ability to follow simple verbal and written instruction. A participant's MMSE score places the person on a scale of cognitive function ranging from 0 to 30 with higher numbers indicating intact neurocognitive function. A MMSE score of 18-23 indicates mild cognitive impairment and a score below

Figure 9: Participants on Medications

Classification	Medication
Angiotensin converting enzyme inhibitor	Lisinopril
Antianginal calcium channel blocker	Nifedipine Verapamil
Antihypertensive agent	Maxzide
Cholinesterase inhibitor	Mestinon
Histamine receptor antagonist	Zantac
Platelet-reducing agent	Acryline
Beta-selective adrenoreceptor blocker	Atenolol Metoprolol Tenormin
Muscarinic receptor antagonist	Detrol LA
Glucocorticoid	Prednisone
Osteoclast-mediated bone resorption inhibitor	Actonel
Hypothyroidism	Levoxyl
Hormone treatment	Premarin

18 indicates probably dementia (Kim, Caine, Currier, Leibovici, & Ryan, 2001). In a large study looking at population-based norms for the MMSE, Crum, Anthony, Bassett, and Folstein (1993) found that MMSE scores were related to both age and education level. According to its authors, the MMSE has demonstrated validity and reliability in

psychiatric, neurological, geriatric, and other medical populations (Folstein, Folstein, & McHugh, 1975).

Forward and Backward Digit Span Memory Tasks

Digit span tasks are widely used to measure memory function in neurocognitive studies. Forward and backward digit span tasks are used to assess short-term memory (limited storage of information) and working memory (an active interaction between passive storage and dynamic engagement). Participants are required to repeat the digits in the order in which they were presented—either forward or backward. Difficulty level begins with a series length of two digits, and then each series progressively increases by one digit. When the participant's response is incorrect on two consecutive series, testing ends and scores report the highest number of digits recalled during each task.

In a 2005 meta-analysis of studies looking at age differences in digit span tasks, Bopp and Verhaeghen found that older adult age-differences are demonstrated in all digit span measures (both forward and backward). Another study reported that including both forward and backward spans significantly increased the reliability of the measure in aging populations (Wilde, Strauss, & Tulsky, 2004). Further support for inclusion of both tasks when assessing memory function in seniors is provided by Hester, Kinsella, and Ong (2004) whose results indicated that age-related performance decline was the same for both tasks. Interestingly, Clark et al. (2004) identified frontal alpha frequency as a significant predictor of reverse digit span scores, regardless of age. This finding suggests a positive correlation between alpha power and working memory function.

The visually presented forward and backward digit span tasks were implemented in the current study during two phases as a behavioral assessment of any change in working memory before and after exposure to the CD containing binaural beats. The tasks were administered at eye level, on an 18" monitor, with the participant sitting at arms' length from the screen, and using PsyScope computer software for Macintosh (Cohen, MacWhinney, Flatt, & Provost, 1993).

Assessment of Attentional Focus in Aging

Studies assessing attentional focus in healthy seniors report age-related deficits in performance. Decrements in age-related attention are most prominent in modalities involving selective response inhibition. Mani et al. (2005) report that the number of commission errors (failure to inhibit a response) committed by healthy aging adults demonstrates a significant age-related increase. Research including a wide range of age groups found that continuous performance task (CPT) performance follows an inverse U-shaped curve across the life span with improved scores from childhood through adulthood after which, scores declined (Riccio et al., 2002). In a study comparing younger with older adults, Castel and Craik (2003) demonstrated that the younger group had significantly better hit rates (correct answers) than did the seniors who were aged 65-75 years.

From childhood through adulthood, the CPT, or modified versions thereof, is a popular tool for the assessment of individuals suspected of having attentional deficits. Continuous performance tasks measure the ability to maintain attention toward visual stimuli over a period of time. During the task, participants are presented with letters of the alphabet on a computer screen, and must press a mouse button every time any letter but an "X" appears (missing a response constitutes an error of omission), and do nothing when an "X" appears (pressing the mouse button when an X appears results in an error of commission). Scores from the task reflect attentional processes related to risk taking, sensitivity to interference, overall average reaction time, and standard error of reaction time for correct answers.

A shortened version (4 minutes rather than the full test's 15 minutes) of the CPT 3.0 (Conners, 1994) was used during each "music" phase of this study as a behavioral assessment of any improvement in task completion while listening to music containing binaural beats. The attentional scores for this task were analyzed to determine *correct* response rates measuring sustained alertness (pressing the mouse button each time any letter but an "X" appeared on the screen), errors of *omission* measuring selective attention (not pressing the mouse button when required), and errors of *commission* measuring impulse control (pressing the mouse button when not required).

Electroencephalography

EEG recording was accomplished using a BIOPAC Systems, Inc., Data Acquisition Unit, along with electrode lead sets, disposable vinyl electrodes, electrode gel, adhesive electrode holders, and abrading paste. The BIOPAC equipment is widely used in research laboratories to acquire measures of instantaneous activity within the cerebral hemispheres at the cortical level. EEG translates electrical activity from the cortex and during this study, the electrical activity was collected through a monopolar electrode placed at the International 10-20 Electrode Placement System scalp location of Cz with electrodes attached to each earlobe, one acting as a reference and the other as a ground. Impedance levels were monitored and were kept below 10 kilo-Ohms. According to Sams (1995, p. 5), the EEG power that correlates with most sustained alertness tasks in aging adults is the 7-11 Hz alpha frequency band whose power is maximal at the central electrode sites (Hogan, Swanwick, Kaiser, Rowan, & Lawlor, 2003; Klimesch, Doppelmayr, Rohm, Pollhuber, & Stadler, 2000; Sauseng et al., 2002). BIOPAC Acq*Knowledge*® software was used to record the EEG data, filter the data into the specific bandwidths for alpha, theta, beta, and delta, and display the results on-screen in real time. The software includes procedures for analyzing EEG signals and quantifying the relative and total power in each band. Additionally, the fluorescent lights in the laboratory were turned off during all EEG recording phases to avoid the 60 Hz spikes they cause during recording. Only illumination from the incandescent floor lamp in the testing room was used.

Binaural Beat Stimulation

As described previously, the auditory effect of binaural beats occurs when tones of two slightly different frequencies are presented separately to each ear and the brain perceives the difference between the frequencies as a “middle” frequency. This perception engages internal processing within the nervous system rather than external presentation of sound frequencies. Two CDs were specially produced for this project using SHARM’s Digital Graph Editor enabling precise definition of the binaural beat frequencies that play on a timeline-based graph[1]. The control phase CD contained no binaural beat stimulation, and the CD for the experimental phase contained binaural beats in the alpha frequency. The alpha tones were defined using 7 and 11 Hz binaural beats.

Subjectively, the two CDs sounded identical and were presented via a battery-operated CD player through stereo headphones.

Procedure

This study was conducted at UNLV's Cognition in Aging (CiA) Laboratory. After the consent and screening forms were completed, and the MMSE was administered, the participant was familiarized with the CPT program. Each person practiced the CPT for 3 to 5 minutes until he/she was comfortable with the protocol.

Participants were kept blind to the true purpose of the project. When recruited, they were informed that the project was being undertaken to rate new computerized sustained alertness tasks designed for healthy aging adults and that the consistency of their scores across two different sections of each task would be measured. During each session, participants were told that the CDs they were listening to were meant to block out any external noise that might distract them. The deception was essential in order to prevent any expectation bias of treatment conditions and participants were debriefed at the conclusion of their session.

