ABSTRACT

Title of Thesis: THE INFLUENCE OF FITNESS ON AGE-RELATED CHANGES IN CORTICAL ACITIVATION ASSOCIATED WITH COGNITIVE FUNCTION

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Brain function generally declines with age after the fifth decade. EEG Studies generally report that low- frequency EEG activity decreases with age while high-frequency EEG increases, the latter possibly for compensatory reasons. Because exercise has been reported to improve brain neurobiology such as cerebral metabolism and neurotransmitter function, it was expected that exercise would attenuate the age-related changes in EEG activity. Participants were men and women aged 18-35 and 60-75 years that were screened on health and indexed on the basis of physical fitness. Continuous EEG was recorded during each of four cognitive task conditions (eyes-closed, eyes-open, analytical, and spatial) using standardized electrode placements (Fz, Pz, Cz, O1, O2, C3, C4, T3, and T4) and referenced to the average of two ear electrodes (A1 and A2). To examine the relationship of physical fitness, age, and task to spectral power, multivariate analyses of variance were employed (2 x 3 x 2 x 9; Age x Fitness x Task x Site). It was predicted that both young and old participants would have a positive relationship between fitness and low-frequency power. However, the elderly group alone was expected to have a negative relationship between fitness and high-frequency power. Results of the

study indicated that aging was associated with substantial changes in cortical dynamics. Furthermore, although the elderly brain appeared to be working in a more effortful manner, fitness did not seem to substantially alter cortical dynamics in relation to fitness level.

THE INFLUENCE OF FITNESS ON AGE-RELATED CHANGES IN CORITCAL ACTIVATION ASSOCIATED WITH COGNITIVE FUNCTION

By

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TABLE OF CONTENTS

Appendices:

LIST OF FIGURES

CHAPTER I

Introduction

As healthy adults age the brain appears to “work harder”. This means in behavioral terms that brains of elderly individuals are more active and expend greater metabolic effort at rest and under conditions of mental challenge (Dustman et al., 1999; Polich, 1997). However, there is empirical and theoretical evidence that supports that exercise can slow the aging process and reduce the age-related change reflected in cognitive activity. Evidence supporting this age-related decline in the cortical activity of the elderly (i.e. working less efficiently) comes from EEG studies (Breslau et al., 1989; Dustman et al., 1999; Marciani et al., 1994; Polich, 1997). Due to the association between changes in EEG patterns with alterations in cerebral metabolism reported in these studies, it has been proposed that the observed EEG changes are a sign of deterioration accompanying normal aging. As a result of the increase in cerebral blood flow and enhancement in neurotrophic effects associated with physical activity it has been predicted that exercise attenuates age-related changes of the brain (Cotman & Engesser-Cessar, 2002; Rogers, Meyer, & Mortel, 1990). These neurophysiological changes are expected to be observable via EEG.

The review of literature will present theoretical and empirical evidence supporting the notion that fitness influences age-related changes in the cortical activation associated to cognitive function. The first part of the review will present neurobiological evidence that brain function generally declines with age. This section explores global aspects of cerebral metabolism decline and its connection to age-related changes in neurotransmitter function that is characteristic for healthy, normal aging and may account for changes associated age-related alterations in EEG. The next section examines empirical support for age-related changes in EEG spectral power in the elderly. The literature reviewed in this section provides support for age-related changes in theta power and the need to investigate whether low-frequency and high-frequency power alterations are a consequence of normal aging or pathology. The third section presents empirical evidence that exercise positively influences cognitive and motor performance shown to decline as a consequence of the aging process. Collectively, this review of literature conceptually establishes a link between exercise and its effect on age-related neurobiological changes in EEG in elderly adults. Lastly, the specific hypotheses regarding the predicted spectral power of elderly adults who differ in long-term physical activity involvement are presented. Hypotheses are also proposed for young adults who vary in physical fitness.

Purpose of Study

A range of studies has demonstrated that brain function declines with age including those reporting decreases in oxygenation and neurotransmitter function. EEG studies suggest that while low frequency activity declines with age, high frequency activity increases with age (as a compensatory response to the decline in lower frequency activity). Exercise has been suggested to attenuate the global decline in brain function. As a consequence, exercise is expected to attenuate the age-related declines in low frequency activity and the need for the high frequency compensation, which may moderate the increase in high-frequency activity associated with normal aging.

The purpose of this study is to examine the relationship between EEG (low- and high-frequency power) and physical fitness in old and young adults. Little investigation has been done on the effects of exercise on EEG spectral power in aging populations even though there is abundant research evidencing a positive influence of exercise on brain function. Additionally, previous research investigating age-related changes in the spectral content of the elderly has shown an inconclusive picture of age-related change in spectral power. The current study will demonstrate the effect of aging on EEG spectral content and will examine whether exercise influences any age-related changes demonstrated in the EEG spectral power of the participants.

Hypotheses

The research summarized in the previous sections has been used to generate hypotheses regarding the influence of physical fitness on the relationship between electrocortical activity and the aging process in healthy adults. The following hypotheses are proposed for both resting and cognitive challenge conditions, however it is expected that the findings will be more robust during cognitive challenge conditions compared to resting conditions in light of the higher degree of mental engagement inherent to the cognitive tasks.

Low frequency power

1. Older participants will exhibit less low-frequency power than younger participants.
2. All participants will show a positive relationship between fitness and low-frequency power, but the magnitude of the relationship will be greater in the older group than the young.

High-frequency power

3. Older participants will present more high-frequency power than older participants.
4. Older participants will show a negative relationship between high-frequency power and fitness.

Amplitude Variability

5. Older participants will exhibit less amplitude variability within all bands than younger participants.

6. All participants will also show a positive relationship between amplitude variability (within all bands) and fitness but the effect for older participants will be of greater magnitude.

Mean Frequency

7. Older participants will exhibit higher mean frequency within all bands than younger participants.
8. All participants will also demonstrate a negative relationship between amplitude variability (within all bands) and fitness but the effect for older participants will be of greater magnitude.

Delimitations

1. Participants consisted of non-smoking, right-handed volunteers that consisted of two age ranges: 18-36 and 61-72 years of age. Individuals free of disease and not taking any medication for cardiovascular and/or neurological pathologies were defined as "healthy".
2. Volunteer elderly participants for the initial high-fit aerobically trained group were individuals from the Annapolis/Baltimore/Washington, DC, metropolitan areas who were recognized Senior Olympiad participants. Young volunteer participants for the high-fit aerobically trained group were members of the University of Maryland varsity track and field team. High-fit participants in both the young and elderly age groups participated in activities well in excess of the American college of Sports Medicine's (ACSM, 1990) minimum standards for aerobic training as documented b the activity history questionnaire (Appendix A). Each participant also reported 10K running times below 50 min on the average.
3. Volunteer elderly participants for the moderate- and low-fitness groups were students enrolled in the Prince George's College Senior exercise classes who participated in light calisthenics (range of motion exercises) and low intensity walking activities. Young volunteer participants for the moderate- and low-fitness groups were students at the University of Maryland. The participants' combined weekly activities for age groups, as recorded by and activity history questionnaire (Appendix A), fell below the minimum standards for aerobic training as prescribed by the ACSM (1990).

Limitations

1. Participants were selected based on the differences that existed between them at the moment of the study, as a consequence genetic and/or other dispositional factors may confound this study. In other words, the cross-sectional nature of the study prevents the conclusion of any causal connection between aerobic fitness level and task or EEG differences.
2. Because participants in the study volunteered and thus the participant sample was not a random sample from the population, selection bias may have occurred.
3. A direct test of aerobic capacity is precluded from the elderly low-fitness participants because of the high-risk nature and possible cardiovascular trauma associated with such a test. Instead, self-reported activity levels and a submaximal test of aerobic capacity were used to determine aerobic training status.

Significance of Study

The number of older men and women in the United States is increasing and they are significantly challenged with brain related decline. In light of this, significant social concern, the present study seeks to understand the influence of physical activity as a preventive measure for neurocognitive decline.

Definitions

1. Aerobic Training – As reported by the American College of Sports Medicine (ACSM, 1990): any activity utilizing large muscle groups of an intensity of 60-90% of maximal heart rate of a duration of 20-60 min of continuous aerobic activity occurring 3-5 days a week.

2. Electroencephalography (EEG) – EEG is a recording of the summated postsynaptic potentials obtained through various electrodes located on the scalp. It is a non-invasive measure revealing the spectral composition of the cortical activity in the brain. The EEG waveform(s) recorded is quantified and characterized in terms of its amplitude. 0-50 μv, and frequency, 1-30 Hz, with the frequency being directly related to the activity of the underlying tissue.

3. Embedded Figures Task – The Embedded Figures Test is a visual spatial cognitive test that examines an individual's visual perceptual organization. During the test, a participant is expected to find a simple figure hidden within an embedded more complex figure. Slower time is associated with more adherence to the structure of the given visual field, labeled as field-dependent while field-independent scorers were able to more quickly find the figure because that they were better able to ignore the visual field in which the figure was hidden (Witkin, 1950).

4. High-frequency power – EEG waves of the specific frequency 19-40 Hz as measured by electrode placements at sites FZ, CZ, Pz, O1, O2, C3, C4, T3, and T4 according to the 10-20 international system of electrode placement.

5. Low-frequency Power - EEG waves of the specific frequency 3.5-13 Hz as measured by electrode placements at sites FZ, CZ, Pz, O1, O2, C3, C4, T3, and T4 according to the 10-20 international system of electrode placement.

6. Mental Arithmetic Task – Participants resolved mental arithmetic problems in their head and decided whether the given answer was correct or not with a finger wave.

7. Power Spectral Analysis – a mathematical process utilizing a fast Fourier transform which when complete "reflects the abundance and amplitude of EEG within specified frequency bands: (p.19, Dustman et al. 1985).

8. Seniors – individuals that are 60 years of age of older.

CHAPTER II

Review of Literature

Aging and Cognition

Research on cognition and aging suggests that during the course of normal aging, both general and process-specific cognitive declines occur in a variety of perceptual, cognitive and action-related processes. Elderly adults have shown decreases in reaction time, psychomotor speed, working memory, decision-making and multiple-task processing (Chodzko-Zajko & Moore, 1994; Colcombe & Kramer & Atchley, 2000; Dustman et al., 1990; Kramer & Atchley, 2000). However, research has also shown that many of these age-related deficits are not permanent and are amenable to interventions such as intellectual training or exercise that may slow or reduce aspects of age-related cognitive decline (Kramer et al., 1999). This provides evidence that the aging brain still yields an amount of plasticity with which it can adapt to environmental demands. More importantly, this research may indicate the underlying mechanisms in the neurobiology of the aging brain that can be improved with a lifestyle of physical activity.

Neurobiological Changes with Age

Many neurophysiological alterations, both gross and specific, occur as humans age that affect brain function and consequent behavior. Some of these alterations are: decreased brain weight and cortical thickness, neuronal cell loss, shrinkage of neurons, reduced density of neuronal spines and synaptic connections and the loss of synaptic connections (Brody, 1973; Coffey et al., 1992; Giannakopoulos, 1997; Jernigan et al., 2001; Morrison & Hof, 1997; O'Sullivan et al., 2001). These various age-related neurophysiological alterations provide a basis for the reduction in brain functioning evident in normal aging.

Various studies document a decline in cognitive and motor functioning for healthy aging adults (Chodzko-Zajko, 1994; Mortimer, 1992; Roth & Joseph, 1994; Spirduso, 1980; Volkow et al, 1998). Several mechanisms potentially influence age-related decline. The reduction of cerebral metabolism in the cortex is a key factor suggested to underlie age-related decline in the brain. Energy is formed mainly when glucose is oxidized to CO2 and water. Cerebral metabolism is based on the aerobic metabolism of glucose. Oxygen and glucose consumption must be increased in proportion to any increase in activity. If there were a decline in glucose or oxygen, energy production would be compromised and hence glucose or oxygen reduction would reduce brain functioning.

Cerebral Blood Flow (CBF)

Positron Emission Topography (PET) studies in the elderly indicate a decline in cerebral oxygenation due to reductions in cerebral blood flow (Marchal et al., 1992; Martin et al., 1991; Bentourkia et al., 2000; Noda et al., 2002). Martin et al. (1991) found regionally specific decreases in cerebral blood flow in participants ranging in age from 30-85 years. Bentourkia et al. (2000) also discovered a decline in cerebral blood flow and glucose metabolism with age. In aged monkeys, Noda et al. (2002) obtained parallel findings of decreases in regional cerebral blood flow (rCBF) and regional cerebral metabolic rate of glucose metabolism (rCMRglc) as age increased. Another study measuring cerebral perfusion in the elderly clearly demonstrate that CBF values progressively decrease with age (Rogers, 1990). Marchal et al.(1992) reported that cerebral blood volume and metabolic rate of oxygen decreased with age.

Two concerns arise when interpreting these reports. First, the subject sample of early studies in which the CBF assessment took place was not clearly free of cardiovascular disease, neurophysiological or cognitive abnormalities. The association of cardiovascular disease and neuropathology has been documented by both neuroanatomical reports as well as other gerontological investigations that suggest that decreases in cerebral oxygenation may indicate progressive cerebral atherosclerosis (Moody et al., 1997; Cervos-Navarro et al., 1987; Shaw et al., 1984; Pantoni et al., 1996). This draws attention to the possibility that the findings in CBF studies may not be attributed to normal healthy aging, but rather some form of disease or neuropathology.

The second concern is that the severity of oxygen decrease needed to produce a detrimental effect may not be shown with healthy aging populations. According to Lassen and Ingvar (1980), the small reduction in pO2 in the elderly is not enough to demonstrate a decline in brain function as in cases of cerebral ischemia. Cerebral ischemia is associated with somatic or mental disease not normal aging. Pantoni et al. (1996) claims that cerebral ischemia is due to two mechanisms not related to benign aging: athlerosclerotic changes and occlusion of small blood vessels. As a consequence, these reports suggests that decreases in oxygenation large enough to impair brain function may be a sign of disease or pathology because a substantial reduction in oxygenation may not occur in normal aging.

Glucose Metabolism

Even though reports of age-related reductions in cerebral oxygenation via CBF may be influenced by the factors mentioned above, a general decrease in cerebral metabolism assessed through glucose metabolism has been robustly demonstrated in aging literature (DeSanti et al., 1995; Noda et al. 2002; Petit-Taboue et al., 1998; Smith, 1980,1981). Furthermore, the reduction in glucose utilization, consumption and metabolism may play an important role in the aging process by influencing neurotransmitter levels because cerebral metabolism is critical to the functional metabolic activity of the nervous tissue including neurotransmitter (NT) synthesis and activation (Rogers & Aston-Jones, 1988).

Age-related decreases in both glucose utilization and metabolism have been found in both animals and humans. Animal studies show that glucose utilization is reduced as age increases in the resting, but conscious task conditions (Smith, 1980,1981; Noda et al. 2002). The major association area in rats, the parietal cortex, demonstrated the most significant reductions between aged rats and young rats. Additionally, significant decreases in elderly rats were found in the basal ganglia, caudate-putamen and globus pallidus when compared to the young rats (Smith, 1980, 1981).

Recent aging studies with humans verify decreased glucose metabolism in similar frontal and/or temporal association regions in the elderly (DeSanti et al., 1995; Petit-Taboue et al., 1998). In a study by DeSanti et al. (1995), age-related metabolic reductions in the frontal lobes had the greatest percentage of change (13-24%) and frontal lobe metabolism had the strongest relationship with age. In addition, Petit-Taboue et al., (1998) showed an age-related decline in cerebral glucose metabolism in all areas except for the occipital cortex and part of the cerebellum. The most significant effects were found bilaterally and symmetrically in the following association cortical regions: anterior parietal, anterior temporal, inferior and posterior-lateral frontal, and anterior cingulate regions. The head of the caudate nucleus and anterior thalamus also had significant effects.

Neurotransmitters

As mentioned previously, cerebral metabolism plays an essential role in the neurotransmitter (NT) synthesis and activation (Rogers & Aston-Jones, 1988). Similar to cerebral metabolism, neurotransmitters have also been reported to decline with age (Cote, 1986; Inoue et al., 2001; Kaasinen et al., 2000; Spirduso, 1980; Roth & Joseph, 1994;). Therefore, acetylcholine, dopamine, norepinephrine, serotonin, gamma amino butyric acid (GABA), and other neurotransmitters and their receptors have great potential to account for some of the characteristics of normal aging including: altered sleep pattern, mood, appetite, neuroendocrine functions, motor activity, and memory (Cote, 1986; Spirduso, 1980; Roth & Joseph, 1994).

In particular dopamine (DA) is a neurotransmitter that has been robustly linked to age-related changes in the elderly. In aging, 20-30% of the brain cells that produce DA are lost by age 60 (Spirduso, 1980). Additionally, DA uptake, receptor binding affinity, and the number of receptors are drastically reduced as age increases (Inoue et al., 2001; Kaasinen et al., 2000; Rinne et al., 1993; Spirduso, 1980; Volkow et al., 1996). Receptor loss has been documented in both striatal and extrastriatal regions in which the frontal region showed the fastest rate of decline (Inoue et al., 2001; Kaasinen et al., 2000). With age, there are also drastic reductions in the enzymes involved in the synthesis of dopamine (and norepinephrine) in the human brain (Cote, 1986). It is important to note that these general patterns of chemical change in DA are characteristic for normal aging, not diseases of aging like Parkinson's disease, which are generally associated with more selective and severe changes (Cote, 1986).

In conjunction to general declines of DA levels with age, the dopaminergic system is also highly associated with motor and cognitive performance declines (Chodzko-Zajko, 1994; Spirduso, 1980; West, 1996). Parkinson's disease (PD) is the severe example of the consequences of a deficit in the DA system. Two motor characteristics documented to decline with age, motor speed and reaction time, are demonstrated to be related to decreases of brain dopamine activity (Roth & Joseph, 1994; Volkow et al., 1998). In fact, Parkinson's disease is suggested to be an acute and accelerated aging because of the clinical symptoms of aging such as tremor, akinesia, and rigidity closely resemble PD patients. Furthermore, age-related declines in cognitive task performance in association with D2 receptor loss have been documented in both striatal and extrastriatal regions (Inoue et al., 2001; Kaasinen et al., 2000). Interestingly, the frontal region showed the fastest rate of decline suggesting that cognitive and motor function associated with that area would also be first to deteriorate.

Indeed, studies suggest that a decline in DA is responsible for a decline in cognitive and/or motor function. As Spirduso (1980) points out, a marked and severe decrease (70-90%) in DA must occur before even mild symptoms of akinesia, tremor or rigidity would occur. However, performance decrements occurred with losses of DA as small as 25% if participants are maximally challenged such as in a reaction time task where maximum speed is demanded (Chodzko-Zajko, 1994; Mortimer, 1982; Spirduso, 1980). In fact studies of behavioral cognitive deficits in the elderly have demonstrated that cognitive processing abilities directly reflect NT integrity, especially if those tasks are effortful, attentionally demanding or require rapid processing (Chodzko-Zajko, 1994; Spirduso, 1980). Therefore these studies collectively provide evidence suggestive of an age-related reduction in DA influencing motor and/or cognitive behavioral deficits (psychomotor speed in an effortful task).

