DOES LIFETIME ENGAGEMENT IN PHYSICAL ACTIVITY AFFECT EXECUTIVE COGNITIVE FUNCTION IN OLDER ADULTS?

Colleen M. McCracken

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Doctoral Committee

__________________________
Joel M. Stager, Ph.D.

__________________________
Peter R. Finn, Ph.D.

__________________________
Lesa Huber, Ph.D.

__________________________
David Koceja, Ph.D.

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Where do I begin? Ah, this has been a long road, with many twists and turns; and yet I managed to make it to the end! Hooray! This journey would not have been anything without some of the great people with whom I managed to share the ride. For setting the course for to the road less traveled, I thank my advisor, Dr. Joel Stager. Without your honesty, leadership, and openness this journey wouldn’t have been possible; and it probably would have been a lot less interesting! For always keeping wind in my sails, I thank my family. For keeping me sane and filling my life with laughter, tears, and happiness, I thank my Bloomington tribe. People have come in and out of the tribe over the years, but a few have remained strong. To the King family, who always welcomed me with open arms, I feel so honored to call you part of my family. Thank you for your endless wine, food, dance parties, and most importantly love. To Louisa Raisbeck, Andrew Cornett, Brian Wright, Carly Rasner, and Jenya Iuzzini you have helped to keep me grounded when I was sailing away, and uplifted me when the work seemed too much to bear. Thank you for encouraging and supporting me throughout this process of graduate school. To my editor and friend Elisabeth Andrews, your guidance, support and encouraging words helped me move beyond my inner critic so I could actually write. Thank you so much to my tribe for your love, support, and humor. Finally to my committee, thank you for your expert guidance throughout my graduate journey. I have learned so much from each of you, and these lessons I shall remember always.
Introduction: Executive cognitive functions are known to decline with advancing age. However, Kramer and colleagues (1999) showed with a modest walking protocol (~45min/day, 3 times/wk; for 6 mo.), executive cognitive functions improved in inactive older adults. Select habitually active adults (Masters Swimmers) are known to maintain frequent participation in physical activity into late life (Tanaka and Wilson, 2003). The purpose of the study was to examine executive cognitive functions in Masters Swimmers and compare this to more typical inactive older adults.

Methods: Thirty five (67.6yr ± 6.22) healthy, registered Masters Swimmers (MS) and thirty three (66.6 ± 5.33) self-reporting inactive controls (IC) completed Lifetime Historical Physical Activity Survey (LPHAS; Paffenbarger, 1978) to assess lifetime physical activity energy expenditures. Additionally, subjects performed three executive cognitive function tasks (Flanker, Task Switching, and Stopping).

Results: Executive cognitive function was different (p < 0.05) between Masters Swimmers and controls for flanker task trials (incongruent and congruent) and task switching. No differences between groups were apparent for the stopping task. MS and IC were confirmed to be different (p > 0.05) in accumulated energy expenditure the most recent time periods (Past Year activity, and Over the age of 65 yr.), however no differences were evident in total lifetime physical activity LHPA (MS: 38,891 ± 20,287 kcal/wk, IC: 29,561 ± 26,777 kcal/wk).
Conclusion: This study suggests that a lifetime of engagement in physical activity has cognitive protective benefits. These benefits might be due to differences in attention, speed of information processing, and perhaps low-level functioning. It is possible that a combination of these factors is responsible for the cognitive benefits demonstrated in this study. These findings lend support to engage in physical activity throughout the lifespan, especially in after the age of 65 yr.

Joel M. Stager, Ph.D.

Peter R. Finn, Ph.D.

Lesa Huber, Ph.D.

David Koceja, Ph.D.
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CHAPTER 1
INTRODUCTION

By 2030, the percentage of the U.S. population that is over age 65 will increase from 12.4% to 19.6% (US Census Bureau, International Data Base as cited in (63)). This increase was even more dramatic elsewhere - Singapore, for example, will see its 65+ population increase from 8.1 to 24.9% (US Census Bureau, International Data Base as cited in (63)). This grouping of the population begs a number of important questions for the health community. Will this increase in the aging of the population have a significant impact on our society? Although the effects of aging are multifactorial, is some amount of the decline attributed to aging mitigated through lifestyle choices? Cardiovascular function, cognitive function and brain health are among the leading health-related issues that can cause loss of independence in old age. To what extent can physiological “aging” can be delayed or prevented?

A number of experimental studies have indicated that exercise can slow or reverse age-related declines; whereas, low levels of physical activity have been associated with decreases in cardiovascular and cognitive function. Increasing exercise can attenuate the typical age-related decreases in cardiovascular and cognitive function. Studies conducted at the University of Illinois recently found that introducing modest aerobic exercise (walking) to sedentary older adults resulted in significant improvements in cardiovascular and cognitive function (27, 74). Additionally, Kramer and colleagues have seen increases in brain volume with exercise interventions, attenuating the typically observed cause of atrophy that accompanies older age (25, 26, 75).
These studies, however, followed individuals who transitioned from sedentary to active. Less is known about how consistently highly active older population compares with a consistently inactive cohort. This study aims to compare the cardiovascular and cognitive health of highly active adults with their habitually less active peers.

**Problem Statement**

Cardiovascular fitness and cognitive function typically decrease as a function of age. Engaging previously sedentary individuals in routine aerobic exercise has increased cardiovascular fitness and cognitive function. However, little is known about the effects of engagement in habitually high levels of routine exercise on cognitive function in older adults.

**Purpose of the Study**

The purpose of this study was to examine the relationship between long-term habitual exercise training and cognitive health in older adults.

**Significance of the Study**

Common physiological functions that deteriorate with age include a decrease in arterial compliance, an increase in blood pressure, a decrease in VO\textsubscript{2max}, a decrease in muscle mass, and a decrease in muscle strength (12, 33, 46, 63, 98). Recent research demonstrates that many of these aging characteristics may be slowed or even begin to be reversed through exercise training (16, 89, 92, 130). These studies, however, were experimental. It is not clear how persistent high levels of routine physical activity affect age-related declines in physiologic and cognitive domains.
Until recently, cognitive research held that once the brain matured, no new brain cells were formed. Similarly, age-related brain atrophy was thought to be irreversible and inevitable. New evidence, however, indicates that new brain cells can grow throughout the lifespan (41) and that physical activity can increase brain volume (25, 26), which is associated with an improvement in cognitive function (25, 54, 75). Given these promising interventions, the critical question emerges as to whether or not a lifetime of routine exercise can prevent the typically reported age-related reductions in cognitive function and brain volume.

**Hypotheses**

1) Individuals who have engaged in habitual physical activity will demonstrate superior executive cognitive functioning as compared to their inactive peers.

   a. Masters Swimmers will have faster stop-signal reaction times (RT) than their inactive peers.

   b. Masters Swimmers will have faster reaction times on the simple and choice reaction time tasks in the stop-signal task as compared to their inactive peers.

   c. Masters Swimmers will have faster task switch cost (RTswitch trial – RTnon-switch trial) than their inactive peers.

   d. Masters Swimmers will have faster response compatibility effects (RTresponse incompatible trial – RTresponse compatible trial) than their inactive peers.
**Research question**

1. Does a lifetime of physical activity attenuate age-associated declines in cognitive health?

**Delimitations**

This study was delimited to the following:

1) Masters Swimmers were healthy adults between the ages of 60-75 years participating in the 2013 Short Course Masters National Championships. Subjects were required to have participated in more than the ACSM exercise recommendations and have done so for at least 10 years.

2) Subjects will have at least some college education.

3) Inactive subjects were recruited from the Bloomington, IN community. Subjects did not complete any regular regimented exercise.

4) Subjects did not sustain any head trauma in their lifetime that induced cognitive damage.

5) Subjects were not smokers or smoked within the last 2 years.
Limitations

The results from this investigation were interpreted considering the following limitations:

1) Application of the data to the rate of loss (cognitive or otherwise) may not be appropriate as this study is cross-sectional rather than longitudinal.

2) Masters Swimmers subjects are Masters Swimmers tend to be highly educated and have a high socio-economic status.

3) Most Masters Swimmers in the Indiana area are of Caucasian descent.

4) Confounding factor with social benefits of masters swimming delaying cognitive decline.

5) Testing occurred in two different venues for the Masters Swimmers and the inactive controls.
   a. Although the testing conditions may have been different they may have resulted in less robust findings, and maybe mitigated those that did show differences.

Assumptions

This study was based upon the following assumptions:

1) Subjects did not have any neurologic disorders that would prevent them from participating in the study.

2) Subjects answered the questionnaires truthfully and honestly.
Definition of Terms

For consistency of interpretation, the following terms are defined:

- Cognition: Functions of the brain, such as memory, association, comparison, abstract reasoning (verbal and quantitative), spatial ability and manipulation, and synthesis (127).

- Exercise: A subset of physical activity that is planned, structured, and repetitive and has a final or intermediate objective: the improvement or maintenance of physical fitness (18).

- Highly Active Older Adult: An adult aged 55 years and older who habitually engages in more than the age recommended ACSM recommended daily physical activity guidelines. Given that less than 5% of the population older than 55 years of age meets the ACSM recommended guidelines for older adults (134).

- Inactive: Engagement in little to no physical activity (48).

- Moderate Exercise: As given by the International Physical Activity Questionnaire (IPAQ), “sports such as golf or doubles tennis, yard work, heavy house cleaning, bicycling on level ground, etc.” (Appendix A)

- Physical Activity: Any bodily movement produced by skeletal muscles that results in energy expenditure that can be measured in kilocalories. It can be further categorized into occupational, sports, conditioning, household or other activities (18).

- Physical Fitness: A set of attributes that is either health- or skill-related and can be measured with specific tests (18).
• Physiologic Functional Capacity: The ability to perform the physical tasks of daily life and the ease with which these tasks can be performed (131).

• Sedentary: A class of behaviors primarily characterized by sitting and associated with low metabolic expenditure (95).

• Vigorous Exercise: As given by the International Physical Activity Questionnaire (IPAQ), “jogging or running, swimming, strenuous sports such as singles tennis or racquetball, digging in the garden, chopping wood, brisk walking, etc.” (Appendix A)
CHAPTER 2

REVIEW OF LITERATURE

The following review of literature will examine background information on: 1) Physiologic and Cognitive aging, 2) Assessing Physical Activity, 3) Exercise Interventions on Cognitive Aging, and 4) Assessing Executive Cognition.