The EEG electrodes were fitted to each participant according to the International 10-20 electrode-placement system. Seven EEG recording phases were designed for this project (see Figure 3). During the first 2-minute baseline-recording phase, each person was asked to focus their eyes on the keyboard, to lower their chin toward their chest

---

[1] Both CDs were prepared specifically for this project by Dr. Gary S. Katz, Assistant Professor of Psychology, California State University, Northridge, and Clinical Psychologist at the Center for Attention Disorders, Thousand Oaks, CA, and I am very grateful for his assistance.

Figure 3: Seven Experimental Phases

Phase I	2-Minute Baseline EEG Recording
Phase II	2-Minute Non-Binaural Beat Music EEG Recording
Phase III	CPT with Non-Binaural Beat Music EEG Recording
Phase IV	Visual WAIS Digit Span Subscale EEG Recording
Phase V	2-Minute Binaural Beat Music EEG Recording
Phase VI	CPT with Binaural Beat Music Recording
Phase VII	Visual WASI Digit Span Subscale EEG Recording

(minimizing movements of the neck muscle), and to remain as still as possible. During the second recording phase, stereo headphones (powered by batteries) were placed over the participant's ears and he/she listened to a CD playing soft music containing no binaural beats. Two more minutes of EEG were recorded. Third, while still listening to non-binaural beat music, the person completed 4 minutes of the CPT. Fourth, the participant completed the first visual forward and backward digit span task. Fifth, the participant listened to a CD playing soft music containing binaural beats, and the next 2 minutes of EEG activity was recorded. Two minutes of recording is considered adequate because the onset of binaural beat oscillation is immediate (Burgio, 2003; Lane et al., 1998; Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Lubar, 1997; Sams, 1995;

Schroeder & Barr, 2001; Southworth, 1999; Swingle, 1996; Swingle, 2000). Sixth, while still listening to the music containing binaural beats, the person completed four more minutes of the CPT. Finally, the participant completed the second visual forward and backward digit span task. Project protocol included EEG recording during all phases except for Phase IV and VII. It is expected that the Phase I baseline recording will appear to be very similar to the Phase II (non-binaural beat music) recording, and Phases III/VI and Phases IV/VII (during which the participant worked on the computer) were not analyzed because they were comprised mainly of movement artifacts.

This protocol design was successful because, to the participant, the fact that the two "music" recordings were the focal phases was concealed. Because the frequency effects of binaural beats have been found to last up to 1 hour or more (Lubar, 1997; Sornson, 1999), any influence of order effect in this study was sacrificed to avoid carryover effects. The participants were then debriefed, given their remuneration, and thanked.

CHAPTER 4

RESULTS

Background Measures

Data were screened for multivariate outliers. Two participants were found to have descriptive measures outside the two standard deviation cutoff score. These participants were not considered further in the analyses reported below. The Pretest Screening Questionnaire background information was assessed and mean alpha power was calculated for a variety of biological and behavioral traits (see Figure 4). Mean alpha power for individuals on and off medication was analyzed to assess any pharmacological interaction with binaural beat stimuli. Using analysis of variance (ANOVA) we found that, in agreement with other studies, there was no significant difference between individuals who were on medication ($M = 78.327$, $SD = 2.780$) and those who were medication free ($M = 79.962$, $SD = 1.029$) during Phase II, $F(1,16) = 2.187$, $p = .159$, $\alpha = 0.05$. We also found no significant difference between individuals on medication ($M = 82.415$, $SD = 1.802$) and medication free ($M = 82.177$, $SD = 1.687$) during Phase V, $F(1,16) = 0.078$, $p = .783$. Furthermore, no differences for gender, MMSE scores, frequency of exercise, use of coffee, level of education, or handedness were found.

For those with a musical background ($M = 80.945$, $SD = 1.473$), compared with those without any musical experience ($M = 82.852$, $SD = 1.527$), significantly lower levels of alpha power brainwaves were found during the binaural beat music phase, $F(1,16) = 5.731, p = .029, \eta^2 = .522$. Although not significant, $p = .067$, lower levels of alpha power to begin with were also found for musicians ($M = 77.329, SD = 4.119$) than for non-musicians ($M = 79.591, SD = 0.852$).

Figure 4: Alpha Power Means Comparison (Phase II $M = 78.963$, Phase V $M = 82.323$)

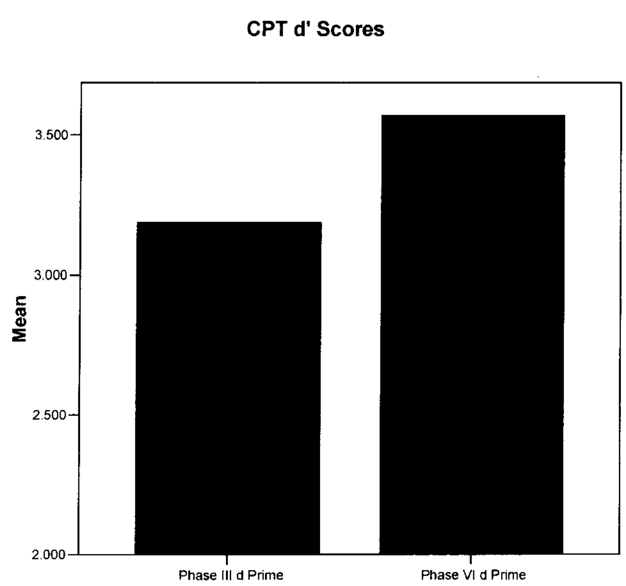
Variable	Level	Phase II Means	SD	Phase V Means	SD
Gender					
	Male	78.401	2.963	82.247	1.817
	Female	79.664	1.132	82.417	1.688
Handedness					
	Right-handed	78.911	2.510	82.264	1.795
	Left-handed	79.374	0.430	82.794	0.978
Medication					
	Off Medication	79.962	1.029	82.177	1.687
	On Medication	78.327	2.780	82.415	1.802
Musical Experience (*$p < .05$)					
	Musician	77.329	4.119	80.945*	1.473
	Non-musician	79.591	0.852	82.853*	1.527
Education					
	Higher Education	79.354	1.192	82.277	1.846
	High School	77.003	5.538	82.553	0.561
MMSE Score					
	High	79.318	1.259	82.041	1.553
	Low	78.404	3.550	82.765	1.976
Exercise					
	Does Exercise	79.013	2.698	82.486	1.719
	Does Not Exercise	78.832	1.378	81.890	1.890
Caffeine Consumption					
	Drinks Coffee	77.789	3.348	82.469	0.979
	No Coffee	79.709	1.098	82.229	2.093

Measurement of Attentional Focus

The CPT was scored using attentiveness analyses for the task completed during each phase. In accordance with signal detection theory, the attentiveness score was analyzed by calculation of d′. Higher CPT scores may reflect higher levels of sensitivity to detection of a signal (in this case, the letter "X"). The sensitivity measure of d′ is the distance along the X-axis between the noise distribution and the signal distribution in standard-score units and indicates its distance from the category boundary (Conners, 1994).