In summary, the above studies show that normal healthy aging has been associated with a decrease in brain metabolism with age. Although studies showing declines in rCBF may be health-related, reports of decreased glucose and neurotransmitter levels (specifically dopamine) have been robustly established in the aging literature. Due to the connection established between small reductions of DA in elderly samples and cognitive-motor performance declines in effortful tasks, the reduction in neurotransmitter synthesis and receptor levels may serve as a potential mechanism behind the aging process reflected in the elderly.

Cognition and Fitness

Recent research has indicated that neurobiological mechanisms such as cerebral blood flow and oxygenation exist that may support a causal link between the beneficial effects of exercise and cognitive function. The notion of exercise improving cognitive function has emerged from literature that report improved psychological health in those that are physically active or physically fit (DiLorenzo et al., 1999; Plante, 1997; Raglin, 1990). Tomporowski and Ellis (1986) concluded from their meta-analysis that exercise of moderate duration and short intensity improved cognitive functioning. Etnier et al.'s (1997) review of studies on cognition and fitness concluded that although many variations in experimental rigor exist in the literature, there is a moderate effect of exercise on cognitive function. Additionally, geriatric and psychogeriatric mental patients exhibit positive cognitive effects from exercise (Folkins & Sime, 1981; Netz, 1994). Although these studies demonstrate strong support of a relationship between fitness and cognition, the research is limited to indirect behavioral investigation into the nature of the link. The mechanisms underlying changes in cortical function need to be investigated to truly determine the effect of exercise and cognition, especially within the context of the normal aging process.

Important to the issue of exercise and cognitive function are the behavioral tests used to measure cognitive performance. Various cognitive processes located in various areas of the brain determine broad categories of cognitive function and different cognitive tests will elicit unique responses from the different cognitive areas (Springer & Deutsch, 1998). Therefore, selecting the appropriate task that elicits a response from the target cognitive process is important in investigating the nature of fitness effects on cognition.

Additionally, there is some evidence that the visual spatial domain adapts more favorably to physical activity participation than other domains of cognitive function such as verbal/analytic (Shay and Roth, 1992). It would seem important in this area of research to challenge participants in both domains. The Embedded Figures Test is a visual spatial cognitive test that examines an individual’s visual perceptual organization. Witkin (1950) separated participants on the basis of their score as either field-dependent or field-independent and these concepts provided the foundation for the theory of psychological differentiation.

EEG & Aging

From the above sections it has been demonstrated that cognitive function declines as a normal function of age. Research in the neurobiology of the brain suggest that this age-related decline in brain function is the result of decreases in overall cerebral metabolism that may influence a number of cortical mechanisms related to neurocognitive processes (i.e. grey matter shrinkage, dendritic or synaptic loss, low NT levels). Alterations in EEG spectral power have been associated with cerebral metabolism specifically via cerebral oxygenation, blood flow and glucose levels (Nagata, 1989; Sadato et al., 1998; Sulg & Ingvar, 1967, 1969). As such, it is reasonable to expect that age-related reductions in the metabolism of the brain would be reflected in EEG spectral power. Research with elderly populations has demonstrated age-related changes in EEG (Breslau et al., 1989; Duffy, 1993; Dustman et al., 1999; Hartikainen, 1977; Koyama, 1996; Marciani et al., 1994; Polich, 1997; Roubicek, 1977; Williamson, 1990). The present section summarizes age-related changes in EEG that are likely related to changes in the mechanisms of cerebral metabolism.

Relative Power

The use of EEG with elderly populations has generally demonstrated specific age-related variations in EEG spectral analysis. Studies generally report decreased power in low frequency bands and increased power in higher frequency bands (Polich, 1997; Breslau et al., 1989; Dustman et al., 1999; Marciani et al., 1994). The following thirteen studies reported age-related variations in EEG spectral power.

Roubicek (1977) examined 159 moderately healthy subjects aged 46-92 years. Persons with major somatic disease (especially brain disease) were excluded from the study. Subjects were divided by age into the following groups: 20-39, 40-59, and 60-91. For spectral analysis, the relative distribution (relative power) of the following frequency bands was calculated: delta (1-3.5), theta (2.5-6.5), alpha (6.5-12), beta (12-16, 16-20, 20-25, 25-30, 30-35, and 35-40). Delta and theta activity significantly increased in relative percentual distribution while alpha activity decreased significantly with age. As for beta activity, a non-divided beta range (12-30 Hz) demonstrated a significant decrease with age along with decreases in sub-bands of 12-16 Hz and 20-25 Hz. The higher sub-bands of 30-35 Hz and 35-40 Hz demonstrated significant increases with age. Additionally, the dominant frequency in persons around the age of 60 was 9 Hz, however between the ages of 80 and 90, the dominant frequency had changed to 7 Hz. This was proposed by the investigators to have been caused by the steady increase of slow waves, together with the decrease of percentual alpha- and lower beta-band waves observed in the EEG.

Duffy et al. (1984) examined the age-differences in electrical activity of 63 healthy men aged 30-80 years. Subjects were divided into four decade groups: 30-40, 50-59, 60-69, and 70-80. EEG was recorded during ten different testing conditions; one being an eyes-closed resting condition for six minutes and the other nine conditions were variations of the resting eyes-open condition (i.e. listening to speech or music). To record the EEG twenty scalp electrodes were used according to the International 10-20 system and linked to ear electrodes (Jasper, 1958). Topographic analysis was performed using the brain electrical activity mapping (BEAM) methodology. The topographic image was created from single measurements taken from each of the twenty electrodes for creation of the topographic image. A single average spectrum was formed using the fast Fourier transform for each electrode and task condition. The spectra were integrated across 4 Hz spectral bands, with one number resulting from each electrode for each band. The bands were delta (0-3.75), theta (4-7.75), alpha (8-11.75), beta 1 (12-15.75), beta 2 (16-19.75), beta 3 (20-23.75), beta 4 (24-27.75), and beta 5 (28-31.75. The results indicated that as age increases, alpha remains unchanged except for reduced reactivity. Instead, there was decreased slow activity and increased fast activity with increased age. Additionally, correlations between memory tests and the temporal BEAM features were positive in relation to EEG slow activity and negative with EEG fast activity. Also, a biphasic timing effect emerged from the data. The largest amount of change (in feature value) with age occurred between the 30-39 and 50-59 groups and the least amount occurred between the 50-59 and 60-69 groups.

Breslau et al. (1989) tested eight elderly patients with dementia of the Alzheimer's type including 15 healthy elderly controls with a mean age of 70, and 10 young controls with a mean age of 23. They recorded EEG during 3 min of an eyes-closed resting state. They applied a montage of 32 electrodes to assess EEG. Absolute amplitude was computed for delta (.8-4.3 Hz), theta (4.7-7.8 Hz), alpha (8.2-12.5 Hz) and beta (13.3-19.9 Hz) frequency bands. Comparing the groups, the healthy elderly exhibited a reduction in amplitude for all frequency bands. The topographic distribution for delta and theta in the elderly was predominantly midline with an increase in mid-parietal and left mid-temporal delta. For alpha, the older group showed a midsaggital distribution and for beta, the old group showed diminished distribution effects in general.

Williamson et al. (1990) studied 53 normal elderly subjects aged 41-85 years to investigate the relationship between EEG spectral power and tests of cognitive decline

(Extended Scale for Dementia) across age and gender. The subject sample was comprised of 30 men aged 65-81 years and 23 women ranging in age from 41 to 85 years. A standard 10-20 electrode montage was utilized to record the subject's EEG at rest during an eyes-closed condition. EEG absolute power was calculated from the following frequency bands: delta (0.5-4.0 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta 1 (12-18 Hz), and beta 2 (18-26 Hz). In frontal, temporal and central leads a general trend was found between decreased delta, theta and alpha power and age. Also at a bipolar electrode comparing parietal sites on the right side (P4O2), a negative correlation found between beta 1 power and age. As for correlations between the Extended Scale for Dementia (ESD) and beta 1 and beta 2 power, positive significant correlations were exhibited between beta power and cognitive test performance for four of eight frontal-central locations in both hemispheres. The ESD was also significantly correlated with theta power in negative direction.

Duffy et al. (1993) examined 202 healthy subjects (males = 93 and females = 109) between the ages of 30 and 80 to further investigate age and gender differences. The men had been previously studied on an earlier project (Duffy et al., 1984). The added female subject data were collected and analyzed in the same manner as the males in the previous study in 1984 (see above). EEG data from both men and women (n = 202) was grouped into five distinct data domains: a) relative slow spectral measures (n =15), b) relative fast spectral measures (n = 16), c) absolute measures of slow activity (n – 8), and d) absolute measure of fast activity (n = 1), and e) visual and auditory evoked potentials (n = 5). Principle Components analysis was done on the four data sets containing more than one measure. For the combined sample, age-related differences of EEG found were decreases in slow activity and increases in fast activity. To determine the degree and shape of linearity of the relationship each of the twelve summary measures was regressed with age as a continuous variable. Two of the three slow activity measures (THETA %, SLOW) demonstrated a significant negative linear trend with age. The DELTA% also showed a significant negative relationship, however it was non-linear. There was a decline from 30-55 years and then it remained relatively stable over later years. Similarly, the spectral fast activity measures also demonstrated a non-linear change in the positive direction. As for the gender differences, females demonstrated lower values for relative slow activity than males, but higher values than males for absolute slow activity. Additionally, females had higher relative and absolute fast activity values than males, but lower absolute alpha values than males. Significantly, there was also an interaction between gender and age in the absolute slow activity measure. Both genders demonstrate a decrease in slow activity from 30-40 years of age that then levels off over the age of 65. Around the age of 65 until 85 males then exhibit another decrease that the females do not show.

Hartikainen et al. (1992) studied 52 subjects ranging in age from 20 to 91 years. The subjects were placed into the following age groups: 20-39, 40-59, and 60-91. Continuous EEG was recorded from T5-O1 and T6-O2 derivations that were placed according to the international 10-20 system during a resting eyes-closed condition. To obtain the frequency spectrum of the whole EEG sample, FFT from a total of 12 sections were averaged. Absolute and relative amplitude and power were calculated for the following frequency bands: delta (1.5-3.9), theta (4.1-7.3), alpha (7.6-13.9) and beta (14.2-20.0). The investigators found that age was inversely related to the amount of delta and theta activity. Absolute amplitude and power for the delta and theta bands in the oldest group (60+) were lower than the youngest group (20-39 years). Although not significant, beta and alpha band activity also exhibited a decreasing trend with age. Additionally, when age was controlled gender effects were exhibited. Women showed a larger amount of beta activity compared to males. In addition, a 2-year follow up examination within the oldest age group demonstrated a positive correlation between learning ability and delta activity and an inverse relationship between delta and acetylcholinesterase activity of the CSF.

Marciani et al. (1994) studied 19 healthy older adults (72-86, mean 78.7 + 7.3), 21 healthy old adults (50-69, mean 60.58 + 5.4), and 21 healthy young controls (mean 29.9+ 10.4). EEG was recorded from 18 electrodes during 4 tasks: resting eyes closed, alpha blocking reaction (BR) of eyes open 6-7 s each, 2 min of visual fixation of cartoons (FIX), and 60-70 s of mental arithmetic (MA) with eyes closed. EEG Absolute and relative EEG power were computed for each electrode and frequency band: delta (1-3.5 Hz), theta (4-7.5 Hz), alpha (8-12.5 Hz), beta 1 (13-19.5 Hz), and beta2 (20-29 Hz). EEG measured during rest was not as sensitive to age-related changes as EEG recorded during challenge. At rest, during eye-closed condition beta power was positively related to age in subjects aged 50-70. Additionally, during mental challenge, alpha reactivity (i.e. percentage of decrease in alpha power from rest to challenge) decreased in elderly subjects. Ray and Cole (1985) theorized that alpha reactivity is related to attentional compensation and cognitive performance. In light of this theory, Marciani et al. proposed that beta power increases in the elderly were compensatory mechanisms to offset age-related decreases in cognitive function.

Holschneider and Leuchter (1995) recorded the EEG of healthy subjects (n = 62, aged 24-90 years), subjects with Alzheimer's type dementia (n = 49, aged 47-89 years), and subjects with multi-infarct dementia (n = 25, aged 64-87 years) in order to examine the effects disease, age and gender on high frequency EEG activity. Electrodes were placed on the scalp according the International 10-20 system and 2 temporal and 2 parasagittal bipolar longitudinal chains were used to collect the data (creating 16 channels: Fp2-F8, F8-T4, T4-T6, T6-O2, Fp1-F7, F7-T3, T3-T5, T5-O1, Fp2-F4, F4-C4, C4-P4, P4-O2, Fp1-F3, F3-C3, C3-P3, P3-O1). During recording, subjects rested with their eyes closed in a supine position for 5 minutes. Absolute and relative power was calculated for each of the 16 channels in 10 frequency bands of 4 Hz width between 14-54 Hz (14-18 Hz, 18-22 Hz, 22-26 Hz, 26-30 Hz, 30-34 Hz, 34-38 Hz, 38-42 Hz, 42-46 Hz, 46-50 Hz, 50-54 Hz). Relative power was calculated using dividing the absolute power in a band by the total power (2-54 Hz). The investigators found highly significant differences between the relative power of healthy control subjects compared separately to the Alzheimer's patients and multi-infarct dementia patients across recording sites and frequency bands. This included some intergroup differences that existed only in specific frequencies at certain sites (interaction effects). Amongst healthy controls, across the age range of 24-90 years, subjects showed modest positive correlations with age and beta activity (absolute or relative power). The most prominent correlations were found in frontal, central and parietal areas. However, there were no correlations of relative or absolute beta power with age across the 60-90 year range. In regards to gender amongst the elderly and young groups, women showed modest increases in beta relative and absolute power.

Brenner et al. (1995) investigated sex differences between healthy, elderly men and women. The investigators recorded the EEG of subjects aged 60-87 years (n = 119) during a resting eyes-closed condition. According to the international 10-20 system, 16 channel EEGs were recorded using a longitudinal bipolar montage. A spectral analysis was computed using the following 8 derivations: C3-P3, P3-O1, C4-P4, P4-O2, F7-T3, T3-T5, F8-T4, and T4-T6. Spectrum total power and relative power was computed in the following frequency bands: delta (1-3.99), theta (4-7.99), alpha 1 (8-9.99), alpha 2 (10-12.99), beta 1 (13-19.99), and beta 2 (20-30). Relative power in each bandwidth was log transformed using log (x/1-x) where x is the fraction of total power for each 2-sec sample. Significant spectral differences were found between men and women. Female subjects higher parasagittal beta 1, beta 2, and theta mean frequencies partially due to the increase in relative power of beta activity. Males on the other hand increased alpha 2 and theta-beta mean frequency and alpha 2 relative power. Age had very little effect when subjects were grouped by decade, nor when any sex-age interactions occur.

Anokhin et al. (1996) assessed relative power in children (mixed sex) aged 7-14 and adults (males) aged 20-61. The children and adults were further divided into two groups on the basis of age (7-8, 13-14, 20-30, 31-45, and 46-60). EEG was recorded from six sites: F3, F4, C3, C4, O1, and O2. EEG theta, alpha, and beta power were calculated as the average log power in the range of 4-8, 8-12 and 14-30 Hz respectively. Among the adult men aged 20-60, the only significant difference between the youngest and oldest adult groups was an increase in relative beta power with age. Anokhin's results partially follow the basic trend found with age. Their study captured beta increases between young and old participants in the frequency range of 14 – 30 Hz. However, no changes in alpha or theta were found after the age of 14.

Koyama (1997) examined the aging effects on EEGs in subjects screened age-related pathology. There were two main age groups that made up a sample of 88 subjects: 68 seniors aged 61-90 years and 20 young controls aged 23-38. For analysis the elderly group was further divided into age bands of 60-69, 70-79, and 80-89 years. Eight electrode locations were used to record the EEG (Fp1, Fp2, T3, T4, C3, C4, O1, and O2) placed according to the 10-20 System and all data were referenced to the ipsilateral earlobe. However, only EEG data from centrooccipital (C3, C4, O1, and O2) sites were used to calculate relative power. Relative power (expressed as a percentage of total EEG power) was calculated for each of the following bands: delta (2-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), and beta (13-30 Hz). The variables were normalized using log [X/(1-X)] for relative power. Koyama et al. found no significant relationship between age and relative delta or theta power. However, relative beta power was found to be significantly higher in the elderly groups compared to the young control group. Relative alpha was found to be significantly lower only in the elderly age group of 60-69 years compared to the young group.

Polich (1997) recorded the EEG of 120 adults aged 20-70 years in order to further examine age-related changes in cortical activation. There were six age groups, one for each decade and each age group consisted of 10 males and 10 females. Midline sites (Fz, Cz, Pz) were recorded during 3 min of eyes-open and eyes-closed task conditions. Spectral analysis was performed and mean frequency computed for each band: delta (.25-4 Hz), theta (4-8 Hz), alpha1 (7.5-9.5 Hz), alpha2 (9.5-12.5 Hz), beta1 (12-20 Hz), and beta2 (20-70 Hz). The study revealed that as age increased, spectral power in delta, theta and alpha2 bands decreased. However, the mean frequency of theta and beta2 increased. Polich's study also provides evidence of the age-related trend found in EEG despite the fact that the alpha (and beta) frequency bands in his study were truncated into smaller bands. Alpha and beta were separated into alpha1, alpha2, beta1 and beta2 frequency bands. Only alpha2 power and beta2 mean frequency was shown to significantly change with age.

Finally, Dustman et al. (1999) collected EEG data from 222 males aged 4-90 years. Three min of EEG was recorded from the participants while their eyes were closed from scalp sites C3, C4, O1 and O2. Spectral amplitudes were computed and divided into five frequency bands: delta (1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta1 (13-20 Hz), and beta2 (20-30 Hz). They computed four measures of EEG activity: absolute amplitude (absAmp), relative amplitude (relAmp), spectral amplitude variability (ampCV), and mean frequency (mnHz). For absolute activity, occipital delta and alpha peak amplitude declined with age. A general trend was found such that central sites exhibited greater absAmp than occipital sites for all bands except alpha. They also found that relative alpha decreased with age while relative beta1 and beta2 increased. This trend was also larger in the central than occipital region. As for ampCV, theta increased while alpha and beta2 decreased. Lastly, mean frequency showed an increase in the theta and beta2 bands.

The results from Dustman et al. (1999) along with the other studies cited above yield an inconclusive pattern characterized by a debate regarding the reduction in low frequency power and the increase in high frequency power with age. Of approximately 60 tests in the studies summarized above there were 12 findings reporting a decrease in low frequency power and one reporting an increase were found (Breslau et al., 1989; Duffy, McAnulty, & Albert, 1993; Dustman et al., 1999; Koyama, 1996; Marciani et al., 1994; Polich, 1997; Roubicek, 1977; Williamson, 1990). A large proportion of the tests performed in the studies showed no relationship between age and low-frequency power. However, of those tests that did find a significant relationship, the majority revealed a negative association between age and spectral power (i.e. decreased power with age).