**Physiologic and Cognitive Aging**

What is aging? Aging can be defined in many ways, from simply ‘getting older’ to the complex physical and mental deterioration that ultimately leads to death (63). Typically, aging is characterized by declines in function in all organ systems of the body (72). Numerous studies have shown that many physiologic and cognitive functions decline in a linear fashion from 30 years to 65 years of age, after which the rate of decline increases (42, 46, 64, 131). In fact, some studies suggest that after 65 years of age, the rate of decline increases exponentially rather than linearly (42, 46, 64, 131). Regardless initial health status, the rates of decline in physiologic function are sex specific with women declining at 0.6% per year until 65 years and men at 0.5% per year until 70 years (117). Thereafter, rates increasing exponentially rather than linearly (117).

There are numerous theories of how aging happens, or what causes aging. A review (88) cites 300 different theories to understand the complex processes that contribute to aging. Although much work has been done to understand the complex processes of aging, there is not one theory that encompasses all aspects of the aging process. However, there are
numerous theories that overlap, allowing understanding of aging to come from multiple perspectives.

There are two main types of biological aging theories, 1) programmed and 2) damage or error theories (68). Programmed theories are based on the idea that aging follows a timetable similar to childhood development and that aging is something that is supposed to happen at a set time (68). These theories Jin (68) has categorized into programmed longevity, endocrine and immunological. Programmed longevity arises from the thought that certain genes responsible for DNA replication may be scheduled to switch on/off switch-off signaling aging to start or progress (68). Endocrine theories look at changes in hormone production and function with age. A common factor in these theories is the age-related changes to the insulin/insulin-like growth factor-1 (IGF-1) pathway (136). Immunological theories are based on data that show immune system effectiveness peaks at puberty and its function decline contributes to the aging process (68). These programmed theories take multiple angles to examine the underlying contributors to the aging process.

The damage or error theories encompass a large scope of the contributing factors to aging. There are six popular theories accepted as components of the damage or error theories. The wear and tear theory was proposed in 1882, by a German biologist, Dr. August Weissman (68). This theory compares parts of the body to car parts and that with time, they eventually wear out. Alternatively, the rate of living theory suggests that the greater the rate of an organism’s basal oxygen metabolism the shorter the lifespan. This has been supported by research examining the IGF-1/growth hormone pathway. Also, researchers have examined caloric restriction as ways of increasing longevity (110). These theories suggest
that body parts may wear out and that there’s a certain allotment of expendable energy that can be used before death is inevitable.

Alternatively, some research has shown that by decreasing the amount of energy expended (by limiting the metabolic rate from a lack of caloric consumption) life can be prolonged. Although caloric restriction has been shown to be effective in increasing longevity in rodents, it is not clear if the same effects can be seen in humans. Mostly, caloric restriction in humans has been effective in decreasing body mass index, and the risk of developing type 2-diabetes and atherosclerosis (60). Observational data of Okinawan centenarians, older adults who have lived impoverished and therefore engage in caloric restriction from a lack of resources to purchase adequate foodstuffs, do not show increases in longevity per se although Okinawa has the largest number of centenarians per capita in the world (60).

Another three theories take into account the damage (internally or externally) that the body undergoes with advanced age. The cross-linking theory suggests that aging is a slowing down of body processes as a result of genetic cross linking and damage (68). Similarly, the somatic DNA damage theory proposes that DNA damage occurs continuously and the repair mechanisms cannot keep up with the demand. The damage accumulates; mutations occur and cause cellular malfunctioning (68). These malfunctions become greater over time and contribute to the aging processes. Another widely accepted theory shares similarities with the cross-linking and somatic DNA damage theories. The free radical theory states that reactive oxygen species (ROS) and free radicals are formed in response to the environment (sunlight) and as a consequence of cellular metabolism (105). These free radicals cause damage to cellular components, cells, and organs. The accumulated damage is associated
with cellular and organ failure. As suggested by these theories, aging is a process brought on by damage accumulating and the body not being able to match the demand for repairs. All of these theories are plausible and there are a multitude of physiologic changes that occur with aging.

The markers of physiologic aging appear in a many forms. Among them are, decreases in growth hormone (GH) and IFG-1. These decreases contribute among other things to typical age-related changes in the cardiovascular system such as decreased maximal heart rate, elevated resting blood pressure, decreased vascular compliance, cardiac output, and maximal oxygen consumption (VO$_{2\text{Max}}$)(7). Decreases in cardiovascular function, in turn, reduce an individual’s functional capacity therefore limiting physical work capacity. Additionally, decreases in cardiovascular function contribute to sarcopenia (the loss of muscle mass) (7, 113-115). However, sarcopenia can be caused by a number of factors, such as decreases in blood flow to skeletal muscles and, of course, decreased physical activity (112, 115, 116, 123). Common adaptions to decreased physical activity include a reduction in blood flow to the skeletal muscles. This is in part due to decreased cardiac output, and also to a decline in the number of arterioles supplying the muscle (65, 66).

Following suit with the rest of the body, there are numerous changes cognitive function and brain structure with advancing age. There is some evidence that cognitive function may begin to decline around 30 years of age (98). Just as with physiologic aging, cognitive function declines at a steady rate, then begins to accelerate after a certain age (22, 52). Most cognitive functions (attention, working memory, executive function, and processing speed) show declines in function with age, however world knowledge, implicit memory, and verbal abilities are preserved in older adults. One of the most impacted areas
of cognition in older adults is the domain of memory. Recent research shows that higher levels of education can successfully slow the age-related decline in memory functions in older adults (30) (21). Although there is a strong relationship with memory functions, education level is not as powerful of a predictor for slowing the decline in fluid abilities and speed of information processing (73). The relationship between education and cognitive decline is a strong one, however socioeconomic status can add influence it (73). Although socioeconomic status can modulate the relationship between education and cognitive decline, the relationship of cognitive function and education alone accounts for a lot of the variance in declining cognitive function with age (21).

One aspect of attention, the ability to suppress irrelevant information, is critically important for older adults to complete tasks. Of the cognitive functions affected by aging, the most affected seem to be those of the executive cognitive functions (22). Although research is not entirely conclusive as to the scope of the executive cognitive functions (69), most researchers define the executive functions as attentional control, planning, set-shifting, and verbal fluency, all of which have been widely studied (69). These functions regulate behavior by allowing an individual to suppress a response (inhibition), quickly process information (information processing), or quickly switch from one task to another (attentional-control).

The executive functions are known to be associated with the frontal cortex in the brain (106). Research has shown that brain volume is known to decrease with advancing age and the frontal cortex has been shown to deteriorate earlier that other regions of the brain (106, 107). Other brain structures of particular interest to aging researchers have been the hippocampus and temporal lobes which are associated with memory and learning (38).
Deteriorations in both of these areas have been implicated in memory impairment and dementia (38). The executive functions are known to decline with advancing age (69, 98), and until recently this cognitive decline was accepted as an inevitable “fact of aging.” Recent research, however, has demonstrated that exercise interventions can be successful in enhancing executive cognitive functions, even in those whose cognitive function is impaired (74). However, exercise is not the only factor that contributes to cognitive function and brain structure with older age.

Social support and social integration are key factors that can have a large impact in older adults’ lives. The influence of social support in older adults can result in increased physical and mental well-being, reduced negative effects of stressful life events, reduced disability risk, improved cognitive abilities, and increases in feelings of personal control, autonomy, and competence. Social support and social integration are both associated with lower rates of diseases (heart disease, hypertension, and depression) that are associated with cognitive decline (121).

Social support has been shown to have beneficial effects on neuroendocrine and cardiovascular reactivity, meaning when older adults are in stressful situations their heart rates, blood pressure, and hormone levels show lower effects of stress (121). Additionally, it’s possible that positive social interactions have intrinsic qualities that promote cognitive engagement therefore they can contribute to increases in cognitive function (121). Research has shown older adults who had limited social support were 3.6 times more likely to die within the next 5 years as compared to those with extensive social support (8). In a longitudinal assessment of the influence of social support on highly-functioning older adults’ cognitive function baseline levels of social support were significant, independent predictors
of better cognitive functioning at follow-up (7.5 yr.) (121). Additionally, research shows that older adults with strong and positive social networks were 60 percent less likely to develop signs of dementia over the 3 yr. follow-up (45). These studies demonstrate some of the beneficial aspects of engagement in social networks. Researchers have also conducted intervention studies and assigned older adults to social or non-social groups. Participants in social groups demonstrated improved cognitive functioning (19). These studies add to the body of knowledge showing that positive social interactions and strong social support networks have beneficial effects on older adults’ cognitive functioning. Alternatively, older adults’ without strong social support show increased psychological reactivity and an increase in negative effects of stressful life events (62). It is clear that a strong social support network is a factor in preserving cognitive function in older adults.

Researchers have hypothesized that engagement in novel activity can have benefits for older adults’ cognitive function. Park et al., (99) have hypothesized that productive engagement is an activity where the older adult is acquiring a new skill, for instance playing the piano, creates new neural pathways whereas taking lessons for an adult who has been playing for years does not have the same effect (99). This theory was examined by testing the cognitive function of older adults after an intervention in the theater arts (94). The authors suggest that theater arts are an ideal productive engagement intervention since they engage deep processing of motives and interactions and this processing is thought to generalize to information processing (99). Additionally, deep meaningful processing of information has been shown to improve memory and neural activations in older adults (99). The intervention subjects for this study were enrolled for a month-long program whereas the other groups were either in a visual arts program or participated in a phone interview. Adults
enrolled in the intervention showed improvements in recall and problem-solving ability and enhanced well-being (94).

Researchers have examined the effects of older adults’ participation in leisure activity to examine what might contribute to healthy cognitive function with advanced age. In a study of 500 older adults, researchers found that regular engagement in leisure activities (reading, playing board games, dancing, and playing a musical instrument) were associated with a reduced risk of dementia (139). Similarly, a larger study of 4,000 community dwelling older adults showed that the involvement in more cognitively stimulating activities on a daily basis was associated with a reduced rate of cognitive decline (141). These studies results have been corroborated by many others showing that regular involvement in cognitively stimulating activities reduces the likelihood of developing Alzheimer’s disease and dementia (53).