A paired-samples *t* test was used to maximize statistical power in comparing the attentiveness scores during Phase III and Phase VI. As predicted, participants exhibited a significantly higher attentiveness level during the binaural beat phase ($M = 3.567$, $SD = 0.461$) than during the non-binaural beat phase ($M = 3.186$, $SD = 0.695$), $t(17) = 3.859$, $p = .001$ (see Figure 5).

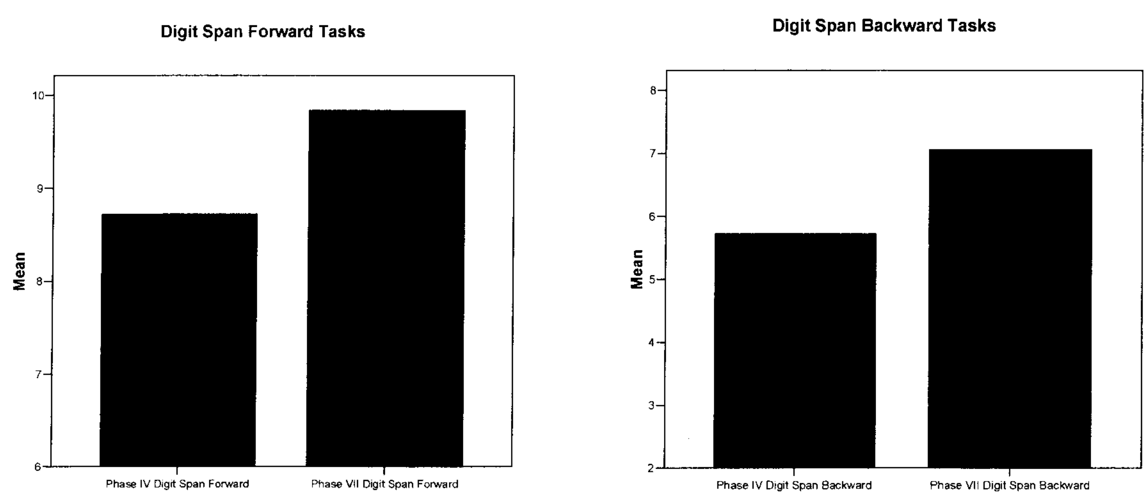
Figure 5: Significant Difference in d′ Measures of CPT Performance during Phase VI



Measurement of Working Memory

The forward and backward digit span tasks were scored using the number of digit spans recalled for the tasks completed during Phase IV and VII. A paired-samples *t* test was used in comparing the total working memory scores during Phase IV and Phase VII. As predicted, participants exhibited significantly higher memory function during the binaural beat phase for the forward digit span ($M = 9.830$, $SD = 2.149$) than during the non-binaural beat phase ($M = 8.720$, $SD = 2.081$), $t(17) = 3.162$, $p = .006$. In addition, a significantly greater improvement was found among the backward spans during Phase VII ($M = 7.060$, $SD = 2.100$), $t(17) = 4.123$, $p = .001$ (see Figure 6), than during Phase IV ($M = 5.720$, $SD = 2.469$).

Figure 6: Significant Differences in Forward & Backward Digit Span Scores during Phase VII

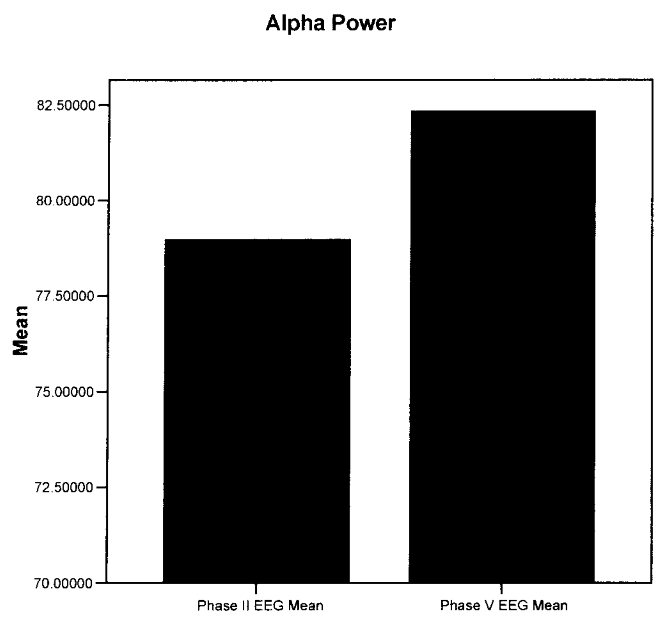


Electroencephalography

The EEG software package used in this study provided a composite of spectral outputs by which to observe recorded brainwaves. All wave-recorded formats were processed using the software's smoothing function, were visually checked to ensure that all movement artifacts had been removed, and were downloaded into files that were opened and analyzed in the computer program SPSS. The analog EEG waves (amplitude measured as voltage over time) were sampled at a rate of 200 samples per second and were translated by the software into digital values accounting for the voltage of each 3-second epoch. Fast Fourier transformation was used to process the voltage over time into voltage over frequency to display the level of electrical energy (power) of the alpha, and mean power was calculated for each epoch.

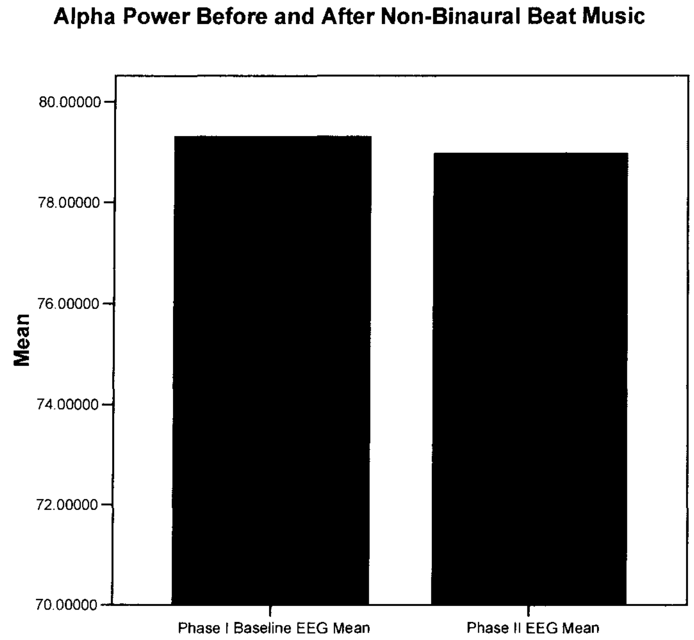
A paired-samples *t* test analysis was used to compare changes in absolute power between Phase II and Phase V. As expected, absolute alpha frequency power was significantly higher during Phase V, recorded while participants were listening to music containing binaural beats ($M = 82.323$, $SD = 1.711$), than during the non-binaural beat music presented during Phase II ($M = 78.963$, $SD = 2.365$), $t(17) = 4.689$, $p < .001$ (see Figure 7). When asked during debriefing whether they could detect any difference between the two CDs all participants claimed that they believed that they were listening to the same music during each research phase. They reported no unique or odd sensation or perception during presentation of auditory binaural beats. Moreover, five participants were proficient musicians (trumpet, violin, piano, organ, and vocals), which did not enable their identifying the binaural beats.