The picture for high frequency power is also inconclusive. Out of approximately 60 tests performed in the studies, there were seven findings in which an increase in high frequency power was found and three of 60 tests found a decrease (Anokhin et al, 1996; Dustman et al., 1999; Koyama et al., 1997; Marciani, 1996; Polich, 1997; Roubicek, 1977; Williamson et al., 1990). The reported increases in high-frequency power may be due to a compensatory aging effect (Ray and Cole, 1985).

Although inconclusive, the overall mixed picture of the findings reported for high frequency activity is also potentially theoretically consistent with the possibility that high frequency activity compensates for low frequency decline in tasks that are not demanding. A compensatory increase combined with an aging decrease would be expected to cause a non-linear change in high frequency activity. As a result, the differences associated with age are of less magnitude because the directional effects of compensation (positive) and aging (negative) and therefore age-related differences would be hard to detect and possibly reversed.

In general, there are also many reasons that may account for the variability found in these studies. Some of these differences involved site location, electrode reference, sample size, age range, EEG recording time, and participant health. Therefore, there are potentially many methodological reasons for the variability of the findings in the studies above. Only factors that displace studies not consistent with the main trends were addressed to keep the present article length reasonable.

One major methodological concern shown to influence EEG activity is the mental and physical health of the study participants. Koyama et al. (1996) addresses this issue directly in his study. A few studies did not rigidly screen their participants for age-related pathology or disease that might go unnoticed in behavioral tests. Because studies on dementia and other neuropathology show similar spectral changes, the changes reported in studies that do not screen their subjects are likely to be the result of the disease rather than the normal aging process (Duffy et al., 1984; Holschneider et al., 1995 Koyama et al., 1997). Roubicek (1977) was the only study to report increased relative beta power and participants in that study were not screened for health, which suggests that her results are due to pathology rather than age.

Recording time is the factor may have affected the results of Williamson's study. Most of the studies cited above recorded continuous EEG for about 3 minutes, however Williamson only recorded 20 seconds. This may be too short of a time interval to capture the shifts in activity accurately. If the change in brain activity is small (which it most likely is), more time is needed to cancel out the noise and amplify the signal.

Breslau's study had a different methodological problem: sample size. Whereas many studies had up to 220 participants, Breslau had the smallest number: 25 (15 elderly, 10 young). It is not clear, that a sample that size is representative of the elderly population and therefore different results may have been shown had more subjects been added. Therefore, each of the three above studies had a confounding methodology factor that may have caused their contradictory findings.

The studies that found an increase in beta activity (Dustman et al., 1999; Anokhin et al., 1996; Koyama et al., 1997; Marciani et al., 1994) all screened their subjects for pathology and/or disease, recorded EEG for at least 3 minutes, and all larger sample sizes ranging from 60 to 230 participants. Therefore, the findings from these four studies seem more credible.

Spectral amplitude Variability and Mean Frequency

There are two other indexes of spectral power that may reflect changes in neurocognitive processes: spectral amplitude variability and mean frequency. Spectral amplitude variability (CV) is an index of variation in amplitude across the spectrum or within a given band in the spectrum. It ranges between 0 and 1. In terms of neurophysiology, it means that the more that there is distinctness in the amplitude associated with neurogenerators that oscillate at different frequencies (Dustman et al., 1999). It has been shown to decline with age which would imply a redistribution (re-weighting) of the neural oscillators that contribute to the surface recorded EEG power while higher oscillators contribute more a redistribution generators oscillating at different frequencies and a reduction (Dustman et al., 1999).

Mean frequency (MF), another EEG index is the sum of amplitudes within a given band (Dustman et al., 1999). It is considered the “center of gravity” as it estimates the frequency that is contributing most to the amplitude of a given frequency band. It also is commonly considered to reflect how hard the brain is working during activation.

Exercise Effects on the Aging Brain

Theoretically, it is reasonable to expect that exercise would bring about such neurophysiological changes because improvements in the cardiovascular system are highly coupled to improvements in the central nervous system. The CNS relies on the cardiovascular system for the transport and delivery of these essential nutrients. Furthermore, adequate supplies of these nutrients are essential for neural metabolism. If there were a decline in glucose or oxygen, energy production would be compromised. For those reasons, it would be expected that improvements in cardiovascular efficiency such as improvements in blood flow and/or increases in metabolism function directly affect CNS function. In the elderly where the metabolism of the brain has exhibited an age-related decline, it is reasonable to expect that any aerobic exercise that improves cardiovascular fitness would also alter the age-related changes in cerebral metabolism. In this manner exercise is theorized to protect CNS health from the decline associated with the normal aging process.

Studies regarding the relationship between fitness and cognition as well as neurobiology of aging suggest that exercise will enhance the integrity of the mechanisms underlying age-related decline in cognitive function (Coffey et al., 1992; Etnier et al., 1997; Jernigan et al., 2001; Morrison et al., 1997; Tomporowski & Ellis, 1986). Mechanisms providing support of a causal link between the beneficial effects of exercise and cognitive functioning include cerebral blood flow, neurotransmitters, and changes in the brain structures such as vasculature density (Blacks et al., 1990; Chodzko-Zajko, 1991; Isaacs, Anderson, Blacks, & Greenough, 1992; Madden, Blumenthal, Allen, &

Emery, 1989). This section will cover the literature that provides evidence of the notion that exercise can influence neurocognitive function.

Research studies with animals have discovered mechanisms that may explain how exercise positively influences neurobiological changes in the brain. In Dustman's (1994) review of cognitive-neuropsychological function, several animal studies with rodents and dogs are reported which confirm that chronic exercise creates fundamental neurobiological alterations in the brain structure, neurotransmitters, vasculature, and exhibition/inhibition ratios within the nervous system. Isaacs (1992) reported that in rats, vigorous aerobic exercise increased angiogenesis in the cerebellar cortex and the generation of blood vessels to meet the increased metabolic demands of the brain. Cotman and Engessar-Ceasar (2002) reports, "exercise in animals increases brain derived neurotrophic factor (BDNF), a molecule that increases neuronal survival, enhances learning, and protects against cognitive decline." Additionally, animal studies show that exercise, even if it begins in middle age, might alter neurophysiological age-related changes such as DA loss (Dustman et al., 1994; Spirduso, 1980).

A longitudinal study by Rogers et al. (1990) examining the effects of physical activity on cerebral perfusion in human adults 62–70 years of age provided evidence that exercise attenuates aging effects on brain metabolism (via blood flow) and cognition in humans. Physically inactive retirees exhibited significant declines in CBF and lower scores on cognitive testing than physically active retirees. The exercising elderly adults maintained their levels of blood flow and consequently attenuated the normal aging affect of CBF decline. Additionally, exercise has been reported to maintain both reactive capacity (reaction time) and cognitive performance in the elderly (Spirduso, 1980, 1983;

Dustman et al., 1994; Blumenthal, 1988; Shay & Roth, 1992; Laurin et al., 2001; bon Von Boxtel et al., 1997).

Cross-sectional exercise studies further support the beneficial effects of exercise on brain function. The results of the studies suggest that aspects of cognitive performance (memory search, visual spatial tasks and cognitive speed) are highly related to a fitness level acquired over extended periods of training (Blumenthal, 1988; Shay & Roth, 1992; Madden et al., 1989; Von Boxtel et al., 1997) compared to monthly periods of training. However, longitudinal intervention studies in this area are rare and difficult to do. As a result, cross-sectional studies have been used to build the evidence for the strong positive relationship found between physical activity and cognitive neuropsychological performance (Dustman et al., 1994). This introduces an inherent design tradeoff in which intervening variables that may influence cognitive performance therefore cannot be systematically ruled out in order to get longer time periods of effect. However, until longer cross-sectional studies are feasible, cross-sectional studies offer the best available evidence of the beneficial effects of exercise.

Collectively, this literature presents evidence of neural mechanisms that may explain the relationship between exercise and brain function. In aging populations, such effects of exercise should attenuate the age-related decline in brain function because these studies demonstrate that exercise augments aspects of brain function shown to decline with age such as cerebral metabolism and neurotransmitters.

Exercise Effects in EEG

In light of the fact that exercise attenuates the reduction of cerebral metabolism that accompanies benign aging, it is reasonable to assume that exercise would reduce age-related changes in EEG (i.e. maintain low-frequency power and attenuate increases in high frequency power). However, little research has been done regarding the effects of exercise on EEG spectral power in aging populations. There are some ERP studies that evidence a link between exercise and EEG, however investigation of EEG spectral analysis is generally lacking in that literature. Lardon and Polich (1996) showed that the alpha power of young adults who participated in regular exercise was higher than with low-exercising cohorts. However, that study did not address any age-related changes.

There is a need to examine the EEG of elderly people who vary in physical activity to determine if long-term aerobic training maintains electrocortical activity and cognitive functioning in older adults. In light of the association between EEG and exercise in young participants, that association may be more robust within the elderly. If a positive association exists, then long-term aerobic training may be used as a preventive measure against age-related losses in cognitive and CNS functioning.

CHAPTER III

Method and Procedures

This chapter will describe the method and procedures used to investigate the effects of age and fitness on EEG activity during rest conditions in participants 18-80 years of age. Individual sections will include the following: (1) subjects; (2) assessment of training status; (3) procedures; (4) EEG data acquisition and recording, which is divided into electrode preparation, EEG recording procedures, and data acquisition subsections; (6) EEG signal processing; (7) data analysis; and (8) statistical analysis.

Participants

Participants aged 55-80 years were asked to volunteer from the community and were classified according to fitness: low-fit, moderate-fit, and high-fit. Younger participants aged 18-30 years were recruited from varsity track and field teams and classes from University of Maryland. In the old age group, participants were selected to the high-fit group based on their ranking in the Washington Running Report, a running publication from the Washington DC area. The elderly participants in the mod- and low-fit groups were solicited from the Prince George's College Senior classes and regular classes. The young and elderly participants in the three fitness groups were matched for education and age (see Results-Participant Characteristics). All participants were screened for psychological, cardiovascular, pulmonary, cerebrospinal disease via personal interview using a modified form of the Patient’s Personal History form (American Society of Internal Medicine, 1978; Appendix B) and an activity history questionnaire (Appendix A). Self-activity level and any medications affecting the central nervous system were additionally screened.

Assessment of Training Status

A self-report measure was initially used to screen and accept participants into low, moderate, and high fitness groups. If the participant’s amount of weekly exercise was below the minimum standards for aerobic training as reported by the American College of Sports Medicine (ACSM, 1990), he/she were placed into the low fitness group. The ACSM (1990) standards include the following: any activity utilizing large muscle groups of an intensity of 60-90% of maximal heart rate of duration of 20-60 min of continuous aerobic activity occurring 3-5 days a week.

The aerobically trained high group had the following criteria: for the most recent 10 years of life, individual aerobic activity occurred at least five times a week for a duration of no less than 45 min for a sustained period. Additionally in the past year, participants must have successfully completed a 10-Kilometer race in the past year below 50 min putting them in the top half of their age group in ability level. A participant was classified into the moderately fit group if he/she trained 3-4 times a week for duration of 20-40 minutes.

The activity history questionnaire was used to further verify the established aerobic training status. The questionnaire required each participant to report the six activities engaged in most frequently during the past year. The energy expenditure per min in k-Cal was calculated for each activity using a conversion table (McArdle, Katch & Katch, 1986). The expenditure per min was multiplied by the average number of minutes the participant participated in each activity session and then was multiplied by the average number of activity sessions the participant participated in each week. The weekly total was divided by seven to obtain the average Kcal expenditure/day. Should participants report anaerobic activity, an average Kcal expenditure/day was calculated separately for anaerobic activities.

To directly measure aerobic capacity, older participants performed a submaximal exercise test to estimate aerobic capacity, which consisted of walking on a motorized treadmill. The younger participants performed a full VO2 max test to estimate aerobic capacity

A fitness index across age and gender was created by adding the numbers from initial fitness categorization (called subjective fitness), aerobic average Kcal expenditure per day, anaerobic average Kcal expenditure per day, and the results from submax test (elderly) or VO2 max test (young) of aerobic capacity. Those four measures were summed with varying weights attached to each measure and each measure was normalized across gender and age. The weights were as follows: 40% for subVO2 max, 25% for participant fitness categorization, 25% for aerobic Kcal total, and 10% for anaerobic Kcal total.

Procedures

Participants were contacted by telephone and were asked to participate in a study investigating the effects of aerobic training status on the CNS. Following the health screening, participants were asked to attend two testing sessions. Each testing session included three phases. Day I involved obtaining the participant's informed consent completing an activity history questionnaire and familiarizing the participant with the electrode cap and other equipment used in EEG activity data collection and Visuospatial/Analytical cognitive tasks. Day II consisted of electrode preparation and EEG data collection during two seated resting conditions: eyes-open and eyes-closed; and during two seated mental challenge conditions: visual spatial and analytical. Participants were thanked at the conclusion of the testing session and later mailed a one-page abstract informing them of the results of the study.

EEG Data Acquisition and Recording

Participants were seated in a soundproof chamber in a comfortable chair to prepare for EEG collection. EEG activity was collected from frontal, central, parietal, occipital, and temporal placements according to the international 10-20 system of electrode placement (Jasper, 1958). The electrodes (see pg. 21) were referenced to linked ears (A1 and A2) and appropriately grounded (Fpz). In order to detect ocular artifact, two electrodes were placed above and below the right eye (VEOG) and on external canthi (HEOG).

Electrode Preparation

The electrodes were prepared in the following order: (1) reference electrodes, A1 and A2; (2) frontal, central, parietal, occipital, and temporal electrodes (Fz, Pz, Cz, O1, O2, C3, C4, T3, and T4) and ground electrode, Fpz; and (3) ocular electrodes, vertical electro-oculogram (VEOG) and horizontal electro-oculogram (HEOG). The participant preparation used all the necessary materials and procedures (Instruction Manual for the Electro-Cap International (ECI) Electro-Cap Electrode System, pp. 11-34, 1983). The process is described below.

First, the earlobes were swabbed with alcohol, abraded using a cotton swab of redux paste, cleaned once more with alcohol, lightly abraded with fine sand paper and cleaned a final time with alcohol. A blunted 26-gauge needle, attached to a syringe, was inserted through a hole in the electrode and rapidly rocked back and forth to provide further abrasion to the earlobe. At the same time, a conducting gel was inserted between the electrode and the prepared site by the syringe. The gel contact with the prepared skin surface will allow electrical conductance from the earlobe to the electrode.

After ear preparation, participants were fitted with an appropriate sized ECI cap, which will contain the recessed frontal, parietal, central, occipital, and temporal electrodes. In order to place the cap accurately on the head, the distance between the nasion to the inion was measured to calculate a reference point. The nasion is the anatomical place at which the nose connects to the forehead. The inion is the bony protuberance located in the center of the posterior portion of the skull. Ten percent of the nasion-to-inion distance was measured and marked centrally on the forehead with a grease pen, proximally to the nasion. This point of reference was used to anchor the cap and place the cap so the electrodes were accurately positioned according to the international “10-20” system of electrode placement.

Two 1.9 cm diameter adhesive foam pads attached to the unused FP1 and FP2 electrodes will anchor the cap. Two elastic straps that attach to the cap near the ears and secure into an elastic fastening belt encircling the chest will also help anchor the cap. Other adjustments to the cap were necessary to ensure precise placement on the head. The inion to the nasion was measured from the preauricular point of the left ear to the preauricular point of the right ear so that electrode CZ was positioned exactly in the middle of the head. The preauricular points are dimples located superior to cartilage, which covers the external ear opening. The needle rocking technique described above ensured electrical conductance between the scalp surface and the electrodes.

The electrodes used for ocular artifact detection were placed using surgical tape around the right eye both vertically (VEOG), above the pupil and eyebrow, and horizontally (HEOG), near the temple. These sites had the same preparation as the reference electrodes.

Lastly, impedance for the frontal, parietal, central, occipital, and temporal sites was maintained below 5000 Kohms. The ocular electrodes had a 10,000-ohm impedance criterion.

EEG Recording Procedures

The door to the soundproof chamber was closed once electrode preparation has finished. Participants will sit quietly and relaxed with their hands in their lap. The participant was asked to close his/her eyes, open his eyes and blink rapidly for various time intervals while the incoming EEG signal is visually checked. If any signal recording problems were detected, the electrode preparation was corrected.

The study had two resting conditions: eyes-closed (EC), eyes-open (EO). Both resting conditions (EC and EO) lasted for approximately four minutes in which the participant sat quietly with his/her hands on their lap. The lights remained on for the eyes-open condition but the lights were turned off for the eyes-closed condition. In order to minimize eye movement participants were asked to keep their head still and focus on a distance of 5-feet directly in front of them. Additionally for the eye-closed condition, participants were asked to keep their eyes focused on a distance of 5-feet directly in front of them. As well, participants were asked to remain awake, yet relaxed and to think emotionally neutral thoughts. Once the participant is in position for EEG collection, a 10-sec delay occurred and then collection started. No sounds were made during the 4-min collection period. To signal completion of the data sampling the words, “OK, you can relax.” was used.

The cap and electrodes were removed from the participant once the EEG collection finishes. Each electrode site was cleaned to prevent infection. In order to ensure cleanliness of the electrode cap assembly, a sterile needle for each participant was used and all the instruments were washed in Ivory dishwashing soap as indicated by the manufacturer.

Data Acquisition

The raw EEG activity was amplified 20,000 times (by a Model- 12 Neurodata Acquisition System, made by Grass Instruments Company: Sterling, VA) in order to increase resolution of the signal. The electrode sites FZ, CZ, Pz, O1, O2, C3, C4, T3, and T4 were referenced to two head electrodes, A1 and A2. The data was converted from analog to digital (A-D conversion) at a rate of 128 samples per sec.

EEG Signal Processing

The following six steps will be completed using Matlab 5.3 (Englewood Cliffs, NJ). For each participant the number of 2-sec epochs was held between 20-40 epochs in order to keep the variance between participants consistent. In addition, the Matlab files were referenced to linked leads as follows: Fz, Cz, Pz, O1, 02, C3, C4, T3, T4. Additionally power spectral density (PSD) was estimated on each 2-second epoch using a Thomson multitaper method (MTM) that specifies a sampling frequency in Hz and returns the power spectral density in units of power per Hz. The MTM used 3.5 tapers to estimate 512 points of data (sampling frequency of 256, 4 windows). Relative power (RP), amplitude variability (CV), and mean frequency (MF) in theta (4-7.5), alpha1 (8-9.5), alpha2 (10-12.5), beta1 (13-19.5), and beta2 (20-30) frequency bands were calculated. Fourier transforms were performed for the linked data. The power variables were calculated using the following formulas: 1) Relative power ($\ln(x/(1-x))$ where x = percentage of total amplitude across bands), 2) Spectral amplitude variability (stdev(amplitudes comprising a band)/mean(amplitudes)), 3) Mean frequency (sum(amp(f)xf)/sum(amp(f)) where amp(f) = amplitude of each frequency.