One of the most impacted areas of cognition in older adults is the domain of memory. Recent research shows that higher levels of education can successfully slow the age-related decline in memory functions in older adults (30) (21). Although there is a strong relationship with memory functions, education level is not as powerful of a predictor for slowing the decline in fluid abilities and speed of information processing (73). The relationship between education and cognitive decline is a strong one, however socioeconomic status can add influence it (73). Although socioeconomic status can modulate the relationship between education and cognitive decline, the relationship of cognitive function and education alone accounts for a lot of the variance in declining cognitive function with age (21).
In summary, many physical functions deteriorate with age. Physiologically, neurotransmitter output decreases, circulating hormone levels decrease, and cardiovascular function decreases. These changes impact (collectively and individually) cognitive functioning and physiological functional capacity. For the aging individual, the attenuation of even one factor can have a major influence on the maintenance of quality of life.

**Aging and Physical Exercise**

Exercise is defined as physical or mental exertion especially for the purpose of athletic training or health improvement (1). Specifically, exercise induces stress (the nonspecific response of the body to any demand made upon it) (122). Exercising (or stressing) the body for long periods of time generally leads to physical adaptations. Physical exercise and its adaptations create a pattern of reinforcement wherein an individual induces the stress, which leads to an adaptation that enables the individual to endure greater stress. Thus, an individual can endure training for longer periods based upon the frequency, intensity, and duration of the training. Physiologic adaptations from aerobic training include decreased resting heart rate, increased stroke volume, increased cardiac output, lower resting blood pressure, increased total blood flow to the body, increased mitochondrial density, increased muscle mass, increased capillary density, increased aerobic enzyme activity, and increased a-vO2 difference (12, 61). Notably and importantly, the decline of many of these functions is commonly associated with advanced age. Significant to the present discussion is, however, that these exercise-induced adaptations have been observed even among in older individuals.
Cardiovascular training adaptations have been observed in groups ranging across the age and health spectrums (143). Wilson & Tanaka (2000) performed a meta-analysis to examine the relationship between habitual aerobic exercise status and age-related decline in VO$_{2\text{Max}}$ (142). They analyzed data from 242 studies categorizing subjects into three groups by exercise status: 1) *endurance trained*, meaning regular vigorous endurance (e.g., cycling, swimming, running) training ≥ 3 times/wk for > 1 yr; 2) *active*, meaning occasional or irregular participation in moderate (e.g., walking, basketball, dancing) activity ≤ 2 times/wk; and 3) *sedentary*, meaning no significant performance of any aerobic exercise. The age-related decline in VO$_{2\text{Max}}$ was similar for each group (rate in ml$^{-1} \times \text{min}^{-1} \times \text{kg}^{-1} \times \text{year}$: -0.40, -0.39, -0.46; *sedentary, active*, and *endurance* trained, respectively). However, differences in age-related decline in HR$_{\text{max}}$ were observed between the groups (–0.81, –0.67, –0.63; in bt$^{-1} \times \text{min}^{-1} \times \text{yr}^{-1}$ *sedentary, active*, and *endurance* trained, respectively). The sedentary group had the highest rate of decline in HR$_{\text{max}}$. Endurance-trained subjects exhibited a higher baseline of physiological capacity; they were able to perform activities their sedentary peers could not. This important result has profound implications for older adults.

The blunted decline in HR$_{\text{max}}$ for active and endurance athletes supports the suggestion that increased levels of physical activity throughout a lifetime can attenuate age-related cardiovascular changes. Maintaining aerobic training throughout life can perturb the typical decline in VO$_{2\text{Max}}$ (49, 71, 144). However, the relationship between habitual exercise status and age-related decline in VO$_{2\text{Max}}$ may depend on sex.

Wiswell et al., (144) examined master athletes to examine the relationship between performance, training intensity, and frequency of training with cardiovascular function, muscular strength, bone status, and body composition. The study examined 224 masters
athletes (146 men, 40-86 years of age) who were actively training and competing at the time of baseline measurements. The majority of the subjects competed in running events (87% of men and 91% of women) with 40% considering themselves to be highly competitive. The results of the study indicate a difference in the rate of decline in VO$_{2\text{Max}}$ between sexes. Specifically, men lose maximal aerobic power at a rate of 1.2% per year from age 40 to 80 and women at a rate of 0.8% per year after the age of 40. The authors also note that several of the functional and performance variables do not decline in a linear manner; and that there is a more rapid loss in VO$_{2\text{Max}}$ between 20 and 30 years of age, which accompanies a proportional decrease in training volume.

In a follow-up study, Hawkins et al., (49) sought to assess the change in VO$_{2\text{Max}}$ and maximal heart rate in master endurance runners over a ten-year period. A group of master athletes (men, n=86; women, n=49) were tested for body composition, VO$_{2\text{Max}}$, and other cardiovascular measurements in the laboratory. Regression analysis was used to explore the relationship between the rate of decline in VO$_{2\text{Max}}$ and training volumes in both trained and sedentary individuals.

Surprisingly, the reduction in VO$_{2\text{max}}$ with age for masters athletes was not different from the rate of decline in sedentary adults. Further, this study proposed that a reduction in training volume is a main factor in the decline in VO$_{2\text{Max}}$. Wiswell et al., (144) and others have demonstrated that the age-related decline in VO$_{2\text{Max}}$ can be attenuated by habitual physical activity (71, 102, 144). Further, additional research shows that aerobic training can increase VO$_{2\text{Max}}$ even in older individuals aged 60-75 years (60-70 yrs, (55); 55-80 yrs (38); 60-79 yrs (26).
Adaptations from physical activity occur with advancing age, and can continue to be observed even for the oldest of ages. Although, an older individual’s physiological capacity for exercise-related gains (as compared to younger adults) is diminished, the benefits attained from physical exercise are worthwhile. Much of this literature has examined the age-related change in aerobic capacity. It may not be possible to completely separate the inactivity-related declines from the age-related declines due to the ethics behind keeping someone completely inactive for an entire lifetime. However, it is possible to examine individuals who engage in lifetime of habitual physical activity and compare their physiologic characteristics to those who have not engaged habitual physical activity. Thus, examining the differences in the physiologic characteristics of the groups is important. Nevertheless, this literature supports the supposition that a lifetime of habitual physical exercise can attenuate some of the typical age-related declines in aerobic capacity.

Assessing Physical Activity

One of the keys in exercise intervention research involves appropriately assessing physical activity status. A number of methods have been employed to accurately assess physical activity (15, 31, 32, 44, 51, 59, 70, 77, 104). Subjective measures (questionnaires, surveys, interviews, and diary/daily logs) are versatile and examine a broad range of specific activities (lifetime physical activity questionnaire) or general “types” of exercise (International Physical Activity Questionnaire). They are inexpensive, easy to administer, and of low burden to the subjects (104). However, one of the biggest barriers of quantifying physical activity with self-report methods is accuracy. Subjects may not always correctly recall their activity, therefore over- and underestimation of activity is possible (134).
However, since they are widely used, they are popular for comparing many different populations on the same measure.

Many questionnaires have been developed to assess physical activity; however there are few that can assess lifetime physical activity. One in particular, the Lifetime Physical Activity Questionnaire, assesses physical activity from youth into old age (77, 97). In 1978, Paffenbarger and colleagues developed the questionnaire when examining physical activity and its relation to heart attack risk in the Harvard Alumni Study (97). Since the study was retrospective, the survey was developed to examine lifetime physical activity. This survey examines light sporting activities, as well as strenuous sports. Weekly energy expenditure (kcal) is calculated by using published values (100) of objective measurement for each sporting activity (97).

Direct methods (heart rate monitors, pedometers, doubly labeled water, indirect calorimetry, and accelerometers) have been used for measuring physical activity in laboratory and free-living settings. In fact, many of these methods are the basis for the energy expenditure measures of surveys. These objective methods of measuring physical activity remove many of the confounds of subjective measures (11, 31, 32, 44, 51, 67, 93, 101, 104, 111, 120, 135, 140). Additionally, they have been used to increase precision and obtain reliable estimates of energy expenditure and have been very useful in obtaining an accurate snapshot of physical activity levels (134). However, most of these methods are relatively expensive, require special training, are somewhat invasive, and are not suitable for field research (104). One measure, accelerometry, has been used widely and in some field research (134). Accelerometers have been widely utilized due to their low subject burden and long battery life. Accelerometry has been used to measure physical activity in all age
group and ethnicities (134). Most accelerometers are worn on the hip or wrist and can measure physical activity during wear time (134). However, these monitors do not measure upper body movement or exercise through cycling or swimming (when worn on the hip) (134).

Until recently, accelerometers were only able to examine the duration of activity based on counts the relative intensity of the exercise. New technology has paired accelerometry with heart rate monitoring in the Actiheart accelerometer. The blending of these technologies allows experimenters to examine the heart rate with each activity. These two indices of intensity give a well-rounded view of daily physical activity. This accelerometer is worn on the chest, attached with two EKG electrodes. It can be worn for days at a time, and is waterproof. Therefore, it can measure some of the activity and intensity associated with swimming and upper body movement. Subjects must be taught how to properly attach the device to the electrodes, the proper technique for attaching the electrodes to the skin, and the proper position for the electrodes. Some of the limitations with this accelerometer are that subjects may be allergic to the electrode adhesive, electrodes can slip off in water or with profuse sweating, and improper electrode positioning decreases heart rate signal.

Although self-reported measures (HPAS) of physical activity were used in the current study, other research with accelerometry corroborates these results. Recent research has shown that over 90% of older adults do not engage in the recommended amount of physical activity (30 min most days of the week) as set forth by the Centers for Disease Control and the American College of Sports Medicine (134). Troiano et al., (134) examined the physical activity status of older adults with accelerometers and found that only 5% of the subjects met
the recommended amount of physical activity. Using Actiheart accelerometers that measure heart rate, as well as activity counts, studies from IU have shown that the intensity and duration of physical activity of Masters Swimmers is different than in sedentary adults, Figure 5 (57, 87). These studies compared activity intensity as the amount of time spent in particular heart rate zones (based on predicted HR_{max} and accelerometer counts), between active and inactive adults. Results showed that both groups spent similar amounts of time in low level physical activity; however the Masters Swimmers spent more time in higher intensity physical activity (57, 87).