Figure 7: Significant Difference in Alpha Frequency Power during Phase V



A paired-samples *t* test analysis was also performed comparing any change in absolute power between Phase I, the resting baseline non-music phase, and Phase II, where non-binaural beat music was first presented. This test was done to determine whether alpha frequency brainwaves would increase because of music stimuli alone. Phase II absolute alpha frequency power ($M = 78.963$, $SD = 2.365$), was found to be not significantly different from the absolute power of Phase II ($M = 79.304$, $SD = 3.157$), $t(17) = 0.953$, $p = .354$ (see Figure 8), suggesting that the influence of music on alpha brainwaves in this study was minimal.

Figure 8: No Significant Difference in Alpha Frequency Power upon Presentation of Music during Phase II



CHAPTER 5

DISCUSSION

Support of Previous Studies

It was expected that the improvements in memory and attentional function found in this study were a result of elevated levels of electrical arousal within the brain elicited by the auditory binaural beats. The observed effects are consistent with the hypothesis regarding enhancement effects of binaural beats in the alpha frequency range on absolute power of alpha brainwaves in healthy seniors. Binaural beats in the EEG alpha frequency range were associated with significantly higher levels of working memory and attentional focus during the binaural beat condition compared the non-binaural beat condition. These findings lend empirical support to studies showing that auditory binaural beats have a positive effect on vigilance, performance, and mood (Lane et al., 1997), on memory (Kennerly, 1996), and on other measures of attention (Clark, Barry, Bond, McCarthy, & Selikowitz, 2002; Grant, Hai, Nussbaum, & Bigler, 1990; Lubar, 1997). The improvement in attention was recorded in the absence of participant expectations. All listening phases of this study were undertaken with the explanation that headphones and music were utilized to eliminate external auditory distractions, and the CDs were placed in the player out of the participant's view so no evidence of change in stimuli was evident.

It is also expected that any improvements in the tasks were influenced by changes in the levels of absolute alpha frequency electrical activity resultant from binaural beat stimulation. Moreover, it would normally be expected that scores on the final CPT measure would be considerably lower due to performance decline as a result of working with the same tedious task for the third time. According to Conners (1994), the performance decline when individuals repeat the task after a treatment protocol is due to the strictness of the CPT's response criterion. "In a boring task people become less efficient as they become less strict in deciding whether a signal is a target or not" (p. 3). The results of this study demonstrated a significant increase in CPT attentiveness scores for the phase VI and this suggests support of the positive effect of the binaural beat recording on attentional focus. This explanation coincides with prior studies that also found changes in EEG in response to presentation of binaural beats (Burgio, 2003; Clark et al., 2002; Lane et al., 1997; Lubar, 1997; Swingle, 1996). Any evidence of improvement in alpha wave activity when presented with binaural beats deserves further study using brainwave-measuring tools capable of quantitative analysis of waveform normalization.

Arguably, significantly higher scores on the forward and backward digit span tasks during Phase VII of this study could be due to practice effects. Through exposure during Phase IV, participants may have developed strategies by which to remember larger chunks of numbers. The digit span task (particularly the backward sequence) is not a favorite with participants, who frequently express distaste when asked to complete the task for the second time. It is possible that fatigue effects may mitigate potential practice effects.

In tests involving the effect of binaural beats on memory, Kennerly's (1996) results indicated that alpha frequency binaural beat audio signals were a successful method for "facilitating simple free recall memory, ability to attend, and the ability to persevere at routine motor tasks" (p. 50). This study's significant results validate Kennerly's work and add to the body of research demonstrating the effectiveness of auditory binaural beats. Overall, our significant findings corroborate and extend previous research indicating that listening to music containing binaural beats in the alpha frequency range may enhance alpha brainwave activity as measured at the scalp, increase performance on attentional focus and working memory tasks for healthy aging seniors over the age of 65.

Future Directions

New studies involving the phenomenon of auditory binaural beat stimulation should include multiple familiarization periods involving memory and attentional focus tasks. Were participants allowed to demonstrate a ceiling of optimal performance on these tasks during a condition absent of binaural beat stimulation and then perform the tasks during presentation of binaural beats, a more pure assessment could be made and any influence of practice effects would be accounted for. Similarly, to avoid the influence of practice effects, a study could be designed during which participants belonging to control vs. binaural beat groups would participate multiple days in randomly designated phases of the procedure used in the current study. Although neuropsychological tests generally have strong test-retest reliability (.70-.90) memory has been the one exception due to inconsistent practice effects (Williams, Simms, Clark, & Paul, 2005). In contrast, measures of attention tend to demonstrate consistent practice effects and therefore have a minimal effect on reliability over time (Ushiyama et al., 1995; Watson, Pasteur, Healy, & Hughes, 1994). Were participants to undergo testing over several days, order effects would no longer need to be sacrificed to avoid carryover effects resultant from the auditory binaural beat stimulus.

Because direction of the relationship between improved memory and attention-measuring tasks and improved alpha frequency cannot be determined in this study, further investigation into cause and effect is indicated. A study in which participants would be trained, using biofeedback techniques, to self-elevate age-related alpha frequency brainwave deficits is recommended. If better scores on memory and attentional measures were uncovered using biofeedback techniques, absent binaural beat stimulation, stronger support regarding predicted directionality of association could be offered.

Future studies should be organized for clinical populations such as individuals in the early stages of Alzheimer's disease within their daily environmental settings. Given any significant improvement in alpha brainwave functioning, we suggest that a study be designed in which individuals would listen to alpha frequency binaural beat music at specific times throughout the day. Because the onset of binaural beats is immediate and the effects last 1 hour or more, we may see an improvement in memory and attention for this population. Moreover, EEG measures of decreased alpha frequency brainwave activity may predict early stages of dementia and are therefore of clinical importance.

Although beyond the scope of this study, future research should analyze the correlation between the production of different neurotransmitters and alpha waves in the aging brain. According to Capel, Pinnock, & Patterson (1982), each brain area generates impulses at a specific frequency based on the predominant neurotransmitters it secretes.

For example, an alpha frequency signal boosts acetylcholine levels, which can provide relief from the cognitive loss associated with early stages of AD (Emmerling et al., 1994). The implications of this research are that by modifying brainwave frequencies, we may be able to alter the brain's neurochemistry and functioning (Kaya et al., 2002; Swingle, 2000; Wess, 1995). This suggests further investigation into the possibility of improving other cognitive deficits by triggering the release of beneficial neurotransmitters (Patterson et al., 1994).

For those with neurocognitive decline in healthy aging the possible improvements in alpha wave activity, working memory, and attentional function may interact and result in benefits beyond the predictions herein. The positive effects of auditory binaural beats may permeate behavioral and emotional modalities, not only functionally improving each, but also improving interactions between the two. It would be useful to study the extent to which improvements in working memory or attentional improvements after binaural beat presentation is sustained after the auditory stimuli is withdrawn. If the effect of binaural beats is prolonged, we may be able to find a way in which individuals could increase their alpha frequency brainwaves when forgetful and non-alert states occur throughout the day.

Binaural beat brainwave enhancement could offer a cost effective, non-pharmacological augmentative tool to neurocognitive function in healthy aging seniors. Because aging is inevitable and our senior population is growing, it is important to develop multimodal approaches to healthy aging. Through compensation and reorganization afforded by neuronal plasticity and facilitated by binaural beat stimuli, older adults may anticipate a productive and satisfying life even into the senior years.

REFERENCES

Allen, J. S., Bruss, J., & Damasio, H. (2005). The aging brain: the cognitive reserve hypothesis and hominid evolution. *American Journal of Human Biology, 17*(6), 673-689.