Data Analysis

The demographic variables age and education were subjected to a 2 x 3 x 2 (Age x Fitness x Gender) MANOVA. Additionally, for both test conditions (resting and cognitive challenge) each of the power spectral estimates within each EEG frequency bin were separately subjected to a 2 x 3 x 9 x 2 (Age x Fitness x Site x Task) MANOVA with repeated measures on the last factor. The 2 x 3 x 9 x 2 MANOVA was applied separately to the resting conditions (eyes-open vs. eyes-closed) and the cognitive challenges (mental arithmetic vs. embedded-figures) Because each analyses was applied to each of five frequency bands (alpha1, alpha2, beta1, beta2) there was total of ten analyses. Because of the exploratory nature of the work alpha level was set to .05 for each analysis. Tukey's HSD was used to complete post hoc testing. There were different numbers of observations for some components as, in some cases, a component was not observable in a participant's record. Thus, the degrees of freedom reported for the spectral analyses vary. SPSS version10 was employed to conduct all statistical analyses.

CHAPTER IV

Section A

Results During Resting Conditions

The purpose of this study was to assess the effect of age and fitness on spectral power estimates throughout a continuum of cognitive challenge conditions ranging from resting conditions to spatial and analytical tasks. This chapter has three sections. Section A presents the results for the resting conditions (eyes-open and eyes-closed). The results for the eyes-open and eyes-closed tasks are presented in the following sections: (1) descriptive statistics of the participants, (2) analysis of group variables, (3) and spectral EEG analysis during resting conditions. Section B will present the results for the cognitive challenges and the results will be organized in the same format. Lastly, Section C will present the discussion of the results presented in the first two sections.

Participant Characteristics

The mean (± SD) participant characteristics for men and women within each age and fitness group can be seen in Table 1. The average age for the older participants was 68.8 years (SD = 4.44), while the young were aged 21.9 years (SD = 3.09). For the low-, moderate-, and high-fit groups, the average age was respectively 43.8 (SD = 24.16), 44.3 (SD = 24.14), and 36.7 (SD = 22.56) years. The average number of years of education for elderly participants was 15.4 years (SD = 3.02) which was similar to the mean number of 15.6 years (SD = 2.12) for young participants. In the low-, moderate-, and high-fit groups the average years of education was 15.6 (SD = 2.50), 15.0 (SD = 2.50), and 16.0 (SD = 2.55) years respectively.

Table 1. Mean values of age and education for participants grouped on the basis of young, old, male, and female.

				Age		Education	
Fit	Age	Gender	N	Mean	SD	Mean	SD
Low	Young	Male	7	22.16	1.86	16.46	1.27
		Female	8	23.25	3.37	15.50	1.41
		Total	15	22.74	2.74	15.95	1.39
	Old	Male	3	70.00	4.36	17.33	2.31
		Female	9	70.22	2.22	14.40	3.56
		Total	12	70.17	2.66	15.13	3.46
	TOTAL	Male	10	36.51	23.25	16.72	1.56
		Female	17	48.12	24.32	14.92	2.75
		TOTAL	27	43.82	24.16	15.59	2.50
Moderate	Young	Male	1	26.00	.[†]	15.00	.[†]
		Female	10	20.50	1.95	14.40	1.32
		Total	11	21.00	2.49	14.45	1.27
	Old	Male	3	65.33	9.02	19.00	1.00
		Female	8	68.38	3.29	14.31	2.86
		Total	11	67.55	5.087	15.59	3.28
	TOTAL	Male	4	55.50	21.00	18.00	2.16
		Female	18	41.78	24.61	14.36	2.08
		TOTAL	22	44.27	24.14	15.02	2.49
High	Young	Male	10	21.30	3.37	15.80	2.81
		Female	7	22.57	4.20	16.38	2.97
		Total	17	21.82	3.66	16.04	2.90
	Old	Male	0	.	.	.	.
		Female	8	68.38	5.53	15.90	2.10
		Total	8	68.38	5.53	15.90	2.10
	TOTAL	Male	10	21.30	3.37	15.80	2.81
		Female	15	47.00	24.13	16.12	2.46
		TOTAL	25	36.72	22.56	15.99	2.55

Analysis of Group Variables

The demographic variables: age and education, were subjected to a 2 x 3 x 2 (Age x Fitness x Gender) MANOVA. The analysis revealed no significant differences between the fitness groups in terms of age. However, there was a significant gender main effect obtained for years of education, F (1, 74) = 6.23, $p < .05$. The analysis revealed that male participants (M = 16.6, SE = 2.30) had significantly more years of education than female participants (M = 15.1, SE = 2.49).

Spectral Analysis Components during Resting Conditions

For resting test conditions each of the power spectral estimates within each EEG frequency bin were separately subjected to a 2 x 3 x 9 x 2 (Age x Fitness x Site x Task) MANOVA with repeated measures on the last factor. The dependent variables were relative power (RP), mean frequency (MF), and amplitude variability (CV). MANOVAs were performed on the EEG data to determine if there were any significant associations between the factors in each of five frequency bins: theta (4-7.5 Hz), alpha1 (8-9.5 Hz), alpha2 (10 -12.5 Hz), beta1 (13-30 Hz) and beta2 (20-30 Hz).

The means of the relative power, spectral variation and mean frequency EEG parameters in the two age groups are presented in Tables 2, 3, and 4.

Table 2. Mean values of RP for participants in the three different fitness levels for young and old groups during resting conditions.

Age group	Young							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	-1.255	.113	-1.093	.132	-1.053	.106	-1.134	0.117
Alpha1	-.648	.092	-.453	.107	-.494	.086	-0.532	0.095
Alpha2	-.879	.094	-1.265	.110	-1.156	.088	-1.100	0.097
Beta1	-2.781	.123	-2.721	.144	-2.866	.116	-2.789	0.128
Beta2	-3.826	.155	-3.786	.181	-3.836	.146	-3.816	0.161
Age group	Old							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	-1.337	.126	-1.655	.132	-1.509	.155	-1.500	0.138
Alpha1	-.541	.103	-409	.107	-.646	.126	-0.532	0.112
Alpha2	-1.161	.105	-.991	.110	-1.091	.129	-1.081	0.115
Beta1	-2.387	.138	-2.325	.144	-1.841	.169	-2.184	0.150
Beta2	-3.259	.174	-3.391	.181	-3.089	.213	-3.246	0.189

Table 3. Mean values of RP for participants in the three different fitness levels for young and old groups during resting conditions

Age group	Young							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	.234	.036	.294	.042	.234	.034	0.254	0.037
Alpha1	.190	.021	.134	.025	.145	.020	0.156	0.022
Alpha2	.344	.043	.428	.050	.430	.041	0.401	0.045
Beta1	.439	.034	.307	.040	.280	.032	0.342	0.035
Beta2	.518	.035	.474	.041	.500	.049	0.497	0.042
Age group	Old							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	.376	.040	.375	.042	.323	.049	0.358	0.044
Alpha1	.142	.024	.137	.025	.114	.029	0.131	0.026
Alpha2	.338	.048	.409	.050	.256	.059	0.334	0.052
Beta1	.232	.439	.207	.040	.257	.047	0.232	0.175
Beta2	.377	.040	.467	.041	.500	.049	0.448	0.043

Table 4. Mean values of MF participants in the three different fitness levels for young and old groups during resting conditions

Age group	Young							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	5.793	.061	5.920	.071	5.822	.057	5.845	0.063
Alpha1	8.818	.015	8.754	.017	8.781	.014	8.784	0.015
Alpha2	11.007	.034	10.944	.040	10.927	.032	10.959	0.035
Beta1	15.693	.070	15.822	.082	15.850	.066	15.788	0.073
Beta2	23.627	.095	23.844	.111	23.611	.089	23.694	0.098
Age group	Old							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	5.919	.068	6.009	.071	5.992	.084	5.973	0.074
Alpha1	8.769	.017	8.802	.017	8.776	.020	8.782	0.018
Alpha2	11.001	.038	10.947	.040	11.074	.047	11.007	0.042
Beta1	15.888	.079	15.948	.082	15.919	.096	15.918	0.086
Beta2	23.971	.106	23.765	.111	23.611	.130	23.782	0.116

Table 5.

Relative Power	Theta		Alpha1		Alpha2	
Source	df	*F*	df	*F*	df	*F*
Age	1, 68	**12.31	1, 68	.00	1, 68	.049
Fit	2, 68	.291	2, 68	1.42	2, 68	.701
Task	1, 68	**14.54	1, 68	**48.55	1, 68	*2.05
Site	2.5, 239.5	**88.85	4, 271.3	**13.95	3.8, 261.6	**64.79
Fit x Age	2, 68	2.06	2, 68	.838	2, 68	*3.68
Task x Age	1, 68	.99	1, 68	3.84	1, 68	3.68
Task x Fit	2, 68	1.90	2, 68	.730	2, 68	1.41
Site x Age	3.5, 239.5	**11.78	4, 271.3	*3.11	3.8, 261.6	**10.65
Site x Fit	7, 239.5	.532	8, 271.3	.79	7.7, 261.6	.53
Site x Task	4, 275.3	**23.65	3.4, 230.6	1.96	4, 269.1	*4.45
Fit x Task x Age	2, 68	2.87	2, 68	.627	2, 68	*3.34
Fit x Site x Age	7, 239.5	.250	8, 271.3	1.14	7.7, 261.6	.55
Site x Task x Age	4, 275.3	.388	3.4, 230.6	.642	4, 269.1	1.18
Fit x Site x Task	8.1, 275.3	.775	6.8, 230.6	.514	7.9, 269.1	.45
Site x Fit x Task x Age	8.1, 275.3	.543	6.8, 230.6	1.62	7.9, 269.1	.96

*p<.05.
**p<.001.

Table 5 (continued).

Relative Power	Beta1		Beta2	
Source	df	*F*	df	*F*
Age	1, 68	**28.00	1, 68	**15.65
Fit	2, 68	1.46	2, 68	.25
Task	1, 68	**90.23	1, 68	**145.5
Site	4, 271.5	**29.01	4.6, 309.7	**49.47
Fit x Age	2, 68	*3.27	2, 68	.47
Task x Age	1, 68	.01	1, 68	.003
Task x Fit	2, 68	1.28	2, 68	1.24
Site x Age	4, 271.5	*3.14	4.6, 309.7	*2.79
Site x Fit	8, 271.5	.67	9.1, 309.7	1.48
Site x Task	3.9, 265.4	**6.23	4, 269	*9.11
Fit x Task x Age	2, 68	.74	2, 68	.16
Fit x Site x Age	8, 271.5	1.37	7.7, 309.7	1.55
Site x Task x Age	3.9, 265.4	2.03	4, 269	1.99
Fit x Site x Task	7.8, 265.4	.563	7.9, 269	.59
Site x Fit x Task x Age	6.9, 265.4	.84	7.9, 269	.75

*p<.05.
**p<.001.

EEG Relative Power (RP)

Table 5 contains the effects found across the relative power (RP) spectral measures computed during resting conditions. All main effects are reported for RP in the following section, however, only the fitness-related or age-related significant interactions are reported for the sake of brevity.

Theta RP

There were main effects for age, task and site within the theta band found to be significant by statistical analysis. Theta relative power was lower in the older group than in the younger participants, $p < .001$. Frontal and central sites had higher magnitudes of

RP compared to other sites, especially PZ, O1 and O2, *p* < .001. Lastly, during the two resting tasks, participants had less theta RP during the eyes-closed condition than the eyes-open condition, *p* < .001. There were no significant main effects for Fitness.

Alpha1 RP

Within the alpha1 band, statistical analysis revealed main effects for task and site. Parietal and occipital sites had higher magnitudes of RP compared to other sites, especially temporal sites T3 and T4, *p* < .001. Lastly, during the two resting tasks, participants had more alpha1 RP during the eyes-closed condition than the eyes-open condition, *p* < .001. There were no significant main effects for Fitness.

Alpha2 RP

Statistical analysis revealed the Fitness x Task x Age interaction was significant in only the alpha2 band, *p*< 0.05. In the young group, the general pattern observed was that the amount of relative alpha2 power was higher in the EC condition than the EO condition. However, post hoc analysis revealed that the increase from eyes-closed to eyes-open was statistically significant only in the young, low-fit subgroup. Post hoc analysis also revealed that between the two tasks, this subgroup (young, low-fit) demonstrated the highest amount of alpha2 RP compared to any of the other subgroups.

Additionally there were significant interactions between Age x Fitness in the alpha2 band revealed by the analysis, *p*<.05. Although post hoc analysis revealed no statistically significant differences for the any of the groups' means, the general pattern of behavior of the means demonstrated a significant effect. In general, the young participants' relative alpha2 power decreased in a non-linear fashion with increasing fitness level (the mod-fit group had the lowest amount), while relative alpha2 power showed a modest non-linear increase from low to high fitness for the elderly participants (the mod-fit group had the highest amount).

The statistical analysis revealed only one main effect: Site, $p < .001$. Parietal and occipital sites (PZ, O1 and O2) had higher magnitudes of RP compared to other sites (FZ, CZ, C3, C3, T3, and T4), $p < .001$. There were no significant main effects for Fitness.

Beta1 RP

Lastly for RP within the beta1 frequency band, statistical analysis revealed a Fitness x Age interaction effect, $p < .05$. Post hoc analysis revealed that the high-fit elderly presented differences in beta1 relative power that were significantly higher than the young participants at each fitness level.

Additionally, statistical analysis found main effects for age, task and site within the beta1 frequency band. Beta1 RP increased with age, $p < .001$. Participants had more beta1 RP during the EO condition than the EC condition, $p < .001$. Lastly, temporal sites had higher magnitudes of RP compared to other sites, $p < .001$. Sites C3 and C4 had the next highest levels of beta1 RP. There were no significant main effects for Fitness.

Beta2 RP

Lastly for beta2 RP, main effects for age, task and site. First, Beta2 RP was found to increase with age, $p < .001$. Secondly, participants had more beta2 RP during the EO condition than the EC condition, $p < .001$. Lastly, temporal sites had higher magnitudes of beta2 RP compared to other sites, $p < .001$. Site PZ had lowest amount of beta2 RP. There were no significant main effects for Fitness.

Table 6.

Amplitude Variability (CV)	Theta		Alpha1		Alpha2	
Source	df	*F*	df	*F*	df	*F*
Age	1, 68	*9.63	1, 68	1.57	1, 68	2.75
Fit	2, 68	.90	2, 68	1.34	2, 68	1.40
Task	1, 68	**17.94	1, 68	*5.73	1, 68	*55.85
Site	3.5, 234.7	**88.85	2.2, 150.6	*18.94	3.5, 240.4	**13.54
Fit x Age	2, 68	.35	2, 68	.84	2, 68	1.78
Task x Age	1, 68	*4.46	1, 68	.09	1, 68	2.46
Task x Fit	2, 68	1.18	2, 68	*4.69	2, 68	.73
Site x Age	3.5, 234.7	*4.68	2.2, 150.6	1.12	3.5, 240.4	1.38
Site x Fit	7, 234.7	1.05	4.4, 150.6	.66	7.1, 240.4	.70
Site x Task	4, 207.8	*3.94	2.7, 186.2	*4.79	4.1, 280.7	*4.07
Fit x Task x Age	2, 68	2.06	2, 68	1.51	2, 68	.42
Fit x Site x Age	7, 234.7	.77	4, 150.6	.93	7.1, 240.4	1.23
Site x Task x Age	4, 207.8	*3.28	2.7,	.96	4.1, 280.7	1.28
Fit x Site x Task	8.1, 207.8	.78	5.5, 186.2	.86	8.3, 280.7	.86
Site x Fit x Task x Age	8.1, 207.8	.31	5.5, 186.2	.40	7.9, 280.7	.96

*p<.05.
**p<.001.

Table 6 (continued).

Amplitude Variability (CV)	Beta1		Beta2	
Source	df	*F*	df	*F*
Age	1, 68	**11.95	1, 68	.84
Fit	2, 68	2.55	2, 68	.25
Task	1, 68	**90.23	1, 68	**34.32
Site	4.9, 333.1	**10.84	3.9, 262.4	**27.19
Fit x Age	2, 68	2.97	2, 68	3.30
Task x Age	1, 68	.80	1, 68	.15
Task x Fit	2, 68	.51	2, 68	.27
Site x Age	4.9, 333.1	*3.70	3.9, 262.4	*2.51
Site x Fit	9.8, 333.1	.60	7.7, 262.4	1.11
Site x Task	2.7, 184.1	2.33	5, 337.2	1.63
Fit x Task x Age	2, 68	.81	2, 68	.01
Fit x Site x Age	8.5, 333.1	1.61	7.7, 262.4	1.22
Site x Task x Age	2.7, 184.1	1.01	5, 337.2	.92
Fit x Site x Task	5.4, 184.1	.45	9.9, 337.2	1.39
Site x Fit x Task x Age	5.4, 184.1	.57	9.9, 337.2	.55

*p<.05.
**p<.001.

EEG Amplitude Variability (CV)

The results for CV under resting conditions are reported in Table 6. Table 6 contains the significant effects found across the amplitude variability (CV) spectral measures computed from resting conditions. All main effects are reported for CV in the following section, however; only the fitness-related or age-related significant interactions are reported for the sake of brevity.

Theta CV

Statistical analysis found significant main effects for age, task and site within the theta band for CV. Theta amplitude variability increased with age, $p < .05$. Occipital and parietal sites (O1, O2, and PZ) demonstrated higher magnitudes of CV compared to other sites, $p < .001$. Lastly, during the two resting tasks, participants exhibited more theta CV during the eyes-closed condition than the eyes-open condition, $p < .001$. There were no significant main effects for Fitness.

Alpha1 CV

Statistical analysis found the Fitness x Task interaction significant at the $p > .05$ level. Post hoc analysis revealed that low-fit participants demonstrated a significant increase in alpha1 CV during the eyes-closed condition compared to the eyes-open condition. This increase was not exhibited by any of the other fitness groups.

As for alpha1 CV, statistical analysis found main effects for task and site. Parietal and occipital sites displayed higher magnitudes of CV compared to other sites, $p < .001$. Lastly, during the two resting tasks, participants exhibited more alpha1 CV during the eyes-closed condition than the eyes-open condition, $p < .05$. There were no significant main effects for Fitness.

Alpha2 CV

The statistical analysis revealed two main effects: site, $p < .001$, and task, $p < .05$. Temporal sites (T3 and T4) displayed the lowest magnitudes of CV compared to other sites, $p < .001$. Additionally, participants reported more alpha2 CV during the EC condition compared to the EO condition. There were no significant main effects for Fitness.

Beta1 CV

As for the CV main effects, statistical analysis found main effects for age, task and site within the beta1 frequency band. Beta1 CV increased with age, $p < .001$.

Participants exhibited more beta1 CV during the EC condition than the EO condition, $p < .001$. Lastly, parietal and occipital sites (PZ, O1, and O2) displayed higher magnitudes of CV compared to other sites, $p < .001$. There were no significant main effects for Fitness.

Beta2 CV

The statistical analysis also revealed a significant Fitness x Age interaction, $p < .05$. However, post hoc analysis revealed that no individual differences between the group means were significant.