**Figure 1.** The average daily time (min/day) spent in different physical activity levels of highly active and regularly active subjects. * indicates a significant difference (p < 0.05). (McCracken et al., 2012)
Physical Activity and Cognitive Function

Many studies have identified improved cognitive function in older adults who exercise regularly or as part of an exercise intervention (4, 5, 13, 14, 24, 26, 34, 40, 47, 103). There are many factors that contribute to the relationship between physical activity and cognitive function. Researchers have speculated and identified many of these variables as moderators (40, 74). These factors range from physiological (aerobic fitness, hormones, blood pressure) to disease and health states (hypertension and Alzheimer’s) (126). Physical activity has an entire cascade of effects it produces in the body ranging from increased blood flow in to the skeletal muscles and brain, to stimulating hormone production in both types of tissue. These physiological responses are a large part of the relationship between physical activity and cognitive function. Additionally, the specifics of physical activity (type, intensity, and duration) and type of cognitive functions being measured are part of the “equation” that determines whether or not measurable differences can be seen from exercise interventions (24).

Animal models, mostly rat models, have allowed researchers to examine specific structural and chemical mechanisms that demonstrate how exercise affects brain tissues. Brain structure changes, including neurogenesis and angiogenesis, have been shown to be up-regulated through peripheral and central regulation of growth factors (29). Increased vascularization in peripheral (body’s) vascular system is a common adaptation to aerobic exercise. Physical activity increases blood flow not only to the skeletal muscles but also to the brain. This increased blood flow stimulates vascular endothelial growth factor, VEGF, and brain derived neurotropic factor, BDNF, production in the brain; these help increase vascularization. These hormones stimulate angiogenesis, the growth of new capillaries off of
existing ones. An increase in the capillary network increases blood flow to certain areas of the brain. Thus, an increase in blood flow allows these areas to be used in cognitive processes.

Animal research demonstrates that for rats who exercise, their brains undergo vascular changes and as a result have greater blood flow to areas of the brain. The work of Brown et al., (13) and Churchill et al., (23) demonstrates that what is intuitively understood for the rest of the body. Specifically, exercise increases short-term and long-term potentiation in the dentate gyrus (DG) (43). These increases contribute to learning and are similar to effects of learning in the brain. Additionally, exercise increases dendritic length, dendritic, complexity, spine density and neural progenitor proliferation in the DG (35). This could be due to tropic factors: BDNF, IGF-1, and fibroblast growth factor-2, FGF-2.

Exercise does increase the levels of BDNF in the DG and it promotes survival of the new neurons (29). Exercise not only boosts levels of IGF-1, but it increases brain uptake of circulating IGF-1 (2), which is a factor in neuronal differentiation and increases BDNF gene expression (17). Typically IGF-1 levels decrease with advanced age, however exercise can counter that reduction. This is a positive feedback system for BDNF. Exercise increases IGF-1 production, and the more BDNF that is circulating increases gene expression for BDNF. The brain vasculature follows similar adaptations to aerobic exercise, thus it is possible that engaging in physical activity throughout life can have a multitude of benefits.

Not only does exercise increase BDNF in the brain, but it also increases the expression of genes associated with plasticity. When combined with BDNF these factors can promote brain vascularization, neurogenesis and functional changes in neuronal structure (28, 29). Many of these changes have been seen in the hippocampus, which is a center for
learning and memory (29). There are common mechanisms regulating behavioral plasticity and can be seen in exercise and behavioral enrichment programs. Together these two paradigms could have a big impact on future training programs for older adults.

In human models, this has been demonstrated in older adults who exercise. Through functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) analysis research has been able to analyze blood flow to the brain while subjects perform cognitive tests. Researchers used fMRI analysis to investigate the age effects on verbal and spatial memory. They showed that during the tasks frontal cortex activity was lateralized in young adults. However, in older adults the activation pattern was bilateral. Researchers suggest that the dedifferentiation of brain regions for cognitive processes could be evidence of a decline in function or shows a compensatory mechanism for cognition. Research comparing exercising vs non-exercising older adults has shown that by engaging in physical activity regions of the brain show greater activity, which could mean that there are increases in all of the factors increasing blood blow.

Recent research demonstrates that older adult women with higher aerobic capacities have increased cerebral blood flow (CBF) as compared to sedentary women (13). Not only did the more active subjects have improved CBF, they also demonstrated lower blood pressure and lower mean arterial pressure (MAP). Improved CBF and lower MAP values were associated with better cognitive functioning in the higher fit group. It has been well documented that high blood pressure is negatively correlated with cognitive functioning in older adults (13, 83). Additionally, hypertension is a known risk factor for developing vascular dementia and mixed vascular Alzheimer’s dementia (13).
Research examining the effects of fitness on cognition started with testing simple reaction time, choice reaction time, and movement time of older racquet sportsmen with non-exercisers (125). More recently, researchers have used cross-sectional and longitudinal studies to elucidate the relationship between cardiovascular fitness and cognition in older adults (25-27, 75, 137). Studies have varied in length intervention, type of exercise, type of cognitive tests, and subject populations. Researchers at the University of Illinois have conducted a number of studies examining the relationship between cognitive aging and aerobic exercise (24-27, 36, 37, 74-76, 84). Their studies have primarily used an aerobic exercise intervention to examine the effects of aerobic exercise on cognitive function, cortical plasticity and brain volume in older adults (26, 27, 37, 54, 74-76). Additionally, a few cross-sectional studies have looked at the relationship between fitness status and cognition (25, 36). These studies primarily studied older adults, 55 to 80 years of age, who were free of neuro-cognitive diseases, and were considered to be relatively healthy. A thorough review of these studies follows:

Kramer and colleagues (1999) studied 124 previously sedentary older adults for 6 months by randomly assigning them to one of two groups: an aerobic training (walking) group (AT), or a stretching and toning group (ST). They administered VO\(_{2}\max\) tests, and executive function tasks (task switching, response compatibility, and stopping). Task switching is a measure of set shifting, the cost of switching between tasks measured by slower reaction time on switching trials. It is quantified by the difference in reaction time (RT) in trials where subjects switch between tasks and those where they continue to perform the same task. Response compatibility is a measure of response suppression, attention, and the ability to ignore task irrelevant stimuli. It is quantified as the difference in reaction times
between trials of stimuli presented with similar distractors compared to trials where the distractors are different from the stimuli. Stopping is a measure of inhibition, and is assessed as the difference in reaction times between trials of a choice reaction time task (CRT; go-trial) and a CRT when a stopping tone is present (stop-trial).

The results of this study indicate that the AT had significant improvements in VO\textsubscript{2Max}, task switching, response compatibility, and stop-signal tasks following the exercise intervention. Subjects did not improve on non-executive control dependent functions (non-switching trials, response compatible, and simple reaction time). Authors suggest this indicates selective improvement in that only executive functions in the frontal and prefrontal areas show benefits from increased physical activity.

To extend this line of research, Colcombe et al., (25) used fMRI to examine the relationship between aerobic fitness and in vivo brain tissue density in an older adult population. The subjects included 55 adults (31 women, 55-79 yr; 66.5 ± 5.3), were well educated (16.1 ± 2.9 yr), cognitively healthy (mini-mental state examination scores, 24-30; 28.6 ± 1.9) and had normal cardiovascular health (VO\textsubscript{2Max}, 11.2 - 49.9 ml*kg\textsuperscript{-1}*min\textsuperscript{-1}; 31.1 ± 8.5 ml*kg\textsuperscript{-1}*min\textsuperscript{-1}). The subjects performed a 1-mile walk to estimate VO\textsubscript{2Max}, and had a fMRI to identify the regions of the brain hypothesized to be affected by fitness. The areas of the brain that showed the most age-related declines in grey matter also showed the most sparing effects from fitness. This finding is a great observation, however the direct link cannot be made, due to the cross sectional nature of this study. Therefore the authors cannot conclusively state that exercise has mediated the greater brain volume in the active. Additionally, the authors note that fitness has little effect on brain tissue density, which tends
to decrease with advanced age. However, they claim fitness has a detectable role in the age-related decline in brain tissue density.

In an attempt to further examine structural changes in the brain associated with age and cardiovascular fitness, the same researchers (27) conducted another investigation utilizing both cross-sectional and longitudinal designs. Two studies were conducted: 1) Cross-sectional: 41 older adults (high-fit age: 66.23 ± 8.17 yr; low-fit age: 67.86 ± 7.79 yr) completed the following measures: VO\textsubscript{2max} estimated by Rockport 1 mile walk test, cognitive testing (flanker task which assesses working memory and inhibition), reaction time, and fMRI while performing flanker task and a go-no go task.  2) Longitudinal: 29 older adults, 65.6 ± 5.66 yr, 11 men, were randomly assigned to an aerobic training group or stretching toning group and for six months. Both groups met three times per week and performed exercises for ~40-45 min. VO\textsubscript{2} peak was measured through a modified Balke protocol graded max test on a treadmill; subjects participated in the same cognitive tests as study 1.

The high-fit and low-fit subjects in study 1 were statistically different based on VO\textsubscript{2max} values, although they did not differ in age, education, IQ and presence of hypertension. In study 2, subjects showed a significant reduction in conflict, meaning they demonstrated faster reaction times on trials with conflicting stimuli whereas control subjects did not. The flanker task results showed that both groups in study 1 had low error rates, but high-fit subjects were more efficient (interference 18% vs. 26%) in dealing with conflicting cues than the low-fit subjects. Additionally, for the high-fit subjects fMRI results show increased activation in areas associated with attentional control, with reduced activity in the anterior cingulate cortex. Authors suggest that increased cardiovascular fitness is associated
with increased task related activity in regions of the brain thought necessary for successful task completion.

fMRI examinations following the exercise intervention in study 2 showed increases in grey and white matter, in the areas associated with executive functions, frontal and temporal lobes (27). Specifically, the areas associated with executive function show the most greater increases in plasticity, volume, and vascularity (27). Additionally, tests of cognitive function confirm improved cognition following the exercise intervention (27).

One of limitations of these studies is that the subjects in study 1 were compared against each other as being high-fit or low-fit and separated by a median split although, high-fit and low-fit were not quantified with actual values. Authors noted groups differed significantly in VO₂Max but did not report mean values. No data on VO₂Max for either study was presented except for % increase in VO₂Max (10.2% vs. 2.9%) in study 2.