Atwater, F. H. (1997). Cortico-thalamic adaptation of binaural beating. In Monroe Institute (Ed.), *Proceedings of the Eighth International Symposium on New Science: Vol. 201* (pp. 11-15). Fabar, VA: The Monroe Institute of Applied Sciences.

Atwater, F. (1988). *The Monroe Institute's Hemi-Sync Process, a theoretical perspective.* The Monroe Institute of Applied Sciences, Fabar, VA, 4-7.

Basar, E., Basar-Eroglu, C., Karakas, S., & Schurmann, M. (2001). Gamma, alpha, delta, and theta oscillations govern cognitive processes. *International Journal of Psychophysiology, 39*(2-3), 241-248.

Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: evidence from the Simon task. *Psychology and Aging, 19*(2), 290-303.

Bierman, E. J., Comijs, H. C., Jonker, C., & Beekman, A. T. (2005). Effects of anxiety versus depression on cognition in later life. *The American Journal of Geriatric Psychiatry, 13*(8), 686-693.

BIOPAC Systems, Inc. (2004). *Electroencephalography (EEG) and hemispheric asymmetry* (PRO Published Lesson 10). Santa Barbara, California: Lambert, J., & Chantrier, N.

Bopp, K. L., & Verhaeghen, P. (2005), Aging and verbal memory span: A meta-analysis. *Journal of Gerontology, 60B*(5), P223-P233.

Borisyuk, A., Semple, M. N., & Rinzel, J. (2002). Adaptation and inhibition underlie responses to time-varying interaural phase cues in a model of inferior colliculus neurons. *The Journal of Neurophysiology, 88*(4), 2134-2146.

Bruce-Keller, A. J., Umberger, G., McFall, R., & Mattson, M. P. (1999). Food restriction reduces brain damage and improves behavioral outcome following excitotoxic and metabolic insults. *Annals of Neurology, 45*(1), 8-15.

Bryan, J., & Luszcz, M. A. (1996). Speed of information processing as a mediator between age and free-recall performance. *Psychology of Aging, 11*(1), 3-9.

BTG Technology (2004). *Brain wave entrainment* (Position Statement). Auckland, New Zealand.

Burgio, M. R. (2003). *Clinical trials of NeuroStim Sound Therapy: A preliminary report.* Westwood, California: UCLA, Clinical Trials.

Capel, I. D., Pinnock, M. H., & Patterson, M. A., (1982). The influence of electrostimulation on hexobarbital induced loss of righting reflex in rats. *Acupuncture & Electro-Therapeutics Research, 7*(1), 17-26.

Castel, A. D., & Craik, F. I. (2003). The effects of aging and divided attention on memory for item and associative information. *Psychology and Aging, 18*(4), 873-885.

Chaparro, A., Wood, J. M., & Carberry, T. (2005). Effects of age and auditory and visual dual tasks on closed-road driving performance. *Optometry and Vision Science, 82*(8), 747-754.

Christian, W. (1984). The electroencephalogram in advanced age. *Der Nervenarzt, 55*(10), 517-524.

Clarke, A. R., Barry, R. J., Bond D., McCarthy, R., & Selikowitz, M. (2002). Effects of stimulant medications on the EEG of children with attention-deficit/hyperactivity disorder. *Psychopharmacology, 164*, 277-284.

Clark, R. C., Veltmeyer, M. D., Hamilton, R. J., Simms, E., Paul, R., Hermens, D., et al. (2004). Spontaneous alpha peak frequency predicts working memory performance across the age span. *International Journal of Psychophysiology, 53*(1), 1-9.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, and Computers, 25*(2), 257-271.

Conners, C. K. (1994). Conners' Continuous Performance Test Computer Program 3.0: Users Manual. Toronto, Canada: Multi-Health Systems.

Coombes, S. (2001). From periodic traveling waves to traveling fronts in the spike-diffuse-spike model of dendritic waves. *Mathematical Biosciences, 170*(2), 155-72.

Crum, R. M., Anthony, J. C., Bassett, S. S., & Folstein, M. R. (1993). Population-based norms for the Mini-Mental State Examination by age and education level. *Journal of the American Medical Association, 269*(18), 2386-2391.

Deptula, D., Singh, R., & Pomara, N. (1993). Aging, emotional states, and memory. *American Journal of Psychiatry, 150*(3), 429-434.

Emmerling, M. R., Gregor, V. E., Schwarz, R. D., Scholten, J. D., Callahan, M. J., Lee, C., et al. (1994). PD 142676 (CI 1002), a novel anticholinesterase and muscarinic antagonist. *Molecular Neurobiology, 9*(1-3), 93-106.

Ernst, M., Kimes, A. S., London, E. D., Matochik, J. A., Eldreth, D., Tata, S., Contoreggi, C., et al. (2003). Neural substrates of decision making in adults with attention deficit hyperactivity disorder. *The American Journal of Psychiatry, 160,* 1061-1070.

Faubert, J., & Bellefuille, A. (2002). Aging effects on intra- and inter-attribute spatial frequency information for luminance, colour, and working memory. *Vision Research, 42*(3), 369-378.

Fera, F., Weickert, T. W., Goldberg, T. E., Tessitore, A., Hariri, A., Das, S., et al. (2005). Neural mechanisms underlying probabilistic category learning in normal aging. *The Journal of Neuroscience, 25*(49), 11340-11348.

Finch, C. E., & Stanford, C. B. (2004). Meat-adaptive genes and the evolution of slower aging in humans. *The Quarterly Review of Biology, 79*(1), 3-50.

Fingelkurts, A., Fingelkurts, A., Krause, C., Kaplan, A., Borisov, S., & Sams, M. (2003). Structural (operational) synchrony of EEG alpha activity during an auditory memory task. *Neuroimage, 20*(1), 529-542.

Folstein, M. F., Folstein, S. E., & McHugh P. R. (1975). Mini-mental state: A practical method for grading the state of patients for the clinician. *Journal of Psychiatric Research, 12*, 189-198.

Freo, U., Ricciardi, E., Pietrini, P., Schapiro, M. B., Rapoport, S. I., & Furey, M. L. (2005). Pharmacological modulation of prefrontal cortical activity during a working memory task in young and older humans: A PET study with physostigmine. *American Journal of Psychiatry, 162*(11), 2061-2070.

Gazzaley, A., Cooney, J. W., Rissman, J., & D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature and Neuroscience, 8*(10), 1298-1300.

Geesaman, B. J. (2006). Genetics of aging: Implications for drug discovery and development. *American Journal of Clinical Nutrition, 83(92)*, 466S-469S.

Gomez, L., Kanneworff, M., Budelli, K. R., & Grant, K. (2005). Dendritic spike back propagation in the electrosensory lobe of Gnathonemus petersii. *The Journal of Experimental Biology, 208*(Pt 1), 141-155.

Grabner, R. H., Fink, A., Stipacek, A., Neuper, C., & Neubauer, A. C. (2004). Intelligence and working memory systems: Evidence of neural efficiency in alpha band ERD. *Brain Research: Cognitive Brain Research, 20*(2), 212-225.

Grant, M. L., Hai, D., Nussbaum, N. L., & Bigler, E. D. (1990). The relationship between continuous performance tasks and neuropsychological tests in children with attention-deficit hyperactivity disorder. *Perceptual and Motor Skills, 70*(2), 435-445.