Lastly for CV, statistical analysis found main effects for task and site within the beta2 frequency band. Secondly, participants displayed more beta2 RP during the EC condition than the EO condition, $p < .001$. Lastly, temporal sites exhibited lower magnitudes of beta2 RP compared to other sites, $p < .001$. There were no significant main effects for Fitness.

Table 7.

Mean Frequency (MF)	Theta		Alpha1		Alpha2	
Source	df	*F*	df	*F*	df	*F*
Age	1, 68	*5.13	1, 68	.01	1, 68	2.30
Fit	2, 68	1.27	2, 68	.59	2, 68	1.44
Task	1, 68	**39.98	1, 68	3.37	1, 68	**49.31
Site	4.3, 294.9	**12.79	2.3, 156.5	**56.57	3.6, 247.8	**13.67
Fit x Age	2, 68	.16	2, 68	*4.28	2, 68	2.42
Task x Age	1, 68	1.20	1, 68	*5.26	1, 68	1.93
Task x Fit	2, 68	2.15	2, 68	.96	2, 68	.77
Site x Age	4.3, 294.9	**8.28	2.3, 156.5	**7.25	3.6, 247.8	.21
Site x Fit	8.7, 294.9	1.42	4.6, 156.5	.33	7.3, 247.8	.44
Site x Task	3.4, 234.1	*4.20	3.9, 264.4	**7.15	4, 268.9	1.67
Fit x Task x Age	2, 68	.84	2, 68	*3.82	2, 68	.64
Fit x Site x Age	8.7, 294.9	.63	4.6, 156.5	.29	7.3. 247.8	1.29
Site x Task x Age	3.4, 234.1	*4.72	3.9, 264.4	.73	4, 268.9	1.25
Fit x Site x Task	6.9, 234.1	.57	7.8, 264.4	.78	7.9, 268.9	.89
Site x Fit x Task x Age	6.9, 234.1	.40	7.8, 264.4	.62	7.9, 268.9	1.29

*p<.05.
**p<.001.

Table 7 (continued).

Mean Frequency (MF)	Beta1		Beta2	
Source	df	*F*	df	*F*
Age	1, 68	*3.98	1, 68	.08
Fit	2, 68	.99	2, 68	.51
Task	1, 68	.61	1, 68	**37.48
Site	5, 340.2	**10.92	4.3, 293.8	**32.37
Fit x Age	2, 68	.73	2, 68	*3.65
Task x Age	1, 68	.01	1, 68	.04
Task x Fit	2, 68	.02	2, 68	.75
Site x Age	5, 340.2	**5.00	4.3, 293.8	*3.97
Site x Fit	10, 340.2	.93	8.6, 293.8	1.14
Site x Task	3.5, 237.6	**6.80	4.3, 293.7	2.00
Fit x Task x Age	2, 68	.56	2, 68	.024
Fit x Site x Age	10, 340.2	1.81	8.6, 293.8	1.44
Site x Task x Age	3.5, 237.6	1.25	4.3, 293.7	2.04
Fit x Site x Task	5.4, 237.6	.90	8.6, 293.7	1.11
Site x Fit x Task x Age	7, 237.6	.62	8.6, 293.7	.74

*p<.05.
**p<.001.

EEG Mean Frequency

The results for MF under resting conditions are reported in Table 6.

Table 7 contains the significant effects found across the mean frequency (MF) spectral measures computed from resting conditions. All main effects are reported for MF in the following section, however, only the fitness-related or age-related significant interactions are reported for the sake of brevity.

Theta MF

Statistical analysis found significant main effects for age, task and site within the theta band for MF. Theta amplitude variability exhibited a smaller magnitude in the older group than in the younger group, $p < .05$. Parietal and occipital sites (PZ, O1 and O2) displayed higher magnitudes of MF compared to other sites, $p < .001$. Lastly, during the two resting tasks, participants exhibited more theta MF during the eyes-closed condition than the eyes-open condition, $p < .001$. There were no significant main effects for Fitness.

Alpha1 MF

For alpha1 MF, a significant three-way interaction, Fitness x Task x Age, was revealed through statistical analysis. Post hoc analysis confirmed that the young, low-fit participants exhibited the highest amount of MF compared to all other fitness levels in both age groups, $p< 0.05$. The older, mod-fit group displayed a non-significant increase in MF while the young, mod-fit group demonstrated a non-significant decrease in MF.

Statistical analysis also revealed a significant two way interaction between Fitness and Age, $p<0.05$. However post hoc analysis revealed that none of the differences between the groups were significant. The general pattern exhibited by the interaction was a non-linear decrease in alpha1 MF as fitness level increased for the young participants, while the elderly participants demonstrated a non-linear increase in alpha1 MF from low to high fitness.

As for alpha1 MF main effects, statistical analysis revealed only one main effect, which was for site. Parietal and occipital sites (PZ, O1, and O2) demonstrated higher magnitudes of MF compared to other sites, and sites Fz and CZ exhibited the lowest amount of alpha1 MF, $p < .001$. There were no significant main effects for Fitness.

Alpha2 MF

The statistical analysis revealed two main effects: site, $p < .001$, and task, $p < .001$. Temporal sites (T3 and T4) displayed the highest amount of alpha2 CV compared to all other sites, $p < .001$. There were no significant main effects for Fitness.

Beta1 MF

As for the MF main effects, statistical analysis found main effects for age and site within the beta1 frequency band. Beta1 MF decreased with age, $p < .05$. Lastly, temporal sites demonstrated the highest magnitudes of beta1 MF compared to other sites, $p < .001$. There were no significant main effects for Fitness.

Beta2 MF

For the beta2 frequency band, statistical analysis revealed a significant two-way interaction between Fitness and Age, $p<0.05$. However post hoc analysis revealed that none of the differences between the groups were significant. The general pattern exhibited by the interaction indicated a non-linear increase in beta2 MF with increasing fitness level for young participants and a linear decrease in beta2 MF as fitness level increased in the elderly group.

Lastly for MF, statistical analysis found main effects for task and site within the beta2 frequency band. Participants demonstrated less beta2 MF during the EC condition than the EO condition, $p < .001$. Also, temporal sites exhibited higher magnitudes of beta2 MF compared to other sites, $p < .001$. There were no significant main effects for Fitness.

Section B

Results During Cognitive Challenge

The purpose of this study was to assess the effect of age and fitness on spectral power estimates throughout a continuum of cognitive challenge conditions ranging from resting conditions to spatial and analytical tasks. This chapter presents the results for the cognitive challenge conditions (spatial and analytical) and is divided into results and discussion sections. The results during the challenge conditions are presented in the following subsections: (1) descriptive statistics and spectral EEG analysis, (2) analysis of group variables, (3) and spectral EEG analysis. The last subsection, EEG Spectral Analysis is further divided into three subsections: EEG relative power, EEG spectral amplitude variability, and EEG mean frequency. Lastly, this chapter presents the discussion section that incorporates both the resting and challenge conditions. This section discusses the reasons the predicted hypotheses were or were not supported. The discussion is separated into the following subsections: (1) manipulation checks, and mechanisms of group differences.

Participant Characteristics

Not all participants completed the four tasks. The group who completed the two cognitive challenges was somewhat different from the group that completed the two resting tasks; therefore participant characteristics for the cognitive challenges are summarized as follows. The mean (± SD) participant characteristics for men and women within each age and fitness group can be seen in Table 5. The average age for the older participants was 68.4 years (SD = 4.26), while the young were aged 21.6 years (SD = 2.77). For the low-, moderate-, and high-fit groups, the average age was respectively 54.3 (SD = 23.37), 46.7 (SD = 24.15), and 43.1 (SD = 23.70) years. The average number of years of education for elderly participants was 16.0 years (SD = 3.16) which was similar to the mean number of 15.9 years (SD = 2.99) for young participants. In the low-, moderate-, and high-fit groups the average years of education was 15.9 (SD = 2.99), 15.3 (SD = 2.81), and 16.5 (SD = 2.31) years respectively.

Table 8. Mean values of age and education for participants grouped on the basis of young, old, male, and female.

Fit	Age	Gender	N	Age Mean	SD	Education Mean	SD
Low	Young	Male	3	23.378	2.27	17.533	0.50
		Female	2	25.500	4.95	17.000	1.41
		Total	5	24.227	3.17	17.320	.844
	Old	Male	3	69.464	1.86	16.533	.924
		Female	6	71.667	2.58	14.333	4.13
		Total	9	70.932	2.50	15.067	3.48
	TOTAL	Male	6	46.421	25.31	17.033	.862
		Female	8	60.125	21.56	15.000	3.74
		TOTAL	14	54.252	23.37	15.871	2.99
Moderate	Young	Male	3	24.333	1.53	16.000	.00
		Female	9	20.320	1.80	14.718	1.45
		Total	12	21.330	2.46	15.039	1.37
	Old	Male	6	68.167	4.17	17.833	3.55
		Female	8	68.625	3.58	13.750	2.82
		Total	14	68.429	3.69	15.500	3.67
	TOTAL	Male	9	53.556	22.18	17.222	2.95
		Female	17	43.057	24.99	14.263	2.19
		TOTAL	26	46.691	24.15	15.287	2.81
High	Young	Male	8	20.875	2.53	15.627	2.05
		Female	7	20.857	2.67	16.239	2.90
		Total	15	20.867	2.50	15.913	2.40
	Old	Male	7	64.540	3.37	18.335	1.19
		Female	7	69.143	5.64	15.929	2.17
		Total	14	66.842	5.06	17.132	2.09
	TOTAL	Male	15	41.252	22.73	16.891	2.16
		Female	14	45.000	25.41	16.084	2.46
		TOTAL	29	43.061	23.70	16.501	2.30

Table 8 (continued)

Fit	Age	Gender	Age Mean	Age SD	Education Mean	Education SD
Overall (L,M,H)	Young	Male	22.152	2.65	16.115	1.70
		Female	21.109	2.85	15.563	2.21
		TOTAL	21.566	2.77	15.805	1.99
Overall (L,M,H)	Old	Male	66.823	3.92	17.809	2.31
		Female	69.667	4.18	14.643	3.06
		TOTAL	68.437	4.26	16.012	3.16
	Overall	Male	45.977	22.91	17.019	2.19
		Female	47.256	24.78	15.068	2.71
		TOTAL	46.700	23.82	15.916	2.66

Analysis of Group Variables

The demographic variables age and education were subjected to a 2 x 3 x 2 (Age x Fitness x Gender) MANOVA. The analysis demonstrated that the elderly and young participant groups were statistically different from each other in terms of age (M = 68.4, SE = 4.26, and M = 21.2, SE = 2.66, respectively. In addition to the significant main effect for age, the differences in age between the low-, moderate-, and high- fit groups were also found to be significant, F (1, 68) = 5.239, *p* < .01. Post hoc analysis revealed that the low-fit group (M = 54.3, SE = 23.37) was significantly older than both the moderate-fit (M = 46.7, SE = 24.15) and high-fit (M = 43.1, SE = 23.70) groups, and the moderate-fit were significantly older than the high-fit participants. As well, there was a significant Gender effect obtained for years of education, F (1, 74) = 6.23, *p* < .05. Statistical analysis revealed that the male participants (M = 17.0, SE = 2.19) held significantly more years of education than women (M = 15.1, SE = 2.71).

Spectral Analysis Components during Cognitive Challenge Conditions

For cognitive challenge test conditions each of the power spectral estimates within each EEG frequency bin were separately subjected to a 2 x 3 x 9 x 2 (Age x Fitness x Site x Task) MANOVA with repeated measures on the last factor. The dependent variables were relative power (RP), mean frequency (MF), and amplitude variability (CV). MANOVAs were performed on the EEG data to determine if there were any significant associations between the factors in each of five frequency bins: theta (4-7.5 Hz), alpha1 (8-9.5 Hz), alpha2 (10 -12.5 Hz), beta1 (13-30 Hz) and beta2 (20-30 Hz).

The means of the relative power, spectral variation and mean frequency EEG parameters in the two age groups are presented in Tables 8, 9, and 10.

Table 9. Mean values of RP for participants in the three different fitness levels for young and old groups during cognitive challenge conditions

Age group	Young							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	-.564	.152	-.466	.107	-.687	.096	-0.572	0.118
Alpha1	-.951	.126	-.466	.107	-.687	.096	-0.701	0.110
Alpha2	-1.265	.122	-1.503	.086	-1.206	.077	-1.325	0.095
Beta1	-2.595	.149	-2.484	.105	-2.528	.094	-2.536	0.116
Beta2	-3.442	.218	-3.196	.154	-3.227	.138	-3.288	0.170
Age group	Old							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	-.891	.124	-.849	.099	-.799	.099	-0.846	0.107
Alpha1	-1.071	.103	-.881	.083	-1.010	.083	-0.987	0.090
Alpha2	-1.379	.100	-1.347	.080	-1.366	.080	-1.364	0.087
Beta1	-1.906	.122	-2.127	.097	-1.999	.097	-2.011	0.105
Beta2	-2.546	.178	-2.991	.143	-2.783	.143	-2.773	0.155

Table 10. Mean values of CV for participants in the three different fitness levels for young and old groups during cognitive challenge conditions

Age group	Young							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	.281	.033	.278	.023	.242	.021	0.267	0.026
Alpha1	.101	.017	.127	.012	.146	.011	0.125	0.013
Alpha2	.264	.047	.240	.034	.239	.0300	0.248	0.037
Beta1	.362	.039	.274	.027	.310	.024	0.315	0.030
Beta2	.314	.059	.338	.042	.334	.037	0.329	0.046
Age group	Old							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	.253	.027	.211	.022	.231	.022	0.232	0.024
Alpha1	.088	.014	.084	.011	.105	.011	0.092	0.012
Alpha2	.163	.039	.225	.031	.181	.031	0.190	0.034
Beta1	.208	.032	.210	.025	.210	.025	0.209	0.027
Beta2	.298	.048	.365	.038	.338	.038	0.334	0.041

Table 11. Mean values of MF participants in the three different fitness levels for young and old groups during cognitive challenge conditions

Age group	Young							
Fitness group	Low		Moderate		High		Marginal	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Theta	5.536	.067	5.557	.047	5.535	.042	5.543	0.052
Alpha1	8.760	.019	8.720	.013	8.768	.012	8.749	0.015
Alpha2	11.052	.041	11.079	.029	11.083	.026	11.071	0.032
Beta1	15.656	.089	15.844	.063	15.814	.056	15.771	0.069
Beta2	24.147	.161	24.140	.114	24.103	.102	24.130	0.126
Age group	**Old**							
Fitness group	**Low**		**Moderate**		**High**		**Marginal**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Theta	5.600	.055	5.654	.044	5.568	.044	5.607	0.048
Alpha1	8.742	.016	8.745	.012	8.744	.012	8.744	0.013
Alpha2	11.157	.033	11.091	.027	11.124	.027	11.124	0.029
Beta1	15.952	.072	15.919	.058	15.968	.058	15.946	0.063
Beta2	24.264	.131	24.033	.105	24.070	.105	24.122	0.114

Table 12.

Relative Power	Theta		Alpha1		Alpha2	
Source	df	*F*	df	*F*	df	*F*
Age	1, 64	*8.62	1, 64	.088	1, 64	.603
Fit	2, 64	.39	2, 64	.486	2, 64	1.541
Task	1, 64	*7.59	1, 64	3.241	1, 64	1.501
Site	2.5, 360.6	**63.37	5, 254.5	**13.635	5.8, 369.6	**17.381
Fit x Age	2, 64	.992	2, 68	.565	2, 64	2.077
Task x Age	1, 64	.909	1, 64	.945	1, 64	.010
Task x Fit	2, 64	.018	2, 64	1.816	2, 64	.685
Site x Age	3.5, 360.6	**6.26	4, 254.5	.829	5.8, 369.6	*3.003
Site x Fit	7, 360.6	.103	8, 254.5	1.472	11.5,369.6	1.760
Site x Task	6.3, 401	*2.35	6.1, 426.8	**5.406	6.3, 404.5	1.122
Fit x Task x Age	2, 64	2.13	2, 64	1.670	2, 64	.444
Fit x Site x Age	11, 360.6	1.57	8, 254.5	1.159	11.5,369.6	1.090
Site x Task x Age	6.3, 401	1.353	6.1, 426.8	.710	6.3, 404.5	*2.437
Fit x Site x Task	12.5, 401	.697	12, 426.8	1.179	12.6,404.5	1.244
Site x Fit x Task x Age	12.5, 401	.596	12, 426.8	.504	12.6,404.5	.453

*p<.05.
**p<.001.

Table 12 (continued).

Relative Power	Beta1		Beta2	
Source	df	*F*	df	*F*
Age	1, 64	**32.703	1, 64	*14.704
Fit	2, 64	.139	2, 64	.244
Task	1, 64	.092	1, 64	**7.768
Site	4.9, 312	**49.994	4.5, 288.5	**44.677
Fit x Age	2, 64	1.002	2, 64	1.939
Task x Age	1, 64	2.430	1, 64	2.976
Task x Fit	2, 64	*5.797	2, 64	2.975
Site x Age	4.9, 312	**9.115	4.5, 288.5	3.937
Site x Fit	9.8, 312	1.305	9, 288.5	.855
Site x Task	6, 384.6	2.109	4.2, 270.6	*3.152
Fit x Task x Age	2, 64	.803	2, 64	1.240
Fit x Site x Age	9.8, 312	*1.912	9, 288.5	.738
Site x Task x Age	6, 384.6	*3.589	4.2, 270.6	.801
Fit x Site x Task	12, 384.6	.889	8.5, 270.6	.430
Site x Fit x Task x Age	12, 384.6	1.444	8.5, 270.6	.822

*p<.05.
**p<.001.

EEG Relative Power (RP)

Table 12 contains the significant effects found across the relative power (RP) spectral measures computed from cognitive challenge conditions. All main effects are reported for RP in the following section, however, only the fitness-related or age-related significant interactions are reported for the sake of brevity.

Theta RP

There were main effects for age, task and site within the theta band found to be significant by statistical analysis. Post hoc analysis revealed that the amount of relative power significantly decreased with age, *p* <.001. Post hoc analysis revealed that frontal, central and temporal sites (FZ, CZ, T3 and T4) exhibited significant differences in the amount of beta1 RP compared to other sites, $p < .001$. Although not significantly different from each other, sites FZ and CZ displayed significantly higher amounts of theta RP than the other seven sites. In contrast, sites T3 and T4 exhibited significantly lower amounts of theta RP from the other seven sites, as well as not showing any significant difference between each other. Lastly, during the two cognitive challenge tasks, participants demonstrated significantly higher amounts of theta RP during the cognitive-left condition (analytical) than the cognitive-right condition (spatial), $p < .05$. There were no significant main effects for Fitness.

Alpha1 RP

Within the alpha1 band, statistical analysis revealed a significant main effect for site, $p < .001$. Post hoc analysis revealed that specifically site T3 displayed significantly higher amounts of alpha1 RP than sites PZ, O1 and O2, while site T4 demonstrated significantly lower amounts of alpha1 RP than site O2. There were no significant main effects for Fitness or any significant interactions involving the factor fitness.