Other research has shown that the degree or extent of social interaction, education level, cognitive training, cardiovascular disease (risk factors), and diet are factors that can influence cognition (3, 36, 81, 98, 137). While most studies report education level (25-27, 40), cognitive status (25-27, 36) hormone replacement therapy (25-27, 36, 37), and hypertensive status (25-27) as moderating variables, others have failed to mention potential factors (social interaction, cognitive training, work environment, physical activity routine) than can influence cognitive gains. The literature supports cardiovascular fitness and exercise as an inexpensive intervention to improve cognition (25-27, 40). However, these reports have been primarily conducted cross-sectionally or occasionally longitudinally in previously sedentary cohorts (25-27, 36, 54). The methods of measuring cardiovascular
fitness have been VO$_{2\text{max}}$ testing or more commonly VO$_{2\text{max}}$ indirect estimation (25-27, 36, 40, 75). Subject’s daily activity, regular fitness routines, and cognitively stimulating activities were commonly not reported. Although there are limitations for many studies, researchers have examined common factors contributing to significant outcomes in this line of research (24, 40, 124).

In an important report, Colcombe and Kramer (2003) conducted a meta-analysis examining the effect of fitness interventions on cognitive processes. This meta-analysis studied the effect of fitness interventions on cognitive processes from 18 different studies (24, 40). Part of the motivation of the authors in writing this article was to address problems the current literature had not addressed. The influence of moderator variables on the exercise and cognition relationship was not examined in previous studies. Hence, effect sizes of the outcomes and moderator variables were calculated to evaluate the relationship of fitness interventions on cognition. These analyses also examined the results when accounting for certain methodological factors: the wide age range of groups studied; differences in nature, intensity and length of aerobic exercise interventions; the type of fitness measures; the initial health and fitness level of participants; subject’s gender and type of cognitive tasks; and nature of control groups. Another methodological limitation of previous research was for the acquisition of fMRI data the semiautomated segmentation technique does not allow for precise examination of the mechanisms that cause changes in brain structures as a result of exercise intervention.

Authors identified four types of hypotheses regarding cognitive processes: speed (low-level neurological functioning such as simple reaction time or finger-tapping), visuospatial (ability to transform or remember visual and spatial information), controlled
processing (tasks that require some cognitive control, such as pressing different keys for choice reaction time), and executive control (tasks relating to the planning, inhibition and scheduling of mental procedures). These hypotheses reflect what the different research teams postulated were the most sensitive to aging. The cognitive processes examined were categorized as: speed, visuospatial, controlled processing and executive control. The authors also examined the effect of different types of exercise interventions used in the research. Exercise was characterized as: aerobic or combined (aerobic and resistance exercise). Exercise bouts were categorized by duration: short (15-30 min.), moderate (31-45 min.), and long (46-60 min); and intervention duration was categorized as: short (1-3 mo.), medium (4-6 mo.), and long (6 + mo.). Lastly, the authors analyzed subject characteristics, categorizing ages as: young-old (55-65 yrs.), middle-old (66-70 yrs.), and old-old (71+).

Analyses of effect sizes (ES) show that, of the cognitive processes, executive processes are most effected (ES = 0.68, p < .05) by exercise interventions compared to other types of tasks. Controlled tasks respond more (0.461, p < .05) than spatial (0.426, p < .05) and speed tasks (0.274, p < .05). Additionally, when controlled tasks were separated from the overlap of executive and spatial tasks, ES was different from zero, meaning: controlled tasks show an effect from exercise interventions. These results are meaningful as they provide information which cognitive processes have potential to be affected by an exercise intervention.

Observations of intervention characteristics resulted in combined exercise having a larger effect than aerobic exercise, although both yield high effect sizes (ES .59 vs .41, combined and aerobic, respectively). The intervention length analysis demonstrated that long interventions yielded higher effect sizes than short, and both were significantly larger
than mid (0.674, 0.522, and 0.269; long, short, and medium, respectively). Finally, the exercise session analysis indicated that moderate and long sessions resulted in greater outcomes, whereas short sessions were not different from zero (0.614, 0.466, 0.167; moderate, long, and short, respectively). Middle-old and old-old showed the highest effect sizes (.693, .594, respectively) whereas, the young-old showed a small effect (.298). Other analyses showed that when studies were comprised of more than 50% women subjects ES were larger than those with less than 50% women subjects suggesting a sex bias. Interestingly, in studies that were comprised of more than 50% men, the ES was still different from zero (0.604, 0.150; for women and men, respectively).

It is notable that exercise intervention length showed high effects for long and short interventions whereas medium length interventions yielded a much smaller effect. While it is also surprising that studies with a higher percentage of women yielded higher effect sizes, it may be that women were not as active throughout life and therefore could gain the most from exercise interventions. Also, women tend to live longer than men, which may influence why more women would be available to participate in studies. One of the biggest contributing factors to these studies is that all subjects must be sedentary. These studies do not examine the effects of exercise on older adults who have been regularly active.

One seminal study that led much of this research, Kramer et al., (75) showed great improvements from a very modest 6 month walking protocol. Kramer’s study represents the foundation upon which the proposed study is based. Kramer et al., (75) report that as a result of the aerobic training, executive functions in the older adults showed significant improvements. These results were part of the motivation for examining whether or not executive cognitive functions are preserved (less age-related cognitive decline) in older
adults who have been Masters Swimmers. The first step in this process began in 2009 at USMS long course nationals. This preliminary study’s aims were 2 fold: 1) To test if the high levels of physical activity in Masters Swimmers were associated with increased levels of executive cognitive function and 2) To reexamine the work of Chase, Sui and Blair (20), who proposed that swimmers had a 50% reduction in all-cause mortality risk from cardiovascular disease when compared with runners, walkers, and sedentary individuals. While this later paper was an astounding result, the comparisons were made between 20,356 Runners, 3,746 walkers, 15,883 sedentary subjects, and only 562 swimmers.

The subject inclusion criteria were subjects must be highly active (engaging in over 450 min/wk) Masters Swimmers, 45-65 years of age, have no history of cardiovascular or cognitive disease, and be free of any sympathetic nervous system antagonist medication. All subjects were asked to complete a physical activity and health history questionnaire. Physiologic tests were conducted at the competition site. Tests conducted were body composition (bioelectrical impedance analysis), blood pressure profiles (Cardiovascular Profiler, HDI, Eagan, MN), echocardiogram, blood lipid profiles, nerve conduction velocity, and cognitive tests (simple reaction time, choice reaction time, letter numbers sequencing, trails-B, and BRIEF-A). The results were promising, the Masters Swimmers cardiovascular health and cognitive function were consistently higher than published norms (50, 85). Specifically, arterial elasticity indices for the Masters Swimmers when compared with values reported in the literature indicated that the Masters Swimmers had a 15-20 year offset. Meaning, the older Masters Swimmers (age 56-65) when compared with health controls (mean age 33) were not different from one another. Meanwhile, the younger Masters Swimmers (age 45-55) had significantly better arterial elasticity values when compared to the
same controls. In addition, executive cognitive function on the letter-number-sequencing task of these Masters Swimmers was also superior to published normative values.

The test of the hypothesis showed some promising results and with that a grant proposal was generated to investigate the relationship between brain health, balance, cognitive function and cardiovascular function in older adults. This project involved a complete cognitive battery (Letter Number Sequencing, Digit Symbol Coding, Digit Symbol Copy, Symbol Search, Consonant Delay, Conditional Associative Learning and Matrix Reasoning) and Cardiovascular tests of estimated $\text{VO}_{2\text{max}}$ (Rockport 1 mi. test), Cardiovascular compliance, seven-day physical activity recall (accelerometer and self-report). Subjects were also tested on gait variability and static balance and finally eligible subjects participated in a structural fMRI. 96 subjects completed parts of the testing with 75 adults aged 40-78 years completing all parts for which they were eligible. Subjects were divided into two groups, highly active swimmers (engaging in at least 180 min of vigorous activity per week) and normally active adults.

Among the results was the finding that the Masters Swimmers had better balance when compared to their less active counterparts (87). However, in addition, when the groups where split into older (> 55 y.o.) and younger (< 55 y.o.) differences between the groups showed the younger Masters Swimmers had faster information processing speed but no other cognitive differences (87). How could the older Masters Swimmers not be any different from less active adults, when Kramer’s work had shown such robust differences? A few subsequent results indicated a next possible step.
First, the Masters Swimmers were only somewhat different in terms of activity patterns, from the regularly active adults. They were more active, but lifetime physical activity was not tightly controlled for, and thus many supposedly inactive adults were simply too active. In order to see robust differences it would appear to be important to compare a highly active group and a group that is mostly inactive. Second, a higher percentage of all subjects were under the age of 55 years. It has been shown that cognitive decline, especially of the executive cognitive functions, begins more rapidly between the ages of 60-75 yr. Without specifically targeting the group that is most susceptible to cognitive declines it becomes difficult to determine the differences in cognitive function, especially when comparing age-matched subjects in such small sample sizes (12 for each age group). The Kramer study had 56 subjects in the aerobically trained group. Having a larger sample size in a smaller age range, helps control those confounds. Third, the tests of executive function tapped into the functions that Kramer’s study examined. However, since these tasks were not the exact tests of task switching, stopping (inhibition), and response compatibility (attention) it is difficult to determine if similar or alternative conclusions can be made about these subject groups and these two studies.

In order to examine if Masters Swimmers older adults share the attenuation of age-related cognitive decline observed in Kramer’s study a few steps need to be followed. First, the subject population needs to be more tightly controlled by restricting the subjects age range (60-75 y.o.) and selecting groups that are clearly different in activity levels (habitually highly active and habitually inactive). Second, the same tests of executive function utilized in Kramer’s study ought to be used to examine the same functions in another group. Although, the validity of the tests of executive cognitive function is acceptable, in order to
fully investigate if Masters Swimmers do share the benefits in cognition demonstrated by the active subjects in Kramer’s study, similar procedures and methodology need to be followed.

As such, the subjects in the proposed study were aged 60-75 yrs. The highly active subjects will have been engaged in routine physical activity for over 10 years; whereas, the inactive subjects will not engage in any routine physical activity. Activity status was determined by a phone screening and by completion of a lifetime physical activity survey (77). The tests of executive cognitive function will follow the experimental details of the stopping task, response compatibility, and task switching utilized in the Kramer study (75, 76). This study will examine the relationship between a lifetime of engagement in routine physical activity and age-related cognitive decline.

*Assessing Executive Cognitive Function*

A number of experimental tasks have been developed to assess the executive cognitive functions (56, 69). Of the numerous tests, three that were used in Kramer et al., (75), stopping, task switching, and response compatibility were discussed in further detail. These tasks test the executive cognitive functions of inhibition, set-shifting, and response suppression. The detailed experimental procedures from Kramer et al., (75) were followed for these tasks (76).