Haarmann, H. J., Ashling, G. E., Davelaar, E. J., & Usher, M. (2005). Age-related declines in context maintenance and semantic short-term memory. *The Quarterly Journal of Experimental Psychology. A, 58*(1), 34-53.

Hawkes, K. (2003). Grandmothers and the evolution of human longevity. *American Journal of Human Biology, 15*(3), 380-400.

Halliwell, J. V. (1989). Cholinergic responses in human neocortic neurons. *EXS, 57*, 138-149 [Switzerland].

Hedden, T., & Gabrieli, J. D. (2005). Healthy and pathological processes in adult development: new evidence from neuroimaging of the aging brain. *Current Opinion in Neurobiology, 18*(6), 740-747.

Hedden, T., & Park, D. (2001). Aging and interference in verbal working memory. *Psychology of Aging, 16*(4), 666-681.

Hendrickx, H., McEwen, B. S., & Ouderaa, F. (2005). Metabolism, mood and cognition in aging: The importance of lifestyle and dietary intervention. *Neurobiology of Aging, 26*(Suppl 1), 1-5.

Hess, T. M. (2005). Memory and aging in context. *Psychological Bulletin, 131*(3), 383-406.

Hester, R. L., Kinsella, G. J., & Ong, B. (2004). Effect of age on forward and backward span tasks. *Journal of International Neuropsychological Society, 10*(4), 475-481

Hiew, C. C. (1995). Hemi-Sync into creativity. *Hemi-Sync Journal*, *13*(1) 5-7.

Hogan, M. J. (2003). Divided attention in older but not younger adults is impaired by anxiety. *Experimental Aging Research, 29*(2), 111-136.

Hogan, M. J., Swanwick, G. R., Kaiser, J., Rowan, M., & Lawlor, B. (2003). Memory-related EEG power and coherence reductions in mild Alzheimer's disease. *International Journal of Psychophysiology, 49*(2), 147-163.

Hutchison, M. (1994). *Megabrain Power.* Ballantine Books: NY, p. 84.

Irvine, D. R. F., Park, V. N., & McCormick, L. (2001). Mechanisms underlying the sensitivity of neurons in the lateral superior olive to interaural intensity differences. *The Journal of Neurophysiology, 86*(6), 2647-2666.

Jenkins, L., Myerson, J., Joerding, J. A., & Hale, S. (2000). Converging evidence that visuospatial cognition is more age-sensitive than verbal cognition. *Psychology and Aging, 15*(1), 157-175.

Johnson, M. K., Mitchell, K. J., Raye, C. L., & Greene, E. J. (2004). An age-related deficit in prefrontal cortical function associated with refreshing information. *Psychological Science, 15*(2), 127-132.

Johnson, T. E. (2005). Genes, phenes, and dreams of immortality: the 2003 Kleemeier Award lecture. *Journal of Gerontology. Series A. Biological Sciences and Medical Sciences, 60*(6), 680-687.

Kaasinen, V. , Maguire, R. P., Kurki T., Bruck, A., & Rinne, J. O. (2005). Mapping brain structure and personality in late adulthood. *Neuroimage, 24*(2), 315-322.

Kaya, G. C., Pekcanlar, A., Bekis, R., Ada, E., Miral, S., Emiroglu, N., & Durak, H. (2002). Technetium-99m HMPAO brain SPECT in children with attention deficit hyperactivity disorder. *Annals of Nuclear Medicine, 16*(8), 527-531.

Kelly, K. M., Nadon, N. L., Morrison, J. H., Thibault, O., Barnes, C. A., & Blalock, F. M. (2006). The neurobiology of aging. *Epilepsy Research, 68*(1), S5-20.

Kennerly, R. C. (1996). An empirical investigation into the effect of beta frequency binaural-beat audio signals on four measures of human memory. *Monroe Institute Reports, 96*(3), 35-51.

Kim, S. Y., Caine, E. D., Currier, G. W., Leibovici, A., & Ryan, J. M. (2001). Assessing the competence of persons with Alzheimer's disease in providing informed consent for participation in research. *American Journal of Psychiatry, 158*(5), 712-717.

Klimesch, W., Doppelmayr, M., Pachinger, T., & Russegger, H. (1997). Event-related desynchronization in the alpha band and the processing of semantic information. *Brain Research: Cognitive Brain Research, 6*(2), 83-94.

Klimesch, W., Doppelmayr, M., Rohm, D., Pollhuber, D., & Stadler, W. (2000). Simultaneous desynchronization and synchronization of different alpha responses in the human electroencephalograph: A neglected paradox? *Neuroscience Letters, 284*(1-2), 97-100.

Klimesch, W., Doppelmayr, M., Schwaiger, J., Auinger, P., & Winkler, T. (1999). 'Paradoxical' alpha synchronization in a memory task. *Brain Research: Cognitive Brain Research, 7*(4), 493-501.

Lane, J. D., Kasian, S. J., Owens, J. E., & Marsh, G. R. (1998). Binaural auditory beats affect vigilance, performance, and mood. *Physiology & Behavior, 63*(2), 249-252.

Lee, R. D. (2003). Rethinking the evolutionary theory of aging: Transfers, not births, shape senescence in social species. *Proceedings of the National Academy of Sciences of the United States of America, 100*(16), 9637-9642.

Loo, S., Teale, P., & Reite, M. (1999). EEG correlates of methyl-phenidate response among children with ADHD: A preliminary report. *Biological Psychiatry, 45*(12), 1657-1660.

Lubar, J. F., Swartwood, M. O., Swartwood, J. N., & O'Donnell, P. H. (1995). Evaluation of the effectiveness of EEG neurofeedback training for ADHD in a clinical setting as measured by changes in T.O.V.A. scores, behavioral ratings, and WISC-R performance. *Biofeedback and Self-Regulation, 20*, 83-99.

Lubar, J. F. (1997). Neocortical dynamics: Implications for understanding the role of neurofeedback and related techniques for the enhancement of attention. *Applied Psychophysiological Biofeedback, 22*(2), 111-126.

Lubar, J. F., White, J. N., Jr., Swartwood, M. O., & Swartwood, J. N. (1999). Methylphenidate effects on global and complex measures of EEG. *Pediatric Neurology, 21*(3), 633-637.

Lubar, J. F. (Personal communication, 11th Annual Winter Brain Conference, January 22, 2003, Palm Springs, CA).

Mani, T. M., Bedwell, J. S., & Miller, L. S. (2004). Age-related decrements in performance on a brief continuous performance test. *Archives of Clinical Neuropsychology, 20*(5), 575-586.

Marcshner, A., Mell, T., Wartenburger, I., Villringer, A., Reischies, F. M., Heekeren, H. R. (2005). Reward-based decision-making and aging. *Brain Research Bulletin, 67*(5), 382-390.

Mattson, M. P., Maudsley, S., & Martin, B. (2004). A neural signaling triumvirate that influences ageing and age-related disease: insulin/IGF-1, BDNF and serotonin. *Ageing Research Reviews, 3*(4), 445-464.

McEvoy, L. K., Pellouchoud, E., Smith, M. E., & Gevins, A. (2001). Neurophysiological signals of working memory in normal aging. *Brain Research: Cognitive Brain Research, 11*(3), 363-376.