Alpha2 RP

The statistical analysis revealed only one main effect: Site, $p < .001$. Further post hoc analysis showed that frontal and central sites (FZ and CZ) demonstrated lower magnitudes of alpha2 RP compared to other sites (PZ, O1, O2, C3, C4, T3, and T4; and PZ, O1, O2, C4, T3, and T4, respectively), $p < .001$. There were no significant main effects for fitness or any fitness related significant interactions.

Beta1 RP

For beta1 RP, statistical analysis revealed a two-way interaction between factors task and fitness, $p < .05$. Further post hoc analysis revealed significant differences between the low group in the CR condition to other groups in the CL condition. Specifically, the low-fit participants during the CR task exhibited significantly higher amount of beta1 RP compared to the low-fit participants during the CL task. As well, the moderate-fit group in the CL condition displayed a lower amount of beta1 RP than the low-fit group in the CR condition.

Statistical analysis found main effects for age and site within the beta1 frequency band, $p < .001$. Beta1 RP increased with age, $p < .001$. Lastly, temporal sites (T3 and T4) displayed higher magnitudes of beta1 RP compared to other sites, $p < .001$. The temporal sites were also similar in their respective amounts of beta1 RP, as post hoc analysis also did not reveal any significant difference between them. There were no significant main effects for Fitness.

Beta2 RP

Lastly for RP, statistical analysis revealed main effects for age and task within the beta2 frequency band. First, Beta2 RP was found to increase with age, $p < .05$. Secondly, participants exhibited a significantly higher amount of beta2 RP during the CR condition (spatial) than the CL condition (analytical), $p < .001$.

Table 13.

Amplitude Variability (CV)	Theta		Alpha1		Alpha2	
Source	df	*F*	df	*F*	df	*F*
Age	1, 64	2.970	1, 64	**9.247	1, 64	*3.925
Fit	2, 64	.685	2, 64	1.401	2, 64	1.541
Task	1, 64	*10.711	1, 64	.313	1, 64	*4.149
Site	5.2, 329.5	**8.065	4.6, 291.2	.601	5.2, 369.6	**10.931
Fit x Age	2, 64	.846	2, 64	.571	2, 64	2.077
Task x Age	1, 64	.050	1, 64	*4.921	1, 64	2.773
Task x Fit	2, 64	.156	2, 64	2.691	2, 64	1.242
Site x Age	, 329.5	**5.752	4.6, 291.2	.489	6.2, 369.6	1.651
Site x Fit	10.3,329.5	.877	9.1, 291.2	1.307	10.4,369.6	1.760
Site x Task	5.9, 379.7	5.459	6.7, 427	1.684	5.7, 367	2.812
Fit x Task x Age	2, 64	.283	2, 64	1.670	2, 64	.790
Fit x Site x Age	10.3,329.5	.903	9.1, 291.2	.903	10.4,369.6	.548
Site x Task x Age	5.9,379.7	3.052	6.7, 427	.747	5.7, 367	1.656
Fit x Site x Task	11.9,379.7	.905	13.3,427	1.150	11.5, 367	1.567
Site x Fit x Task x Age	11.9,379.7	1.630	13.3, 427	.731	11.5, 367	.876

*p<.05.
**p<.001.

Table 13 (continued).

Amplitude Variability (CV)	Beta1		Beta2	
Source	df	*F*	df	*F*
Age	1, 64	**19.780	1, 64	.016
Fit	2, 64	.951	2, 64	.458
Task	1, 64	.234	1, 64	**8.510
Site	4.9, 316.6	**9.033	, 322.2	**8.109
Fit x Age	2, 64	1.002	2, 64	.109
Task x Age	1, 64	3.903	1, 64	.024
Task x Fit	2, 64	.865	2, 64	.719
Site x Age	4.9, 316.6	2.290	5, 322.2	.609
Site x Fit	9.9, 316.6	.884	10, 322.2	.671
Site x Task	5.6, 356.6	1.991	5.7, 366.6	*2.296
Fit x Task x Age	2, 64	.803	2, 64	.567
Fit x Site x Age	9.9, 316.6	.216	10, 322.2	1.466
Site x Task x Age	5.6, 356.6	1.016	5.7, 366.6	.367
Fit x Site x Task	11, 356.6	1.310	11.5,366.6	.711
Site x Fit x Task x Age	11, 356.6	1.249	11.5, 366.6	1.422

*p<.05.
**p<.001.

EEG Amplitude Variability (CV)

The results for CV under cognitive challenge conditions are reported in Table 13. Table 13 contains the significant effects found across the amplitude variability (CV) spectral measures computed from resting conditions. All main effects are reported for CV in the following section, however, only the fitness-related or age-related significant interactions are reported for the sake of brevity.

Theta CV

Statistical analysis found significant main effects for task and site within the theta band for CV, $p < .05$ and $p < .001$, respectively. Further post hoc analysis revealed that site O2 exhibited significantly lower amounts of theta CV than sites T4 and PZ. Lastly, during the two resting tasks, participants exhibited more theta CV during the cognitive-left condition (analytical) than the cognitive-right condition (spatial), $p < .05$. There were no significant main effects for Fitness.

Alpha1 CV

As for alpha1 CV, statistical analysis found main effects for age. Alpha 1 CV exhibited a decrease with age, $p < .001$. There were no significant main effects for Fitness.

Alpha2 CV

The statistical analysis revealed three main effects: age, $p < .05$, site, $p < .001$, and task, $p < .05$. Alpha2 CV demonstrated a decrease with age. Additionally for alpha2 CV participants reported more alpha2 CV during the CL condition (analytical) compared to the CR condition (spatial). Lastly, further post hoc analysis revealed that although site CZ displayed the highest amount of alpha2 CV than other sites, and that site T3 demonstrated the lowest amount, none of the reported significantly different amounts of alpha2 CV. There were no significant main effects for Fitness.

Beta1 CV

As for the CV main effects, statistical analysis found main effects for age and site within the beta1 frequency band. Beta1 CV decreased with age, $p < .001$. As well, post hoc analysis revealed that site T4 displayed lower magnitudes of beta1 CV than sites PZ and C4, $p < .001$. There were no significant main effects for Fitness.

Beta2 CV

Lastly for CV, statistical analysis found main effects for task and site within the beta2 frequency band. Participants displayed more beta2 RP during the CL (analytical) condition than the CR condition (spatial), *p* < .001. Lastly, temporal sites exhibited lower magnitudes of beta2 RP compared to other sites, *p* < .001. Further post hoc analysis revealed that although the pattern of the effect was significant (PZ was highest, and T3 was lowest), none of the individual sites showed any significant differences in their amounts of beta2 CV. There were no significant main effects for Fitness.

Table 14.

Mean Frequency (MF)	Theta		Alpha1		Alpha2	
Source	df	*F*	df	*F*	df	*F*
Age	1, 64	2.442	1, 64	.237	1, 64	*4.292
Fit	2, 64	.758	2, 64	1.939	2, 64	.287
Task	1, 64	1.454	1, 64	.313	1, 64	*5.659
Site	4.6, 296.4	**7.481	5, 320.2	**27.395	5.2, 332	**10.931
Fit x Age	2, 64	.257	2, 64	2.077	2, 64	1.005
Task x Age	1, 64	2.132	1, 64	1.985	1, 64	2.765
Task x Fit	2, 64	1.452	2, 64	1.399	2, 64	1.255
Site x Age	4.6, 296.4	**5.072	5, 320.2	**6.146	5.2, 332	*2.748
Site x Fit	9.3, 296.4	.924	10, 320.2	*2.021	10.4, 332	1.343
Site x Task	5.4, 345	**8.770	6.4, 408.5	1.812	5.8, 373.6	1.892
Fit x Task x Age	2, 64	.111	2, 64	.113	2, 64	1.101
Fit x Site x Age	9.3, 296.4	.777	10, 320.2	1.424	10.4, 332	1.292
Site x Task x Age	5.4, 345	*2.385	6.4, 408.5	1.482	5.8, 373.6	1.950
Fit x Site x Task	10.8, 345	.741	12.8, 408.5	.988	11.7, 373.6	1.496
Site x Fit x Task x Age	10.8, 345	.851	12.8, 408.5	.577	11.7, 373.6	.819

*p<.05.
**p<.001.

Table 14 (continued).

Mean Frequency (MF)	Beta1		Beta2	
Source	df	*F*	df	*F*
Age	1, 64	*10.231	1, 64	.005
Fit	2, 64	.832	2, 64	.518
Task	1, 64	1.341	1, 64	*10.760
Site	, 256.7	**27.001	5.5, 354	**10.545
Fit x Age	2, 64	1.193	2, 64	.376
Task x Age	1, 64	.796	1, 64	.007
Task x Fit	2, 64	.902	2, 64	.554
Site x Age	4, 256.7	*3.686	5.5, 354	.924
Site x Fit	8, 256.7	.528	11, 354	.508
Site x Task	4.2, 270.7	.849	5.9, 376	1.655
Fit x Task x Age	2, 64	.796	2, 64	.448
Fit x Site x Age	8, 256.7	.293	11, 354	1.099
Site x Task x Age	4.2, 270.7	1.046	5.9, 376	.599
Fit x Site x Task	8.5, 270.7	.961	11.8, 376	.438
Site x Fit x Task x Age	8.5, 270.7	1.740	11.8, 376	1.705

*p<.05.
**p<.001.

EEG Mean Frequency

The results for MF under cognitive challenge conditions are reported in Table 14.

Table 6 contains the significant effects found across the mean frequency (MF) spectral measures computed from resting conditions. All main effects are reported for MF in the following section, however, only the fitness-related or age-related significant interactions are reported for the sake of brevity.

Theta MF

Statistical analysis found a significant main effect for site within the theta band for MF, $p <.001$. Further post hoc analysis revealed that site O2 displayed higher magnitudes of MF compared to site PZ. There were no significant main effects for Fitness.

Alpha1 MF

As for alpha1 MF main effects, statistical analysis revealed only one main effect for site, $p < .001$. Post hoc analysis revealed that frontal and central sites (FZ, CZ, and C3) displayed significant differences from other sites. Site FZ exhibited significantly lower amounts of apha1 MF than sites PZ, O1, O2, C3, C4, T3, and T4. Site CZ also displayed a decreased amount of alpha1 MF than sites O1, T3 and T4. Lastly site C3 demonstrated a significantly lower amount of alpha1 MF than site T4. There were no significant main effects for Fitness.

Alpha2 MF

The statistical analysis revealed three main effects: age, $p < .001$, task, $p < .001$, and site, $p < .001$. Alpha2 MF was shown to increase with age. Additionally, all participants exhibited lower amounts of alpha2 MF during the cognitive-right condition (spatial) compared to the cognitive -left condition (analytical). As for the site main effect, post hoc analysis revealed that temporal site T3 displayed the highest amount of alpha2 CV compared to all other non-central sites (FZ, CZ, PZ, O1, O2), $p < .001$. There were no significant main effects for Fitness.

Beta1 MF

As for the MF main effects, statistical analysis found main effects for age, $p < .05$ and site, $p < .001$ within the beta1 frequency band. Beta1 MF decreased with age. For the site main effect, post hoc analysis revealed that temporal sites (T3 and T) demonstrated the highest magnitudes of beta1 MF compared to other sites, while not exhibiting any significant differences from each other. There were no significant main effects for Fitness.

Beta2 MF

Lastly for MF, statistical analysis found main effects for task, $p < .001$, and site, $p < .001$, within the beta2 frequency band. Participants demonstrated less beta2 MF during the CL (analytical) condition than the CR (spatial) condition. Additionally, post hoc analysis revealed temporal sites (T3 and T4) exhibited higher magnitudes of beta2 MF compared to other sites. Specifically, site T3 displayed a significantly higher amount than PZ, while T4 exhibited a significantly higher amount than sites CZ, PZ, and C4. There were no significant main effects for Fitness.

Section C

Discussion

The purpose of the study was to compare the cortical activation patterns of older and younger participants who were characterized by different levels of physical fitness. Based on the benefits to the central nervous system of exercise participation the older fit men and women were predicted to show more similar activation to the young participants as compare to their less fit counter parts. The participants were subjected to a continuum of cognitive challenge beginning with two resting conditions, eyes-closed and eyes-opened; and two active challenge conditions, mental arithmetic and embedded figures. The least cognitively challenging tasks were the resting conditions. Participants were expected to remain seated in a wakeful, relaxed state with their eyes both closed for three minutes and open for three minutes. Next in the continuum of challenge were the cognitive task conditions. Participants resolved both mental arithmetic and embedded-figures problems, which were counter-balanced for order. Once the problem was solved, the participants indicated with a finger wave and moved onto the next problem. The math and embedded figures tasks were chosen because they represent cognitive processes of the left (analytical) and right (spatial) hemispheres (Springer & Deutsch, 1998; Hatfield, Landers, & Ray, 1984).

Basic Changes in Cortical Activation as a Function of Task

Overall, the results demonstrate that the participants in the study exhibited the expected increase in cortical activation. These fundamental changes provide confidence with which to examine the contrasts of interest in the present study dealing with age- and fitness-related effects on cortical activation.

The means of participants' relative alpha power during the resting conditions compared to that of the cognitive challenge conditions indicated that participants displayed higher levels of alpha activity at rest. This is a logical pattern of change in cortical activation because alpha activity, also known as alpha synchronization, should be suppressed when the brain is engaged (Andreassi, 2000; Hatfield & Hillman, 2001).

Additionally, the main effect of task during the resting conditions revealed that participants exhibited elevated levels of relative alpha power when their eyes were closed compared to when they were open. This is an anticipated cortical activation change due to the activity in the occipital lobes being reduced during the eyes-closed condition. Due to the decrease in the amount of sensory information being received, the occipital region became less stimulated and thus sustained an increased level of alpha activity (Galin & Ornstein, 1972). Additionally, the main effect for the electrode-recording site revealed an expected change. Participants' occipital sites exhibited the largest amount of relative alpha1 power and relative alpha2 power, an effect that was more robust when the eyes were closed. The magnitude of change in alpha power between conditions was also largest at the occipital sites. This logically follows as literature shows that the occipital sites are generally the highest alpha generators at rest and especially when the eyes are closed (Andreassi, 2000).

Expected changes were also observed during cognitive challenge. The regional activation at site T3 was differentiated during the two cognitive challenges (math and embedded figures) such that there was lower alpha1 power (i.e. greater activation) in this region during the EFT. This finding is reasonable in light of Kinsbourne's (1980) view that the left temporal-parietal region is involved in feature detection of environmental stimuli. In light of the nature of the EFT, and the likely lack of familiarity with such a task, the EFT may have imposed a greater processing load on this region during the execution of the task as compared to the math task, which would seemingly require less feature detection of the visual field or stimulus array. Interestingly, there was no such difference in activation between the tasks at site T4, which also seems reasonable in light of the integrative processing associated with this region (Kinsbourne, 1980). It would seem reasonable that there would be no substantive differences in integrative processing associated with these tasks. Furthermore, in accord with the notion of regional activation being negatively related to alpha and positively related to beta power, greater beta2 power was also observed at site T3 during EFT, as well as at the neighboring site C3. This finding corroborates that reported above for alpha power in terms of general activation notions associated with general EEG. Again, no difference in activation in the homologous site (T4) was observed for beta2 power between the tasks.

Overall the results demonstrate that the participants in the study exhibited expected changes in cortical activation. As such, these fundamental changes provide greater confidence to examine the contrasts of interest in the present study's hypotheses.

Discussion of Stated Hypotheses

According to Hypothesis 1 the older participants were predicted to exhibit less low-frequency power (theta and alpha) compared to their younger counterparts. This effect was predicted during both rest and challenge, which were tested separately, but the age-related changes were expected to be greater during challenge. Because a higher amount alpha power is associated with integrity of neural structures and synchronicity of low-frequency generators, less alpha power was expected in the older participants because of age-related neurodegenerative processes (Dustman et al., 1999). This expected difference was predicted both for low-alpha (8-10 Hz) which is indicative of general arousal and high-alpha (11-13 Hz) which is indicative of task specific activation (Pfurtscheller, 1992). It is reasonable to expect that low-alpha would be most sensitive to detecting the predicted differences between older and younger during rest and high-alpha would be most sensitive to detecting the predicted differences between older and young participants during cognitive challenge. However, this hypothesis was not supported, as there were no significant age-related effects for both low and high relative alpha power. (note: furthermore, there were no differences in the degree of sensitivity of the alpha bands relative to the rest and challenge conditions.)

The lack of difference in cortical activation seems reasonable as this sample of elderly men and women were all characterized by had healthy lifestyles regardless of fitness group classification. They were screened for significant health problems and could all be described as high-functioning and independent living. Factors like lifestyle and social support are clearly related to cognitive health (Etnier et al., 1997; Plante, 1990). It may be that other factors such as cognitive stimulation and social support, which appear characteristic of the present sample, likely attenuated age-related neurodegeneration and therefore would offset any effect of fitness on the integrity of neural structures. The interactive influence of important lifestyle factors along with physical fitness on brain function should be specifically examined in future research.

In contrast to the lack of age-related differences in alpha power, the predicted effect of less relative theta power was observed in the older participants during both rest and challenge. However, the specific neurocognitive processes associated with theta remain unclear and the age-related findings in previous literature are mixed (Roubicek et al., 1977; Duffy et al., 1993; Polich, 1997; Dustman et al., 1999). But, if it is assumed that theta power is similar to alpha in its relationship to brain health, then the lowered levels are reasonable in light of the likely neurodegenerative processes. In this regard, Polich (1997) speculated that reduced alpha power in the elderly is a result of lowered oxygenation of the brain. However in light of the uncertainty of the neurological processes associated with theta power, it is difficult to account for why these changes occurred in theta RP and not alpha RP.

In light of the benefits of exercise on age-related neural change, Hypothesis 2 predicted that all participants would show a positive relationship between fitness and low-frequency power. Although overall low-frequency power was expected to be lower in older participants, it was also expected to increase with fitness level and that the magnitude of this relationship should be greater in the elderly participants. Exercise has been associated with many psychological benefits like increased cognitive function and reduced stress (Petruzello, Landers & Hatfield, 1990) as well as specific neurophysiological mechanisms thought to underlie age-related changes in cortical function (REF). These would include improved blood flow and maintenance of neurotransmitters such as dopamine (Spirduso, 1983; Issacs et al., 1992; Rogers, 1990). Additionally recent evidence has revealed the up-regulation of brain derived neurotrophic factor (BDNF) that results in synaptogenesis and maintenance of the neuropil, especially in the hippocampal region, which is very sensitive to the aging process (Cotman & Engesser-Cessar, 2002). As such, the deterioration in the brain associated with age-related decline in cognitive function was predicted to be reduced with physical fitness. Although a Fitness x Age x Task effect was observed within the resting conditions for the relative alpha power (as presented in Figure 1.; all figures are presented at the end of the Discussion), the pattern of means alpha levels was not consistent with the prediction. In contrast to the prediction, post hoc analysis revealed that the low-fit young group exhibited higher alpha2 power than all of the other groups when they were resting with their eyes-closed. The other groups showed no significant differences in alpha power. In this regard, the low fit participants showed a heightened burst of alpha typically seen with closing of the eyes. This stereotypic response, which was exaggerated in this group, may have masked any potential effects of fitness on the pattern of mean changes associated with the age and fitness groups in the present study. Being that alpha suppression is associated with activation, or cognitive engagement, the higher amount of relative alpha2 power observed in the low-fit young group suggests that at rest the low-fit participants were less aroused than participants in the other groups. In addition, the prediction stated in Hypothesis 2 above was not supported during the condition of mental challenge (EFT and Math). The lack of difference in alpha power in all the conditions between the young and the old suggest the preservation of neural integrity in all three groups of older men and women. In other words, the failure to detect age-related differences, whether fitness was low, moderate, or high, suggests that, overall, the elderly participants in the present study were aging well. This notion seems reasonable in light of their excellent health status and lifestyle characteristics. Such a finding calls for the need to examine more diverse groups of elderly participants in future studies who would be characterized by greater differences in health status and physical activity participation than in the present.