Logan et al., (79) first developed the stop task in order to examine stopping, an inhibitory goal directed process. The stop signal paradigm is a choice reaction task where the subject discriminates X’s from O’s and at times is presented with a tone that tells them to stop the reaction (on some trials). This test utilizes the race model to detect differences between go trials (no stop-signal present) and stop trials (when the subject hears the stop
signal). The stop process is not directly observable, therefore making it more difficult to understand. However, the race model has two rules that define conditions for the outcomes of the race:

“1) If the stop process is faster than the go process, the response is inhibited.

2) If the go process is faster than the stop process then the response is executed.” (p 208, Logan 1994)

Logan acknowledges that the model works due to is general nature. It addresses the finishing times of the stop and go processes. It does not address the nature of the processes behind the task. It simply measures the end times for the two processes.

Another test utilized in this study were the response-compatibility test. Based on a version of the Eriksen flanker (10, 39) task, this test requires that the subjects ignore irrelevant information in order to complete a response. The subjects were presented with three letters in the center of the display. They were instructed to respond to the letter in the center of the display. If the center letter is an X, they are to press one specified key on the keyboard. If the center letter is an S, they are to respond with a different key press. The theory behind this task is that it takes more work to discriminate the correct response (congruent trial) when the flankers are incompatible (incongruent) with the target. Part of the increased difficulty is the noise associated with the flanking letters. The spatial proximity of the noise letters must be within a ½ degree visual angle of the indicator letter (39). The proximity of the distractor letters to the target increases the difficulty for response, thus, increasing reaction time for the incongruent trials (39).
The last assessment utilized in this study was the task-switching paradigm. This paradigm has been widely used to study executive control processes (90). Cognitive flexibility, rather than a decreased cost of task switching, is helpful for balancing the many tasks in daily life. The cost of switching is increased in young children, older adults, and individuals with brain damage (90, 109, 129). The task-switching paradigm examines reaction time as a function of the task. Task switch cost (reaction time when different tasks happen successively) comes from the time necessary for an individual to switch attention between tasks, incorporate new rules, and configure appropriate responses (90). Task-switch cost can be reduced by the preparation effect, priming the subject on the upcoming task. Although, the preparation effect does not entirely wash out the task switching cost, this residual effect is useful for examining task switch costs. Successive trials where the subject completes the same task (only odd/even) the reaction time is within normal limits. As the subject switches tasks (consonant/vowel to odd/even) the delay in reaction time is, and is and subjects tend to have more errors on these trials (90). The specific task switching test being proposed in this study also follows the experimental protocol outlined by Kramer et al., (76).

**Summary**

The present study addresses the limitations of the previous study, McCracken et al., (87). The subject’s age range in that study was broad (40-79 y.o.), whereas the literature supports using a narrower age range for more meaningful results (24). The subjects in the proposed study were aged 60-75 yr., to concentrate on the age range during which cognitive decline accelerates. In the previous study, there was little difference in the subjects’ physical activity status. The proposed study will recruit highly active subjects who have been engaged in habitual physical activity for over 10 years and inactive subjects who do not
engage in any routine physical activity. This criterion separates the subjects into distinct groups within which routine physical activity is present or absent. Activity status was determined by an in person or phone screening, and by completion of a lifetime physical activity survey (77). Finally, the tests of executive cognitive function will follow the experimental details of Kramer et al., (75); stopping task, response compatibility, and task switching study (75, 76). This study will examine the relationship between a lifetime of engagement in routine physical activity and age-related cognitive decline.

The research summarized gives background for the proposed study that seeks to examine the executive cognitive processes and lifetime activity status of Masters Swimmers and compare with sedentary older adults. The examination of executive cognitive processes in older adults has shown robust differences between aerobically trained and sedentary individuals. I propose that Masters Swimmers older adults, aged 60-75 years, will have higher levels of executive cognitive functioning. This may be, in part, associated with a lifetime of high levels of physical activity.
CHAPTER 3

METHODOLOGY

Institutional Review Board Approval

Prior to testing, all procedures were submitted and reviewed by the Indiana University Institutional Review Board (IRB). In accordance with Indiana University IRB, written consent was received from all subjects prior to testing.

Selection of Subjects

Subjects were recruited by word of mouth to local swim clubs, fliers posted around Bloomington, and advertisements in local media (newspaper and newsletters). Subjects were men and women aged 60-75 yrs. Subjects were healthy, non-smokers, not taking any anti-psychotics, without any history of head trauma, and free of any disease known to alter cognitive function. Subjects will have completed at least some college education. Masters Swimmers subjects were required to have engaged in regular physical activity for at least 10 years. Control subjects were not to have participated in regular physical activity during the preceding 5-year period. The Masters Swimmers data were collected at the 2013 USMS short course nationals in Indianapolis, IN. Control subjects were recruited through fliers and word of mouth in the Bloomington community.

Methods

After obtaining subjects’ consent, the following tests were administered:

1) Historical physical activity questionnaire: Subjects completed a validated questionnaire that assessed their physical activity involvement (77). However
participation levels prior to the age of 30 yrs were excluded in the analyses as they may not be accurate (80). Additional questions regarded demographic information, medical history including any drugs or supplements, current health status, and swimming history (if applicable) (77). This questionnaire was chosen for its validity in measuring lifetime physical activity in older adults (77, 97). Additionally, the additional questions were important for examining subject demographics, and for documenting any prescription drugs that may affect cognitive function (91).

2) **Beck Depression Inventory**: Subjects completed this inventory prior to the testing. This inventory used different indices of depression, appearance, thought content, vegetative signs, and psychosocial performance (6) to determine if a subject is depressed and, if so, the severity of depression. The subject answered each question. The test was scored with each answer from 0-3, indicating: none, mild, moderate or severe depression, respectively (6). Depression is linked to impaired cognitive function and this assessment is widely used as a measure to ensure all subjects are not depressed (108).

3) **Task Switching**: Subjects were seated at a computer and were instructed that they would be presented with a letter-digit pair in a two by two matrix in the center of the screen. They were instructed that, “When the stimuli are in the upper quadrant of the matrix you are to determine if the digit is odd/even and press the F key with your left hand for odd, and press the J key with your right hand for even. When letter-digit pair is in the lower quadrant you are to judge if the letter is a consonant/vowel, and press the F key for consonant and the J key for vowel.” They were told to do this as quickly and accurately as possible. They were told that the letter-digit pair will rotate
clockwise, so they can know where to expect it. Subjects practices were two 30 trial, single-task blocks followed by one 30 trial dual-task block. The experimental protocol was four, 60 trial task-switching blocks. The dependent measures were Switch Rt, Non-Switch Rt, and switch cost (Switch Rt-Non-switch Rt). Subjects were asked to switch tasks every other trial. Each stimulus was presented for 1250ms, with the next stimulus appearing in 400ms.

This task was chosen as a measure of cognitive flexibility and set-shifting. More specifically this task was used by Kramer et al., (75), and in effort to replicate the study this measure was used.

4) **Response Compatibility (Flanker) Task:** Subjects were seated in front of a computer and were instructed to respond to the letter in the center of the screen. If the center letter is an X, they were to press the F key on the keyboard. If the center letter was an S, they were to press the J key. They were instructed that on half the trials they would see all the same letters (either XXX or SSS) and the other half of trials would be (XSX or SXS). Subjects were instructed to respond as quickly and accurately to the center letter for each trial. The reaction time (Rt) for each trial were recorded as well as accuracy.

This test requires that the subjects ignore irrelevant information in order to complete a response. The theory behind this task is that it takes more work to discriminate the correct response when the flankers are incompatible with the target. Thus the Rt for the incongruent trials were longer than the Rt for congruent trials. Using a modified version of the Eriksen flanker (10, 39) task, the subjects were presented with three
letters in the center of a computer screen. Additionally, response compatibility was calculated by IncompatibleRt-CompatibleRt.

The experimental protocol calls for two different conditions, each occurring on 50% of the trials. In the response-compatible trials, the center letter was flanked by two of the same letters (XXX); in the response-incompatible trials, the letter X were accompanied by the two S’s (SXS). The flanker letters appeared at a .25° visual angle from the target. Subjects first practiced the task with 20 trials, then followed-up with one experimental block of 120 trials. This test and protocol were chosen to replicate that of Kramer et al., (75).

5) **Stopping:** The subject was seated in front of a computer and instructed that they would see one of two shapes (square or diamond) on the screen. They were instructed to press the “C” key for square and “M” key for diamond. They were instructed to respond as quickly and accurately as possible. Also, they were instructed that at times the border of the shape would come thicker (the stop-signal) indicating that they should not press the key. They were instructed that, “some of the time this will be quite easy to do, and other times it will be almost impossible to do.” Prior to the start of the experimental task, the subjects participated in a practice round of 32 trials, with the experimenter present, to ensure they understood the instructions.

The program for this task was STOP-IT, a windows executable software program developed by Logan and colleagues (138). The subjects then participated in 256 trials divided into 4 blocks of 64 trials each. The stop-signal was presented randomly on 25% of the trials in each block. The stop-signal was presented in a different random
order for each block of the test. The stop-signal delay (the time between presentation of the stimulus and the stop-signal) was initially set to 250ms and then adjusted following their performance. If the subject correctly inhibited the first trial, then the stop signal delay increased by 50ms (making it harder to inhibit the movement). Conversely, if the subject failed to inhibit the movement at the base time, it was decreased by 50ms. The stop-signal presentation time continued to be adjusted until the subject achieves an effective target error rate of 50% (118). This created an average stop-signal delay that provides an index of inhibitory control.

This test of inhibitory function examined the subject’s ability to abort a planned movement. This test is a combination of two separate tasks, a go-task and a stop-task. Both tests are choice reaction time tasks that require the subject to distinguish between a square and a diamond. The stop-task was stopping the reaction to the stimulus when a stop signal (bold outline) is presented. The difference between the delay in reaction on stop trials and RT on go trials, gives the stop signal reaction time. The method employed for this study utilizes the race model developed by Logan and colleagues (78). The outcome measures are Go reaction time (GoRT), stop signal reaction time (SSRT), Stop signal delay (SSD) and the probability of inhibition given a stop signal. This test and protocol were chosen to replicate that of Kramer et al., (75).
Data Analysis

A cross-sectional design was utilized to compare the activity profiles and cognitive function of the subjects. One independent measure, activity status, was tested. Independent t-tests with education as a covariate examined the differences between the two groups for measures (Incongruent Rt, Congruent Rt, Response Compatibility, Switch Rt, Non-Switch Rt, Switch Cost, Go-Rt, SSRt mean, and SSRt interval) of cognitive function. Also, an independent t-test was used to verify activity status. Chi-squared ($\chi^2$) tests were used to analyze group differences on demographic data. Statistical tests were performed using SPSS 20.0.
Seventy-one (39 Masters Swimmers, MS, and 35 relatively inactive controls, IC) older adults (age: 67.9 ± 5.8 years, 66.6 ± 5.3 years, MS and IC, respectively) were recruited to participate in this study. Masters swimmer subjects were registered Masters Swimmers and were recruited from those swimmers attending the 2013 USMS short course championships held in Indianapolis, IN. Inactive controls were recruited from the local area, and were matched to the MS for age and sex. Subject demographics are found in Figures 1-3.