Nunez, P. L. (2000). Toward a quantitative description of large scale neocortical dynamic function and EEG. *Behavioral and Brain Sciences, 23*(3), 371-398.

Oster, G. (1973). Auditory beats in the brain. *Scientific American, 229,* 94-102.

Ostrander, S., & Schroeder, L. (1991). *Supermemory: The revolution.* New York: Carroll & Graf Publishers, Inc.

Paterniti, S., Dufouil, C., Bisserbe, J. C., & Alperovitch, A. (1999). Anxiety, depression, psychotropic drug use and cognitive impairment. *Psychological Medicine, 29*(2), 421-428.

Patterson, M., Krupitsky, E., Flood, N., & Baker, D. (1994). Amelioration of stress in chemical dependency detoxification by transcranial electrostimulation. *Stress Medicine, 10*(2), 115-126.

Persad, C. C., Abeles, N., Zacks, R. T., & Denbburg, N. L. (2002). Inhibitory changes after 60 and their relationship to measures of attention and memory. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 57*(3), 223-232.

Pierce, T. W., Watson, T. D., King, J. S., Kelly, S. P., & Pribram, K. H. (2003). Age differences in factor analysis of EEG. *Brain Topography, 16*(1), 19-27.

Prvulovic, D., Van de Ven, V., Sack, A. T., Maurer, K., & Linden, D. E. (2005). Functional activation imaging in aging and dementia. *Psychiatry Research, 140*(2), 97-113.

Qiu, C., & Fratiglioni, L. (2003). Epidemiology of cerebrovascular disease related cognitive decline. *International Psychogeriatrics, 15*(Suppl I), 105-110.

Rajah, M. N., & D'Esposito, M. (2005). Region-specific changes in prefrontal function with age: A review of PET and fMRI studies on working and episodic memory. *Brain, 128*(Pt 9), 1964-1983.

Rand-Giovannetti, E., Chua, E. F., Driscoll, A. E., Schacter, D. L., Albert, M. S., & Sperling, R. A. (2006). Hippocampal and neocortical activation during repetitive encoding in older persons. *Neurobiology of Aging, 27*(1), 173-182.

Rankin, E. J., Gilner, F. H., Gfeller, J. D., & Katz, B. M. (1994). Anxiety states and sustained attention in a cognitively intact elderly sample: Preliminary results. *Psychological Reports, 75*(3 Pt 1), 1176-1178.

Rapp, M. A., Krampe, R. T, & Baltes, P. B. (2006). Adaptive task prioritization in aging: Selective resource allocation to postural control is preserved in Alzheimer disease. *The American Journal of Geriatric Psychiatry, 14*(1), 52-61.

Raz, N., Gunning-Dixon, F., Head, D., Rodrigue, K. M., Williamson, A., & Acker, J. D. (2004). Aging, sexual dimorphism, and hemispheric asymmetry of the cerebral cortex: replicability of regional differences in volume. *Neurobiology of Aging, 25*(3), 377-396.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., et al. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex, 15*(11), 1676-1689.

Reuter-Lorenz, P. A., & Lustig, C. (2005). Brain aging: reorganizing discoveries about the aging mind. *Current Opinion in Neurobiology, 15*(2), 245-251.

Riccio, C. A., Reynolds, C. R., Lowe, P., & Moore, J. J. (2002). The continuous performance test: A window on the neural substrates for attention? *Archives of Clinical Neuropsychology, 17*(3). 235-272.

Riello, R., Sabattoli, F., Beltramello, A., Bonetti, M., Bono, G., Falini, A., et al. (2005). Brain volumes in healthy adults aged 40 years and over: A voxel-based morphometry study. *Aging Clinical and Experimental Research, 17*(4), 329-336.

Rodrigue, K. M., & Raz, N. (2004). Shrinkage of the entorhinal cortex over five years predicts memory performance in healthy adults. *Journal of Neuroscience, 24*(4), 956-963.

Rosenzweig, M. R. (1961). Development of research on the physiological mechanisms of auditory localization. *Psychological Bulletin, 9*(58), 376-389.

Roubicek, J. (1977). The electroencephalogram in the middle-aged and the elderly. *Journal of the American Geriatrics Society, 25*(4), 145-152.

Rush, M. C., Panek, P. E., & Russell, J. E. (1987). Cautiousness and visual selective attention performance among older adults. *The Journal of Genetic Psychology, 148*(2), 225-235.

Ruskin, K. J. (1995). Educational synapses in anesthesiology and critical care medicine. *The Journal of Anesthesiology, 2*(10), 2-22.

Sacks, O. (1998). Music and the Brain. In C. M. Tomaino (Ed.), *Clinical applications of music in neurologic rehabilitation* (pp.1-18). St. Louis: MMB Music, Inc.

Sams, M. W. (1995). Mathematically derived frequency correlates in cerebral function: Theoretical and clinical implications for neurofeedback training. *Journal of Neurotherapy, 1*(2), 1-14.

Nunez, P. L. (2000). Toward a quantitative description of large scale neocortical dynamic function and EEG. *Behavioral and Brain Sciences, 23*(3), 371-398.

Oster, G. (1973). Auditory beats in the brain. *Scientific American, 229,* 94-102.

Ostrander, S., & Schroeder, L. (1991). *Supermemory: The revolution.* New York: Carroll & Graf Publishers, Inc.

Paterniti, S., Dufouil, C., Bisserbe, J. C., & Alperovitch, A. (1999). Anxiety, depression, psychotropic drug use and cognitive impairment. *Psychological Medicine, 29*(2), 421-428.

Patterson, M., Krupitsky, E., Flood, N., & Baker, D. (1994). Amelioration of stress in chemical dependency detoxification by transcranial electrostimulation. *Stress Medicine, 10*(2), 115-126.

Persad, C. C., Abeles, N., Zacks, R. T., & Denbburg, N. L. (2002). Inhibitory changes after 60 and their relationship to measures of attention and memory. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 57*(3), 223-232.

Pierce, T. W., Watson, T. D., King, J. S., Kelly, S. P., & Pribram, K. H. (2003). Age differences in factor analysis of EEG. *Brain Topography, 16*(1), 19-27.

Prvulovic, D., Van de Ven, V., Sack, A. T., Maurer, K., & Linden, D. E. (2005). Functional activation imaging in aging and dementia. *Psychiatry Research, 140*(2), 97-113.

Qiu, C., & Fratiglioni, L. (2003). Epidemiology of cerebrovascular disease related cognitive decline. *International Psychogeriatrics, 15*(Suppl I), 105-110.

Sneddon, R., Shankle, W. R., Hara, J., Rodriquez, A., Hoffman, D., & Saha, U. (2006). QEEG monitoring of Alzheimer's disease treatment: A preliminary report of three case studies. *Clinical EEG Neuroscience, 37*(1), 54-59.

Sornson, R. O. (1999). Using binaural beats to enhance attention. *Hemi-Sync Journal, 10*(3) 15-23.

Southworth, S. (1999). A study of the effects of cranial electrical stimulation on attention and concentration. *Integrative Physiological and Behavioral Science, 34*(1), 43-53.

Swann, R., Bosanko, S., Cohen, R., Midgley, R., & Seed, K. M. (1982). *The brain - a user's manual* (p. 92). New York, NY: G. P. Putnam's Sons.