Overall, the failure to support Hypothesis 2 (i.e. detection of fitness-related differences in relative alpha2 power in the predicted direction) during either rest or cognitive challenge may have been due to the lack of consideration of other psychological or genetic factors. Genetic factors have recently been established to play an important role in the neural adaptations to exercise. More specifically, the presence of $APOE_4$ places a person at risk for cognitive decline. Schuit et al. (2001) have shown that carriers of the APOE4 allele receive particularly strong benefits from physical activity participation. Schuit showed a remarkable difference in the effect of physical activity participation in carriers of the $APOE_4$ gene such that those who were sedentary showed a high degree of cognitive deterioration over a three-year period as measured by the Mini-Mental States Exam (MMSE), while those who were highly active showed little decline in function over that same time period.   If a substantial number of participants in the present study had been characterized by this allele, than substantial differences in cortical activation (alpha power) would likely have been observed.   In the present study, the participants were not stratified on the basis of a cognitive decline index such as the $APOE_4$ genotype. As stated above, due to the nature of their high-functioning lifestyle, the majority of participants participating in the study may not have been at risk for cognitive decline regardless of fitness level and therefore no strong effects of physical fitness on brain function occurred.

It is noteworthy that the older participants in the present study showed no decline in alpha activity relative to the young in either cognitive condition, which validates their characterization as psychologically healthy individuals. This finding is consistent with the notion that participants who self select into scientific studies are atypical of the general population and are likely functioning at a higher level.

Hypothesis 3 predicted that elderly participants would exhibit higher amounts of beta1 and beta2 relative power at rest and again, that this effect would be enhanced during cognitive conditions. Greater beta power was predicted as a result of compensation for decline in neural processes associated with cognitive function. As such, it was expected that beta power would exhibit an increase with age. This hypothesis was supported during all four tasks (eyes-open, eyes-closed, math and spatial). Both, in the beta1 and beta2 frequency bands, the elderly participants presented higher levels of relative power than the young participants and the magnitude of difference between the conditions was higher during the analytic and spatial tasks.

In terms of the impact of activity on age, Hypothesis 4 predicted that older participants would show a negative relationship between high-frequency power and fitness. The rationale behind this hypothesis was similar to that posed for low-frequency power in Hypothesis 2 above as the benefits of exercise were expected to lessen the effects of degradation in the brain. Although the prediction was not supported, a significant Age x Fitness interaction was found. However, it was in the opposite to that predicted. In contrast to the prediction, the high-fit elderly exhibited significantly higher beta1 power levels during rest, relative to the three young fitness groups, while the low- and moderate-fit elderly did not differ from the young groups. This effect is presented in Figure 2.

This finding may suggest an altered version of the compensation theory in which fitness influences the capacity to compensate rather than the need to compensate. It is plausible that fitness influences the plasticity of the aging brain in light of the BDNF effects described above. By maintaining the plasticity of the aging brain, elderly high-fit adults would be better able to compensate for cortical decline. As opposed to viewing the increased beta power in the high-fit as a sign of age-related decline, it may be viewed as the ability to marshal increased activation of neural processes. However, it is important to note that no changes were found during the cognitive challenges in math and EFT. This finding is perplexing because it would have been expected that such a compensation effect described above within the beta band would have been more robust during cognitive challenge. This may have been due to the fact that the challenges presented were not optimal for targeting age-related differences in cognitive function (Kramer et al., 1999). The cognitive challenge tasks performed by the participants in the present study included mental arithmetic and the Embedded-Figures Task, which is a test of visual-spatial cognitive processing (Witkin, 1950). Recent research regarding aging and cognitive decline indicates the brain does not age uniformly and therefore, age-related changes in cognitive function are selective and have been most documented to occur in the frontal and pre-frontal cortex (Kramer et al., 1999). Additionally the hippocampal region which is involved with memory is also very sensitive to age-related decline. Although chosen to challenge the participants in the present study with greater cortical activation the tasks employed do not rely heavily on these brain regions. Therefore the tasks used in the present study did not have components that challenged participants' memory or executive processes and thus the cortical activation did not exhibit any age- or fitness-related alterations that were of a detectable magnitude.

According to Hypothesis 5, older participants were predicted to exhibit less spectral amplitude variability (CV) within all bands compared to younger participants. Because CV reflects the “integrity” of neural generators and the clearly defined peaks they produce while oscillating at different frequencies (Dustman, 1999), it was predicted that elderly participants would have more spectral amplitude variability than young participants due to age-related deterioration. That is, older men and women would show a decline in synchronicity of frequency specific oscillators and more homogeneity of amplitude across the spectrum. This hypothesis was partially supported. At rest, the older group displayed lower levels of CV than the younger group in the beta1 frequency band only. Also, in accord with the predictions of the study, when the participants were challenged cognitively, the elderly exhibited even more suppressed levels of CV compared to the young group in the alpha1, alpha2, and beta1 frequency bands.

It is logical that during cognitive challenge conditions more age-related findings occurred than at rest. During cognitive challenge, the elderly group was expected to utilize a more varied employment of neural generators (oscillating at different frequencies) than the young group to compensate for age-related changes in cortical integrity (i.e. health). As more generators at different frequencies were being recruited while the elderly were under cognitive challenge, CV was expected to decrease because the overall spectral power was distributed throughout various frequencies instead of being contained within one frequency.

Hypothesis 6 predicted that older participants would also show a positive relationship between amplitude variability (CV) and fitness (within all bands). It was predicted that fitness would enhance the integrity of neural generators as reflected by greater synchronicity at specific frequencies. In this manner, greater amplitude variability would be seen in fit elderly adults. This prediction was partially supported. Results showed that there was only an effect for Fitness x Age and it occurred within the beta2 frequency band during resting conditions. Although post hoc testing revealed that none of the group means were significantly different from each other, the overall pattern showed increasing amplitude variability with fitness for the elderly participants, while the young participants exhibited decreasing beta2 CV with increasing fitness. This effect is shown in Figure 3.

However during challenge there was a failure to find the expected differences as a function of fitness in the elderly. As explained above, research in aging and cognition demonstrate that the cognitive processes most clearly affected by age-related decline are associated with executive function and memory (Kramer, 1999). Because mental arithmetic and the embedded-figures task do not rely on those types of cognitive process (Oltman, 1979, 1950) it is possible that the neural generators that would have distinguished the high-fit elderly from lower-fit elderly, were not called into play. In other words, the ability of the elderly participants to recruit task-relevant neural generators may not have been tested in light of the nature of tasks employed.

Hypothesis 7 predicted that older participants would exhibit more mean frequency than their younger controls within all bands. Mean frequency (MF) is the “center of gravity” of a given frequency band, as it is an index of which frequency is most influential to the overall amplitude distribution within a given frequency band. Because MF is positively related to metabolic activity within the brain, it is expected that seniors would exhibit higher levels of MF compared to younger adults as a consequence of age-related decline and the presence of compensation in the form of higher frequency neural oscillators.

This hypothesis was partially supported. Predicted age effects occurred in specific bands. At rest, the older group exhibited higher levels of mean frequency (MF) than the younger group in the theta and beta1 frequency bands. When the participants were challenged cognitively, the elderly also exhibited higher levels of MF than the young participants in the alpha2 and beta1 frequency bands. Additionally, the mean levels of MF were higher for the elderly during challenge as compared to those observed during rest. Although the older participants appeared similar to the young in terms of relative power, the more comprehensive examination of the EEG signal enabled the detection of age-related EEG changes. This point underscores the need to examine different dimensions of the EEG when making comparisons between groups. The differences that were detected with MF would be explained by the neurodegenerative processes that occur with age. But, again, these would not appear robust as the other dimensions of the EEG signal did not reveal age-related change.

Hypothesis 8 predicted that older participants would demonstrate a negative relationship between mean frequency (MF) and fitness (within all bands). This was predicted because elderly brains are expected to increase their activation to compensate for age-related decline in brain integrity. Due to the assumption that exercise reduces the age-related changes in the brain, seniors with higher levels of fitness should have lower MF. This hypothesis was partially supported. A Fitness x Age effect was found for beta2 MF (see Figure 4.). The post hoc failed to detect significant differences between the means, but the largest magnitude of difference in MF was found between the low-fit and high-fit elderly in the predicted direction. That is, high-fit older men and women showed a reduction in MF for the beta2 band during rest. In essence there was a progressive decline in MF in the elderly while the young showed relative stability across the fitness groups. Although a Fitness x Age x Task effect for alpha1 MF was found, the pattern of observed means was not consistent with the prediction. This effect is presented in Figure 5. In the eyes-closed condition, the low-fit young participants exhibited a higher level of alpha1 MF than all of the other groups; all other groups were undifferentiated. In summary, the data revealed strong effects of aging on cortical activation. These age-related effects were observed both during rest and cognitive challenge. More specifically, there was increased activation in the elderly as indicated by the differences in relative power, there was a reduction in amplitude variability, and a there was an increase in the mean frequency of various frequency bands. At risk of oversimplification, collectively, these results imply greater effort to negotiate a continuum of cognitive challenges. Generally speaking, physical fitness was not associated with robust alterations in cortical activity. The older physically fit men and women were expected to exhibit cortical dynamics more similar to younger people. Specifically, the high-fit older subjects exhibited higher power for the beta1 band and an increase in amplitude variability along with an attenuation of mean relative to the less fit groups at rest frequency (these later two effects were found in beta2 power). It appears that the older individuals maintained a heightened activation state during rest that was also characterized by more distinct neural generators and a reduction in the mean frequency. This greater activation might be indicative of more alertness. Although there were some effects in accord with this prediction, they were not large in magnitude and may have been due to chance because of the number contrasts.

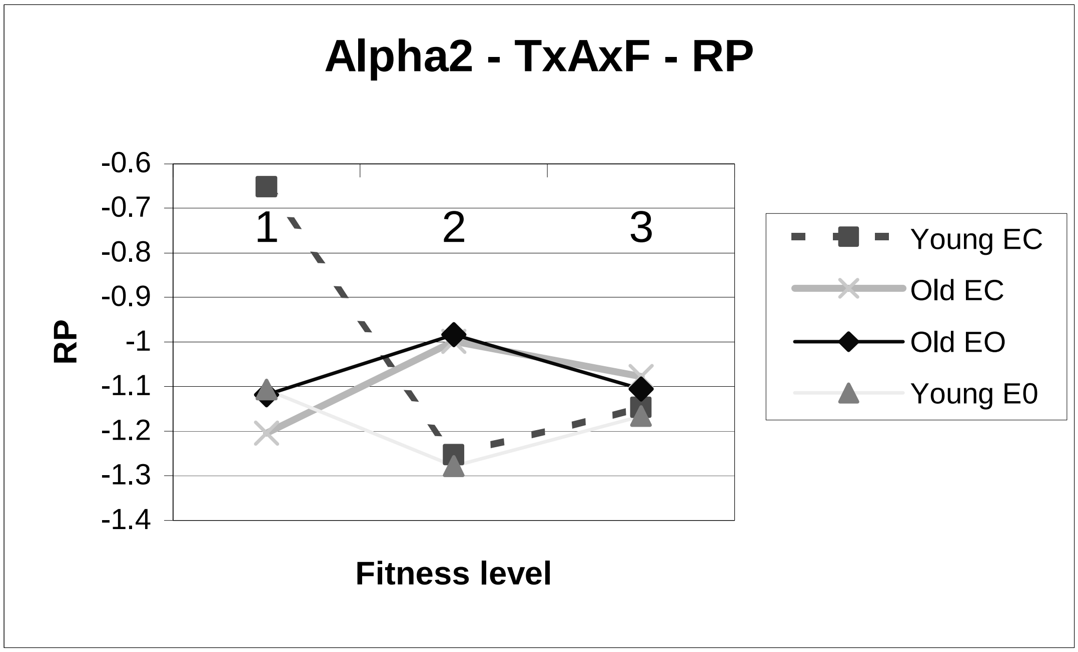

Figure 1. Fitness x Age x Task interaction for relative alpha2 power during resting conditions.

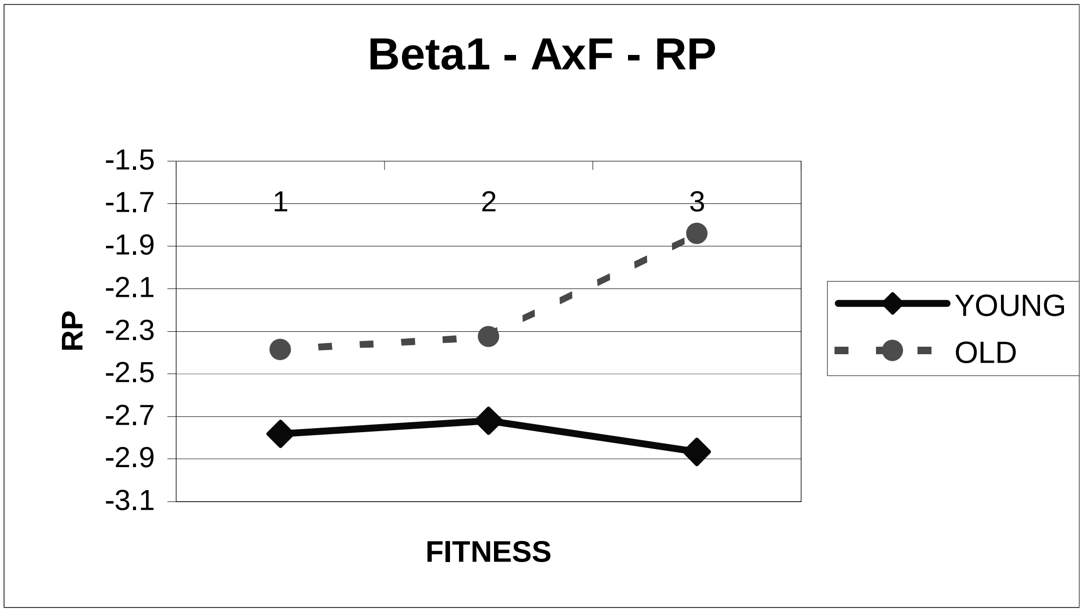

Figure 2. Fitness x Age interaction for relative beta1 power during resting conditions.

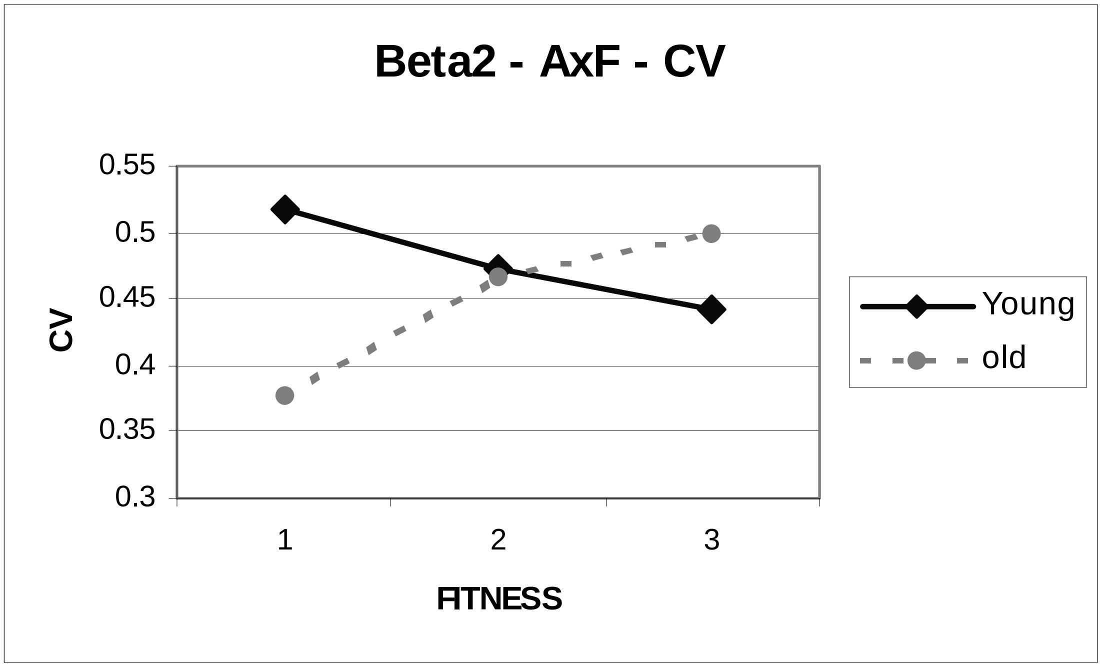

Figure 3. Fitness x Age interaction for beta2 amplitude variability (CV) during resting conditions.

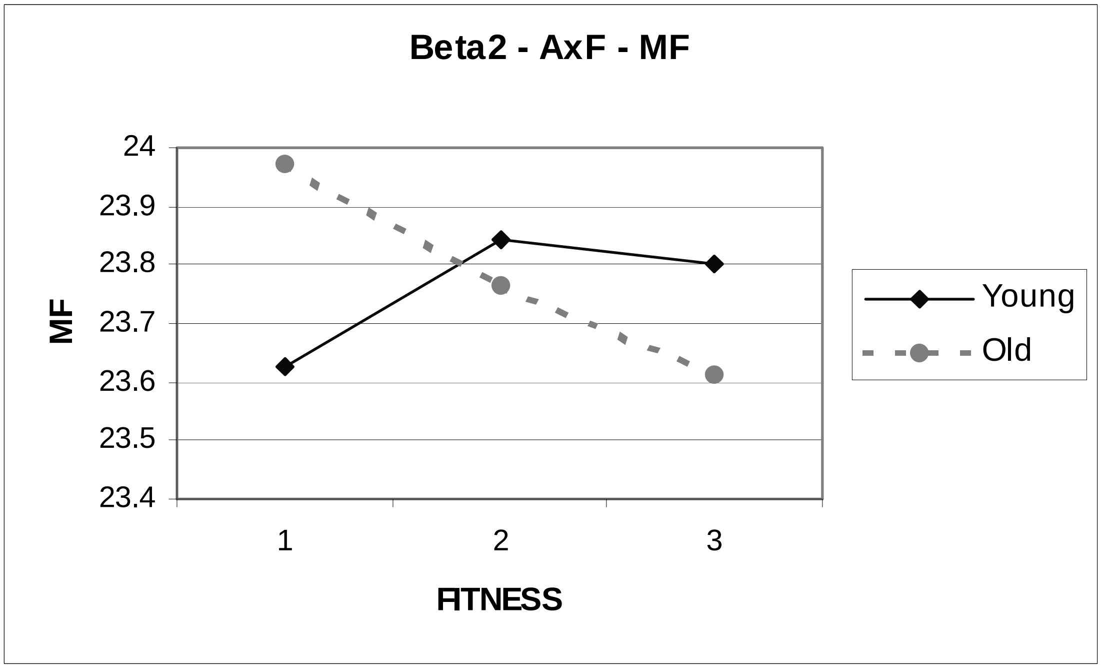

Figure 4. Fitness x Age interaction for beta2 mean frequency (MF) during resting conditions.