**Figure 2.** Education achieved by subjects.
83% of all subjects had attained at least a college degree with a significant number also having completed post-graduate studies (Figure 1). Chi-squared test of independence for education ($\chi^2 = 13.085$, p=.032) and income ($\chi^2 = 15.528$, p=.004) were significant. Income distribution was different between ‘activity’ groups, with more Masters Swimmers subjects reporting higher household incomes (Figure 2). 75% of subjects were married (Figure 3). Additionally, 97.5% of the subjects were White – Caucasian. Beck Depression Inventory (BDI) scores were (p > 0.05) not different between groups (4.0 ± 3.5, 4.9 ± 4.0; MS and IC, respectively).

![Figure 3. Income profiles of subject groups.](image-url)
Figure 4. Marital status of subject groups.

Due to time constraints, two MS subjects completed only the questionnaire portion of the study. Thus, of the 37 remaining Masters Swimmers subjects, three did not complete all of the cognitive tests, citing test difficulty and tests being “illogical” as reasoning for not participating in the tests. Two potential controls were confirmed to be diabetic and were currently prescribed Metaformin which has been shown to cause cognitive impairment (Moore, et. al, 2013). As such, these two subjects were excluded from the analyses. The activity profiles of three potential control subjects were found to overlap that of the MS group and thus were excluded from the analyses. One subject’s Beck Depression Inventory (BDI) score was above 17, indicating possible clinical depression. As such, that subject’s data was excluded from analyses. Additionally, seven other subjects’ scores were excluded
from analyses due to abnormal responses or performances (more than 2.5 standard deviations away from the mean): four MS on TS, one MS on Flanker, and two IC on Flanker and one (IC) because of failing to complete the protocol.

<table>
<thead>
<tr>
<th>Activity Time Period (yr.)</th>
<th>Past Year</th>
<th>Age 65 yr. and older</th>
<th>Ages 51 to 64 yr.</th>
<th>Ages 35 to 50 yr.</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Masters Swimmers</strong></td>
<td>Mean</td>
<td>8606.3*</td>
<td>8338.6*</td>
<td>9962.1*</td>
<td>10490.9*</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>36</td>
<td>22</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>5465.30</td>
<td>8490.38</td>
<td>4851.44</td>
<td>7442.04</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>6825</td>
<td>6075</td>
<td>9600</td>
<td>8475</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>1800</td>
<td>900</td>
<td>1200</td>
<td>2100</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>22950</td>
<td>36750</td>
<td>19800</td>
<td>31800</td>
</tr>
<tr>
<td><strong>Controls</strong></td>
<td>Mean</td>
<td>2551.3</td>
<td>404.6</td>
<td>4456.8</td>
<td>5095.5</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>34</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Std. Deviation</td>
<td>2923.70</td>
<td>891.75</td>
<td>4459.39</td>
<td>4982.77</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>2250</td>
<td>0</td>
<td>3600</td>
<td>3750</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>9600</td>
<td>3150</td>
<td>16500</td>
<td>17400</td>
</tr>
</tbody>
</table>

Table 1. Energy expenditures derived from the Lifetime Physical Activity Survey (units for each column are kCal/wk). * indicates significant difference (p < 0.003).

Independent t-tests of lifetime physical activity energy expenditures revealed significant (p < 0.01) differences (Table 1) between groups age periods: Past year (F[1,68] = 32.8; p < 0.01), over 65 yr (F[1,53] = 28.6; p < 0.01), ages 51-64 (F[1,68] = 23.7; p < 0.01), ages 35-50 (F[1,64] = 32.8; p < 0.01), Lifetime (F[1,68] = 9.2; p < 0.01). Swimmers (MS) engaged in more (p < 0.01) physical activity than IC for all time periods over the age of 30 yr.
<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (ms)</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Not Switch Rt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>756.57*</td>
<td>151.74</td>
<td>27.25</td>
<td>50%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>964.56</td>
<td>163.11</td>
<td>30.29</td>
<td>25%</td>
</tr>
<tr>
<td><strong>Switch Rt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>973.94*</td>
<td>224.57</td>
<td>40.33</td>
<td>50%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>1189.85</td>
<td>204.77</td>
<td>38.02</td>
<td>25%</td>
</tr>
<tr>
<td><strong>Switch Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>217.37</td>
<td>139.84</td>
<td>25.12</td>
<td>NA</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>195.19</td>
<td>237.99</td>
<td>44.19</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Incongruent Rt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>744.94*</td>
<td>166.39</td>
<td>28.96</td>
<td>99%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>810.84</td>
<td>133.01</td>
<td>24.7</td>
<td>99%</td>
</tr>
<tr>
<td><strong>Congruent Rt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>704.05*</td>
<td>160.52</td>
<td>27.94</td>
<td>99%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>773.86</td>
<td>124.73</td>
<td>23.16</td>
<td>99%</td>
</tr>
<tr>
<td><strong>Response Compatibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>5.49</td>
<td>4.94</td>
<td>0.86</td>
<td>NA</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>4.37</td>
<td>5.1</td>
<td>0.95</td>
<td>NA</td>
</tr>
<tr>
<td><strong>GO Rt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>911.58</td>
<td>244.42</td>
<td>42.55</td>
<td>84%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>929.6</td>
<td>183.81</td>
<td>33.56</td>
<td>83%</td>
</tr>
<tr>
<td><strong>SSRt (mean)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>296.52</td>
<td>68.78</td>
<td>11.97</td>
<td>84%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>295.1</td>
<td>63.02</td>
<td>11.51</td>
<td>83%</td>
</tr>
<tr>
<td><strong>SSRt (interval)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masters Swimmers</td>
<td>31</td>
<td>282.76</td>
<td>202.44</td>
<td>35.24</td>
<td>84%</td>
</tr>
<tr>
<td>Controls</td>
<td>29</td>
<td>258.57</td>
<td>73.49</td>
<td>13.42</td>
<td>83%</td>
</tr>
</tbody>
</table>

Table 2. Group times (ms) for each of the cognitive tasks. * indicates significant difference (p < 0.05). NS Rt = non-stop reaction time, SSRt= stop-signal reaction time NA= Not applicable

For the cognitive analyses, data from 63 subjects (31 Masters Swimmers and 29 control subjects) were tested and compared (Table 2). Independent t-tests yielded significant differences between groups on task switching measures (with Swimmers being faster than Controls; Switch Rt, F[1,55] = 14.8, p < 0.01; Non Switch Rt, F[1,55] = 30.7, p < 0.01). Similar results were found on the flanker task (Congruent Rt, F[1,57] = 6.4, p < 0.01, Incongruent Rt, F[1,57] = 7.3, p < 0.01). However, no significant differences (p > 0.05) were found between groups for stop task measures (GO reaction time, F[1,60] = 0.054, p >0.1,
stop-signal reaction time (Mean), $F[1,60] = 0.007, p > 0.1$), stop-signal reaction time (interval), $F[1,60] = 0.434, p > 0.1$; response compatibility (Incongruent Rt – Congruent Rt; Response Compatibility, $F[1,57] = 0.13, p > 0.1$); or switching cost (Switch Rt – NonSwitch Rt; Switch Cost, $F[1,55] = 0.461, p > 0.1$).

**Figure 5.** Comparison of task switching results. Masters Swimmers were significantly faster on both switching and non-switching trials. * indicates a significant difference ($p < 0.05$).

**Figure 6.** Flanker task results. * indicates a significant difference ($p < 0.05$).
CHAPTER 5
DISCUSSION

The purpose of this study was to examine the relationship between engagement in long-term habitual physical activity and executive cognitive function in older adults. Specifically, this was done by examining self-reported lifetime physical activity habits and measures of executive cognitive function in adults ranging in age from 60-75 yr. Lifetime physical activity energy expenditure was examined using the Historical Physical Activity Survey, HPAS, (97) an instrument well validated and widely used. Executive cognitive function was assessed using three performance-based tasks (Stopping, Task Switching, and Flanker). The protocols for these task oriented measures are reportedly valid and have previously been used to describe and compare the ability to inhibit a pre-planned action, restructuring a task set, inhibition, and the ability to ignore task-irrelevant cues (76). The initial hypothesis tested in the current study was that the Masters Swimmers adults present traits consistent with ‘better’ cognitive executive function as compared to their more sedentary age matched contemporaries. Specifically, they would be shown to have faster reaction times than the inactive adults on each cognitive task, and would show better response compatibility and faster switch cost than the controls. The results only partially confirm these hypotheses.

The first task of the project, however, was to verify that these active subjects i.e., Masters Swimmers, were indeed, more active than the recruited inactive controls (IC). In fact, the goal was to identify adults who could be described as ‘Masters Swimmers’ over the
course of their lifetime. Comparisons based upon the self-reported Historical Physical Activity Survey confirmed this parameter with differences existing in all the time periods above the age of 35 yrs. The swimmers in the present study have been active (more active) than the respective age matched control group for nearly 30 years. This data has been previously corroborated by Hawkins et al., (49) who examined the training status of older masters runners (aged 60 yr and older) and found that, on average, current runners had been training consistently for approximately 20 yrs. Additionally, previous research from our lab has shown that on average Masters Swimmers, selected in a manner similar to the cohort in the present study, have been engaged in swim training for at least 17.5 years (128, 132).