Swingle, P. G. (1996). Subthreshold 10-Hz sound suppresses EEG theta: Clinical application for the potentiation of neurotherapeutic treatment of ADD/ADHD. *Journal of Neurotherapy, 2*(1), 13-21.

Swingle, P. G. (April, 2000). *Parameters associated with rapid neurotherapeutic treatment of common ADD (CADD).* Paper presented at the Association for Applied Psychophysiology and Biofeedback Meeting, Denver, CO.

Thompson, P. M., Hayashi, K. M., Sowell, E. R., Gogtay, N., Giedd, J. N., Rapoport, J. L., et al. (2004). Mapping cortical change in Alzheimer's disease, brain development, and schizophrenia. *Neuroimage, 23*(1), S2-18.

Townsend, J. Adamo, M., & Haist, F. (2006). Changing channels: An fMRI study of aging and cross-modal attention shifts. *Neuroimage, 17*[Epub ahead of print]

Trejo, J. L, Carro, E., Lopez-Lopez, C. & Torres-Aleman, I. 2004). Role of serum insulin-like growth factor I in mammalian brain aging. *Growth Hormone & IGF Research, 14*(Suppl A), S39-S43.

Turecek, R., & Trussell, L. O. (2002). Reciprocal developmental regulation of presynaptic ionotropic receptors. *The Journal of Neuroscience, 99*(21), 13884-13889.

Ushiyama, C. L., D'Elia, L. F., Dellinger, A. M., Becker, J. T., Selnes, O. A., Wesch, J. E., et al. (1995). Alternate forms of the Auditory-Verbal Learning Test: Issues of test comparability, longitudinal reliability, and moderating demographic variables. *Archives of Clinical Neuropsychology, 10*(2), 133-145.

Wager, T. D., Jonides, J., Reading, S. (2004). Neuroimaging studies of shifting attention: A meta-analysis. *Neuroimage, 22*(4), 1679-1693.

Watson, F. L., Pasteur, M. A. L., Healy, D. T., & Hughes, E. A. (1994). Nine parallel versions of four memory tests: An assessment of form equivalence and the effects of practice on performance. *Human Psychopharmacology, 9*(1), 51-61.

Wess, J. (1995). *Molecular mechanisms of muscarinic acetylcholine receptor function (molecular geology intelligence unit).* Austin, TX: R. G. Landes Co.

Westendorp, R. G. (2006). What is healthy aging in the 21st century? *American Journal of Clinical Nutrition, 83*(2), 404S-409S.

Wilde, N. J., Strauss, E., & Tulsky, D. S. (2004). Memory span on the Wechsler Scales. *Journal of Clinical and Experimental Neuropsychology, 26*(4), 539-549.

Williams, L. M., Simms, E., Clark, C. R., & Paul, R. H. (2005). The test-retest reliability of a standardized neurocognitive and Neurophysiological test battery: "Neuromarker." *The International Journal of Neuroscience, 115*(12), 1605-1630.

Zacks, R. T., Radvansky, G., Hasher, L. (1996). Studies of directed forgetting in older adults. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 22*(1), 143-156.

VITA

Graduate College
University of Nevada, Las Vegas

Janice Colleen McMurray

Home Address:
5445 West Reno Avenue Apartment 1803
Las Vegas, Nevada 89118-1571

Degrees:
Bachelor of Arts, 2002
California State University, Northridge

Master of Arts, 2004
California State University, Northridge

Special Honors and Awards:
Awarded a 2-year National Institute of Health Postdoctoral Fellowship at Duke University Medical Center, 2006

University of Nevada, Las Vegas, Department of Psychology Experimental Program Graduate Student Representative to the Faculty, 2005/2006

1st Place Poster Presentation Award: 113th Annual APA Convention, Division 6: Behavioral Neuroscience and Comparative Psychology, 2005

Certificate of Accomplished Awareness in Working with Students with Disabilities at the University of Nevada, Las Vegas, 2005

1st Place Platform Award: Graduate & Professional Student Research Forum, University of Nevada, Las Vegas, 2005

University of Nevada, Las Vegas, Travel Grant Award to present at the Western Psychological Association's annual convention, 2005

18th Annual California State University Student Research Competition, representing California State University, Northridge, 2004

1st Place Platform Award: 8th Annual Student Research Symposium, California State University, Northridge, 2003

California State Graduate Equity Fellowship Award, 2003

Psi Chi National Honor Society in Psychology, 2001

Golden Key International Honour Society, 2001

Publications and Presentations:

McMurray, J. C., & Katz, G. S. (in revision). Binaural beats enhance EEG-measured beta frequency brainwaves in individuals with ADHD. *Journal of Physiology & Behavior.*

McMurray, J. C., Kemtes, K. A., and Townsend, C. L. (in progress). Error patterns in younger and older adults' recall of auditory and visual digit spans.

McMurray, J. C., Kemtes, K. A., and Townsend, C. L. *Error Patterns in Younger and Older Adults' Recall of Auditory and Visual Digit Spans.* Accepted poster presentation at the 86th Annual Western Psychological Association, Palm Springs, CA, April 2006.

McMurray, J. C., Jetha, S. S., Katz, G. S., & Kemtes, K. A. (2006). *Improving Memory and Attention on a Standardized Task with Auditory Binaural Beats.* Accepted poster presentation at the 26th Annual National Academy of Neuropsychology Conference, San Antonio, TX, October 2006.

McMurray, J. C., & Katz, G. S. (2005). Improving attention and impulsivity on a standardized task with auditory binaural beats. *Archives of Clinical Neuropsychology, (20)*7, 831.

McMurray, J. C., & Katz, G. S. *Improving Attention and Impulsivity on a Standardized Task with Auditory Binaural Beats.* Poster presentation at the 25th Annual National Academy of Neuropsychology Conference, Tampa, FL, October 2005.

McMurray, J. C., & Katz, G. K. *Auditory Binaural Beats and their Effect on EEG-Measured Beta Wave Activity in Individuals with ADHD and a Control Group.* Poster presentation at the 113th Annual American Psychological Association, Washington, DC, August 2005. First-place Poster Award, Division 6: Behavioral Neuroscience & Comparative Behavior.

McMurray, J. C., & Katz, G. K. *Auditory Binaural Beats Enhance EEG-Measured Beta Wave Activity and Attention in ADHD Individuals.* Poster presentation at the 85th Annual Western Psychological Association, Portland, OR, April 2005.

McMurray, J. C. *Auditory Binaural Beats Enhance EEG-Measured Beta Frequency Wave Activity and Attention in Individuals with ADHD.* Platform presentation for the University of Nevada, Las Vegas, Annual Department of Psychology 3rd Year Graduate Student Research Festival, April 2005.

McMurray, J. C. *Auditory Binaural Beats Enhance EEG-Measured Beta Frequency Wave Activity and Attention in Individuals with ADHD.* Platform presentation for the University of Nevada, Las Vegas, Annual University-wide Graduate Student Research Competition, April 2005.

Dissertation Title: Binaural Beats Enhance Alpha Wave Activity, Memory, and Attention in Healthy Aging Seniors

Dissertation Examination Committee:
Chairperson, Dr. Karen A. Kemtes, Ph.D.
Committee Member, Dr. Daniel N. Allen, Ph.D.
Committee Member, Dr. Charles T. Rasmussen, Ph.D.
Graduate Faculty Representative, Dr. Merrill R. Landers, D.P.T.