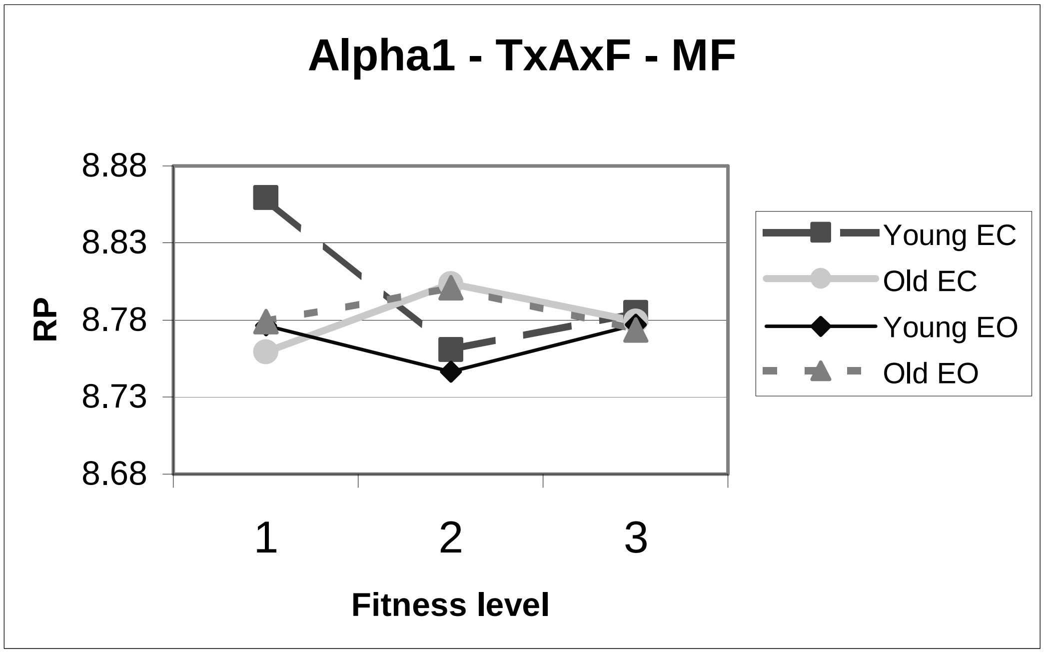

Figure 5. Fitness x Age x Task interaction for alpha1 mean frequency (MF) during resting conditions.

CHAPTER V

Summary, Conclusions, and Implications for Future Research

Summary

Research in aging and cognition has shown that the brains of elderly individuals undergo some amount of decline in cognitive function even though the health of the brain is not compromised by disease (Colcombe & Kramer, 2003; Dustman et al., 1990; Kramer & Atchley, 2000). Importantly, these studies also indicate that the mechanisms underlying cognitive function such as brain oxygenation, cerebral vascularization, cerebral blood flow, and neurotransmitter levels maintain plasticity of function and thus can be influenced by the environment throughout the life span (Bentourkia et al., 2000; Chodzko-Zajko, 1994; Noda et al. 2002; Shaw et al., 1994; Spirduso, 1980).

In fact, because of the psychological benefits associated with exercise, its influence in cognitive function has been explored to determine whether physical fitness would preserve the age-related changes in the brain that underlie neurocognitive processes (Plante, 1990). Recent research has shown that high levels of fitness has been associated to neurobiological improvements such as enhanced neurotransmitter efficiency, greater oxygenation of the brain, and increased blood flow that increase the cognitive performance of elderly adults (Dustman et al., 1984, 1990; Kaasinen et al., 2000; ; Rogers, 1986; Spirduso et al. 1983). Furthermore, studies have provided evidence that increases in fitness produces increases in performance in selective areas of cognitive capacity such as analytic reasoning, memory-related processes or executive function (Dustman, 1994; Kramer et al., 2003; Oltman et al., 1979). The purpose of the present study was to provide information that would help establish the effects of age-related changes in EEG for the investigation of age-related cognitive decline. Secondly, the study intended to directly examine mechanisms underlying the potential benefits of exercise on cognition in the elderly through the use of quantitative EEG.

In summary, the data revealed strong effects of aging on cortical activation. These age-related effects were observed both during rest and cognitive challenge. More specifically, there was increased activation in the elderly as indicated by the differences in relative power, there was a reduction in amplitude variability, and a there was an increase in the mean frequency of various frequency bands. At risk of oversimplification, collectively, these results imply greater effort to negotiate a continuum of cognitive challenges. Generally speaking, physical fitness was not associated with robust alterations in cortical activity. The older physically fit men and women were expected to exhibit cortical dynamics more similar to younger people. Specifically, the high-fit older subjects exhibited higher power for the beta1 band and an increase in amplitude variability along with an attenuation of mean relative to the less fit groups at rest frequency (these later two effects were found in beta2 power). It appears that the older individuals maintained a heightened activation state during rest that was also characterized by more distinct neural generators and a reduction in the mean frequency. This greater activation might be indicative of more alertness. Although there were some effects in accord with this prediction, they were not large in magnitude and may have been due to chance because of the number contrasts.

Conclusions

1. Aging is associated with substantial changes in cortical dynamics. That is, the brain appears to be working in a more effortful manner.
2. For elderly subjects fitness does not seem to substantially alter cortical dynamics in relation to fitness level for tasks that are not heavily loaded on executive and memory processes.

Limitations

1. Participants were selected based on the differences that existed between them at the moment of the study, as a consequence genetic and/or other dispositional factors may confound this study. In other words, the cross-sectional nature of the study prevents the conclusion of any causal connection between aerobic fitness level and task or EEG differences.
2. Because participants in the study volunteered and thus the participant sample was not a random sample from the population, selection bias may have occurred.
3. A direct test of aerobic capacity is precluded from the elderly low-fitness participants because of the high-risk nature and possible cardiovascular trauma associated with such a test. Instead, self-reported activity levels and a submaximal test of aerobic capacity were used to determine aerobic training status.

Implications for Future Research

1. There is a need to more specifically define the populations with which to investigate the influence of exercise on the aging brain because lifestyle and genetic factors likely moderate the influence of fitness.
2. In future studies the use of other forms of signal processing such as coherence or ICA (Independent Components Analysis (ICA) would provide greater ability to detect differences of the cerebral cortical activity.

APPENDIX A

Activity History Questionnaire

PHYSICAL ACTIVITIES

We would like to know what type of physical activities (work and home) you have taken part in over the past year. Read over the list below and mark everything you did, even just once. Mark the things you have done in community recreation centers along with the things you have done with your family and friends at home or in the neighborhood. Try to remember everything you did in the past year, even if once.

No. ACTIVITY
01 [__] Archery
02 [__] Arm Wrestling
04 [__] Badminton
04 [__] Baseball/Softball
05 [__] Basketball
06 [__] Bicycling
07 [__] Bowling/Duckpins
08 [__] Boxing
09 [__] Calisthenics
10 [__] Canoeing/Rowing

No. ACTIVITY
01 [__] Climbing Ropes
02 [__] Aerobic Dance
04 [__] Ballet
04 [__] Disco/Modern Dance
05 [__] Folk/Square Dance
06 [__] Other Dance
07 [__] Diving
08 [__] Fencing
09 [__] Field Hockey
10 [__] Fishing

No. ACTIVITY
01 [__] Football/Tackle
02 [__] Football/Touch
04 [__] Frisbee
04 [__] Golf /Carry Clubs
05 [__] Rock Climbing
06 [__] Riflery
07 [__] Racquetball
08 [__] Ping Pong
09 [__] Lacrosse
10 [__] Karate/Martial Arts

No. ACTIVITY
01 [__] Skipping Rope
02 [__] Jogging/Running
04 [__] Ice Skating
04 [__] Ice Hockey
05 [__] Hunting
06 [__] Horseshoes
07 [__] Horseback Riding
08 [__] Hiking/Backpacking
09 [__] Gymnastics
10 [__] Sailing

No. ACTIVITY
01 [__] Running Sprints
02 [__] Scuba/Snorkeling
04 [__] Skiing
04 [__] Soccer
05 [__] Surfing
06 [__] Swimming/Beach
07 [__] Tennis/Singles
08 [__] Tetherball
09 [__] Track & Field
10 [__] Volleyball

No. ACTIVITY
01 [__] Walking
02 [__] Water Polo
04 [__] Water-skiing
04 [__] Weightlifting
05 [__] Wrestling
06 [__] Yoga
07 [__] Golf/Pull Clubs
08 [__] Golf/Riding Cart
09 [__] Rugby
10 [__] Swimming/Pool

No. ACTIVITY
01 [__] Motor Cycling
02 [__] Wrestling
04 [__] Desk/Office Work
04 [__] Playing Cards
05 [__] Light Housework
06 [__] Auto Repair
07 [__] Woodworking
08 [__] Yard Work
09 [__] Carpentry
10 [__] Painting

No. ACTIVITY
01 [__] Raking/Hoeing
02 [__] Snow Shoveling
04 [__] Splitting Wood
04 [__] Lawn Mowing, push
05 [__] Tennis Doubles
06 [__] Orienteering
07 [__] Washing Car
08 [__] Stair Climbing
09 [__] Relaxation Exercises
10 [__] Officiating

No. ACTIVITY (OTHER)
01 [__] _________________
02 [__] _________________
04 [__] _________________
04 [__] _________________
05 [__] _________________
06 [__] _________________
07 [__] _________________
08 [__] _________________
09 [__] _________________
10 [__] _________________

MOST FREQUENT ACTIVITIES

Refer to the physical activity list on the previous page to select, among those you checked, the physical activities you did most frequently over the past year. Using the Forms given below and on the next page, provide the necessary information for up to six selected physical activities.

No.	ACTIVITY NAME OF ACTIVITY	SEASONS (DARKEN ALL THAT APPLY)	AVERAGE DAYS A WEEK (DARKEN ONE ONLY)	AVERAGE MINUTES A DAY (DARKEN ONE ONLY)
		[__] Summer [__] Fall [__] Winter [__] Spring	[<1] [1] [2] [3] [4] [5] [6] [7]	[__] Under 20 [__] 20 – 39 [__] 40 – 60 [__] Over 60

No.	ACTIVITY NAME OF ACTIVITY	SEASONS (DARKEN ALL THAT APPLY)	AVERAGE DAYS A WEEK (DARKEN ONE ONLY)	AVERAGE MINUTES A DAY (DARKEN ONE ONLY)
		[__] Summer [__] Fall [__] Winter [__] Spring	[<1] [1] [2] [3] [4] [5] [6] [7]	[__] Under 20 [__] 20 – 39 [__] 40 – 60 [__] Over 60

No.	ACTIVITY NAME OF ACTIVITY	SEASONS (DARKEN ALL THAT APPLY)	AVERAGE DAYS A WEEK (DARKEN ONE ONLY)	AVERAGE MINUTES A DAY (DARKEN ONE ONLY)
		[__] Summer [__] Fall [__] Winter [__] Spring	[<1] [1] [2] [3] [4] [5] [6] [7]	[__] Under 20 [__] 20 – 39 [__] 40 – 60 [__] Over 60

MOST FREQUENT ACTIVITIES (CONT.)

No.	ACTIVITY NAME OF ACTIVITY	SEASONS (DARKEN ALL THAT APPLY)	AVERAGE DAYS A WEEK (DARKEN ONE ONLY)	AVERAGE MINUTES A DAY (DARKEN ONE ONLY)
		[__] Summer [__] Fall [__] Winter [__] Spring	[<1] [1] [2] [3] [4] [5] [6] [7]	[__] Under 20 [__] 20 – 39 [__] 40 – 60 [__] Over 60

No.	ACTIVITY NAME OF ACTIVITY	SEASONS (DARKEN ALL THAT APPLY)	AVERAGE DAYS A WEEK (DARKEN ONE ONLY)	AVERAGE MINUTES A DAY (DARKEN ONE ONLY)
		[__] Summer [__] Fall [__] Winter [__] Spring	[<1] [1] [2] [3] [4] [5] [6] [7]	[__] Under 20 [__] 20 – 39 [__] 40 – 60 [__] Over 60

No.	ACTIVITY NAME OF ACTIVITY	SEASONS (DARKEN ALL THAT APPLY)	AVERAGE DAYS A WEEK (DARKEN ONE ONLY)	AVERAGE MINUTES A DAY (DARKEN ONE ONLY)
		[__] Summer [__] Fall [__] Winter [__] Spring	[<1] [1] [2] [3] [4] [5] [6] [7]	[__] Under 20 [__] 20 – 39 [__] 40 – 60 [__] Over 60

APPENDIX B

Subject’s Personal History

SUBJECT'S PERSONAL HISTORY

DATE____________

____
Last Name First Middle

____
Address City State Zip

_____________ _______________ ________
Home Phone Business Phone Sex

Person to Notify _________________________________ Relationship _______________

Address ____ Phone ___________________

Date of Last Examination ____

Family or Referring Physician
____

Address____

Handedness _______________ Hat Size_______________ Color Blind? _______

Vision ______/______

Event(s)______________ Time__________ Place ________ Out of ________ in age group.

Number of Years Participated ____________ Days per week_________________
Time per session______________

PERSONAL HABITS

Yes	No	Do you smoke regularly? Cigarettes Pipe Cigars # Years
Yes	No	Do you usually drink over 6 cups of coffee per day?
Yes	No	Do you regularly drink alcohol? 1oz. 2 oz. 3 oz. 4 oz. 5 oz. 6+ oz.
		Beer: (per day) 1 bottle 2 bottles Over 4 bottles
Yes	No	Do you have difficulty falling asleep?
Yes	No	Do you awaken early in the morning without apparent cause?

MEDICATIONS

Are you presently taking any of the following medications?

Aspirin, Bufferin, Anacin
Blood Pressure pills
Cortisone
Cough medicine
Digitalis
Hormones
Insulin or diabetic pills
Iron or poor blood medications
Laxatives
Sleeping Pills
Tranquilizers
Weight reducing pills
Blood thinning pills
Dilantin
Shots
Water pills
Antibiotics
Barbiturates
Phenobarbital
Thyroid medicine

Other drugs not listed:

Names and years of any operations that you have had:

Name any drugs to which you are allergic:

List the names of any diseases you have had which required hospitalization:

Serious illnesses you have had not requiring hospitalization:

Serious injuries or accidents:

Do you frequently have severe headaches?
If yes, answer the following:

Do they cause visual trouble?
Do they occur on one side of the head?
Do they awaken you at night from sleep?
Do they feel like a tight hat band?
Do they hurt the most in the back of the head and neck?
Does aspirin relieve them?

Have you ever fainted?
Spells of dizziness?
Spells of weakness in arm or leg?
Ringing in ears?

Have you ever had convulsion?
Double vision?
Pains in ears?
Nosebleeds?

Do you frequently have bleeding gums?
Do you frequently have trouble swallowing?
Do you frequently have hoarseness?
Do you frequently have a sore tongue?
Do you frequently have nausea and vomiting?

Have you ever had shortness of breath?

Doing your usual work?
Climbing a flight of stairs?
Which awakens you at night?
Do you have a chronic cough?

Which cause you to cough?
Accompanied by wheezing?
Have you ever coughed up blood?
Do you cough up much septum?

Do you ever have chest pain or tightness in the chest which begins when:

Exerting yourself?
Walking against the wind?
Walking up a hill?
Walking fast?
Walking in cold weather?
Upset or excited?
Radiates down the arm?
Disappears if you rest?

Occurs only at rest?
After a heavy meal?
Palpitations?
Do you sleep with more than 1 pillow?

If you have chest pain or tightness, please describe:

Have you recently had pain in the stomach which:

Occurs 1-2 hours after a meal?
Is brought on by eating fired foods, gassy foods?
Awakens you at night?
Is relieved by antacid medications?
Is relieved with milk or eating?
Occurs while eating or immediately after?
Is relieved by a bowel movement?
Loss of appetite?

Briefly describe your present medical symptoms:

APPENDIX C

Consent Form

INFORMED CONSENT FORM

Identification of Project/ Title	Differences in Central Nervous System Processing Between Aerobically Trained and Untrained Males and Females
Statement of Age of Subject	I state that I am at least eighteen years of age, in good physical health, and wish to participate in a program of research being conducted by Drs. Brad Hatfield and Laine Santa Maria of the Department of Kinesiology at the University of Maryland, College Park, MD.
Purpose	The purpose of the project is to investigate age and fitness effects as they relate to visual, behavioral, and cognitive efficiency.
Procedures	The procedures involve two testing sessions. On one day I will perform reaction time tasks, a finger tapping test, and a word recognition test. Additionally, EEG signals from the surface of the scalp will be monitored while I perform certain visual and mental tasks. The other day requires that I perform a submaximal exercise test to estimate aerobic capacity which consists of walking on a motorized treadmill. I will be given the opportunity to become familiarized with the treadmill and other test equipment. I understand that the test technicians are CPR certified, and there will be an ASCM (American College of Sports Medicine) certified technician in the building during the testing.
Confidentiality	All information collected in this study is confidential to the extent permitted by law. I understand that the data I provide will be grouped with data others provide for reporting and presentation and that my name will not be used.
Risks	EEG monitoring requires that I wear an electrode cap similar to a rubberized “swimming” cap. I understand that there is a small chance of localized skin reaction due to abrasion of the scalp at electrodes. I also understand that as a result of the exercise test, I may experience some soreness over a short period of time and that the statistics have indicated that approximately one nonfatal cardiac complication per 10,000 and one fatal complication over 70,000 participants have resulted from maximal testing. In medical terms this would indicate a RARE occurrence of problems. This is a submaximal test, therefore risks are even less than indicated.
Benefits, Freedom to Withdraw, & Ability to Ask Questions	I understand the experiment is not designed to help me personally, but that the investigators hope to learn more about exercise and the possibility of beneficial effects on the central nervous system. I understand that I am free to ask questions or to withdraw from participation at any time without penalty.

Medical Care	In the event of physical injury resulting form participation in this study, I understand that immediate medical treatment is available nearby at Washington Adventist Hospital. However, I understand that the University of Maryland does not provide any medical or hospitalization insurance coverage for participants in the research study nor will the University of Maryland provide compensation for any injury sustained as a result of participation in the research study except as required by law.
Contact Information of Investigators	Dr. Bradley Hatfield Room 2134C HHP Department of Kinesiology University of Maryland College Park, MD 20742 (301) 405-2485
Name, Signature, & Date	Signature of Subject __________ Date __________ Witness __________ Date __________

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