Importantly, the current study excluded swimmers that had been training less than 10 yr. as a means to ensure that subjects fit the ‘Masters Swimmers’ profile required. Thus, our estimate for historical activity may be greater than that we reported previously. Similarly, Harada (1994) examined physical activity in aging Japanese adults and found that masters athletes are more likely to participate in competitive sport at younger as well as at older ages (above 70 yr. of age). Whereas senior (senior refers to older adults) university students participate in lower intensity leisure activity at the same ages (18.2% and 6.7%, masters athletes and senior students, respectively) and less senior students participate in physical activity as compared with masters athletes. As such, it is probable that older adults who regularly engage in high levels of routine physical activity are more likely to continue to engage in habitual physical activity throughout old age (9). The conclusion, however, is that we were successful in identifying and describing cohorts of Masters Swimmers, and relatively inactive adults as a means to compare their executive cognitive function.
The main finding of this study was that the MS had 20% faster reaction times (~212 ms faster) than the IC for task switching. These findings suggest that engagement in routine physical activity throughout the lifespan can have some cognitive protective benefits or possible improvements. The findings of the current study are supported by previous research that has shown that following exercise interventions, subjects who were in an exercise group out-performed control subjects on cognitive tasks, similar to those used in the present study (27, 34, 75). Kramer et al., (75) demonstrated that previously sedentary older adults who participated in an exercise intervention (6 mo. walking) had 13% faster reaction times on task switching measures compared to the non-exercising controls. However, there are a few differences between these studies, and the current study. First, Kramer et al., (75) found significant differences on the measure of switch cost while the current study did not. One possibility for this different result is that accuracy on this task was much lower for the present study than was reported for the others (25%, 50%, 96-98%; IC, MS, and (75), respectively). One explanation is that the task used in the present study was more difficult than the task in other studies, since the stimulus presentation was shorter (1250 ms vs 2000 ms, present study and Kramer et al., (75), respectively) than in Kramer et al., (75). Although the level of difficulty for this task may have been higher, as indicated by lower accuracy, the results are nonetheless remarkable. The Masters Swimmers were able to perform better under more difficult circumstances thus demonstrating superior information processing speed. Meaning, these older adults when in placed in a situation with many distracters, are able to use the information and make a correct assessment rather than failing to complete a task. That task may be recognizing a phone scammer or it may be hitting the brakes instead of the gas pedal when driving.
The next main finding is for the flanker task during which the MS had 8.5% faster reaction times than the IC on Congruent and Incongruent trials. Together the faster reaction times of the MS on task switching and flanker measures are indicative of faster processing speed. It is well known that processing speed shows a dramatic decline with advancing age (119), and it is possible that the HA have an attenuated slowing of processing speed.

During task switching, the MS were able to process more trials correctly, whereas the IC were not able to answer as many questions correctly. The results of the flanker task show higher accuracy for a less time intense task while the difference between groups in trial type Rt was still apparent. Together these results suggest faster information processing in the MS.

Salthouse (119) discusses two mechanisms that explain the age-related slowing of information processing speed (119). These mechanisms give a deeper understanding of how
the slower information processing speed can impede normal cognitive functioning. The limited time mechanism states that, “the time to perform later operations is greatly restricted when a large proportion of the available time is occupied by the execution of earlier operations.” Whereas the simultaneity mechanism states that, “the products of early processing may be lost by the time the later processing is completed.” For instance, the slower reaction times in the IC suggest that under rapidly changing conditions, the information from the previous trial became obsolete that it was no long accurate or pertinent to the next trial. Thus, for older adults to have slower processing speed, they are at a greater potential for making errors that can have serious consequences.

Colcombe et al., (27), and Kramer et al., (75), compared the executive cognitive functions, (using flanker task, task switching*, and stopping*; only in Kramer et al., (75)) of older adults who had participated in a 6 month exercise intervention with those who were sedentary. Colcombe et al., (27), and Kramer et al., (75) demonstrate that subjects with higher aerobic fitness had faster reaction times on incongruent trials than the non-exercising group. This indicates in increase in function when greater attentional resources are needed. Colcombe et al., (27) not only tested an exercise intervention, but also used a cross-sectional analysis to examine the effects of aerobic fitness on cognitive function through fMRI testing during the flanker task. Results showed that the active subjects showed greater activity in attentional control areas which are necessary for successful task completion, and decreased activity in conflict resolution areas. The increase in attentional control demonstrated in Colcombe et al., (27) supports the results of the present study that the MS subjects out-performed the IC on both types of trials for flanker and task switching. Faster Rt
demonstrated by the MS indicates better conflict resolution and increased attentional control compared with the IC.

The results in the present study indicate that both the flanker and task switching tests show that the MS are able to respond quicker to the stimulus. However, although group differences between trial types were apparent, response compatibility (Incongruent Rt-Congruent Rt) was not different between groups. Accuracy was not a factor in the flanker task, as the accuracy was not different between groups, and was relatively high (99%). Although group differences were not apparent in response compatibility or switch cost, perhaps the executive function in these groups is not different. However, speed of information processing is different between groups, therefore the MS are able to process information more quickly and complete tasks in less time than the IC.

Other research has shown that highly active older adults have faster information processing speed as compared to regularly active adults. McCracken et al., (87) tested highly active Masters Swimmers (MS) and regularly active adults (RA) on a measure of information processing speed, the Colorado perceptual speed test, and tested subject’s balance. Both measures are known to decline with aging. The results showed that the MS were faster on the CPST and had better balance profiles, as demonstrated by lower sway velocity and lower sway area. The results of task switching and flanker tasks show that active older adults have faster information processing speed. The earlier work of McCracken et al., (87) corroborates these findings in similar group of active adults.

The MS can process the information quicker and are able to respond quicker to a stimulus. This first motor response was shown by Spirudoso & Clifford, (125) in active men
who had faster reaction time on a simple reaction time task compared to inactive men. This supports the notion that perhaps speeded functions are beneficially supported in those that exercise. Similarly other researchers have found that following an exercise intervention, when physically active individuals participate in tasks involving a speeded component show advantageous benefits when compared with their non-exercising peers (24). Alternatively, other findings show that areas in the brain responsible for ignoring task irrelevant stimuli similar to those in the response compatibility test, have been associated with increases in brain volume following an aerobic fitness intervention (133). In addition, Colcombe et al., (27) showed that increased cardiovascular fitness (following an exercise intervention) resulted in increased functioning of the attentional network of a cognitively challenging task. Using a flanker task paradigm, their subjects who were involved in an exercise intervention showed they were better able to disregard the flankers while shifting attention to the correct stimulus. This was demonstrated by the MS in the current study, too. These findings indicate that the attentional network is be supported by lifetime engagement in physical activity. Additionally, research shows that higher cardiovascular function is associated with increased functioning in the brain regions associated with attention, specifically areas activated by a cognitively challenging task (27). It is likely that since many of the Masters Swimmers have been engaged in routine physical activity for years that they have higher cardiovascular function as compared to the relatively inactive controls in this study. However, further research is needed to examine other executive cognitive functions and the role of cardiovascular function in older adults. It would be beneficial to use FMRI analysis to examine if any functional and/or structural differences exist between highly active swimmers or other active older adults and their relatively sedentary peers.
Additionally, masters swimmers are a unique group of masters athletes because their training sessions usually take place in a group setting. Other masters athletes, such as runners, may train alone. Group activities have the benefits of building strong social support networks which can be highly beneficial to aging adults (62). Not only does social support reduce the risk of developing dementia, adults with positive social support can respond better to stressful events (19). Individuals with positive social support networks have improved cognitive function as compared to those in non-social groups (19). It’s for this reason that many studies (including the work of Kramer and colleagues) create groups for exercise intervention studies. It eliminates the confounding factor of social support on cognitive function in older adults.

It’s possible that Masters Swimmers are different from other groups of active adults and masters athletes. However, some things set masters swimmers apart from other masters athletes. Median education status collected at numerous USMS national competitions revealed that most MS have some post graduate education (50, 57, 85). Additionally, these swimmers are mostly Caucasian and earn $75,000+ (57, 86, 87). There is not enough data on other masters athletes to compare their exact demographics, however the demographic characteristics of these masters swimmers potentially make this work less generalizable to other masters athletes and/or adults who exercise but do not compete.

Not only could the masters swimmers be different demographically, they might also be different based on physiology and training characteristics. Swimmers typically use interval based training that allows for exercising at higher heart rates for short amounts of time. Masters swimmers are no different. They exercise at a higher percentage of their max heart rate, for longer amounts of time, as compared with regularly active adults (58, 87). As
mentioned in this study, masters swimmers train in groups. Social support is very important in having positive benefits on cognitive function in older adults. Other masters athletes and active adults may not train in groups, therefore they may not receive this benefit.

**Limitations**

The stopping task that was used was slightly altered from the stopping task modeled by Kramer et al., (75). Due to the complexity of the computer programming for the task, the STOP-IT stopping task developed by Logan and Verbruggen was used (78). STOP-IT is an open source model for easier use and dissemination of the task (138). The stopping task presented the subjects with two figures, a square or a diamond, to which they must press a different key in response to the stimulus. Stopping was calculated by the subject’s ability to correctly stop their response when the stop signal (a bold outline on the shape or an auditory tone) is present. The stop signal was presented at varying times throughout the experiment to have the subject’s stopping rate at 50%. In the STOP-IT task, the stop signal was changed to a bold border on the presented shapes instead of the stop signal being an auditory tone, as was described in the original model by Logan, (78) and what Kramer et al.,(75) used. Rather than having two different systems, auditory and visual, differentiating the task, the stimulus moved solely to visual. The testing environment for the MS had louder background noise than the environment of the IC, therefore the visual stimulus controlled for any differences that could have been present in the subject’s ability to hear the stop signal.

Additionally, some subjects reported having a difficult time discriminating when to respond and when to withhold their responses. Even following the practice trials, subjects
may have adapted a strategy for solving that involved a delayed response to GO trials. Not many subjects reported using this strategy; regardless it may have had an effect on the results. Unfortunately, it was not recorded which subjects commented that they used this strategy. As such, no analyses could be run excluding those that used the delayed strategy. However, this delayed response strategy seems to be one that is commonly adopted by subjects to increase the chance of withholding their response if a stop-signal was presented.

Padilla et al., (96) report this type of response strategy (delaying the response to be accurate) is common in the stop-task paradigm. Padilla et al., (96) tested two groups of young healthy adults on the stop signal task, to look at differences in those who engaged in chronic exercise, versus those who were inactive. One subgroup was given standard instructions meaning, participants are instructed that “they should not postpone the response while waiting for the occurrence of the stop signal, and to respond as fast as possible in all trials.” The other subgroup was given strategic instructions, where they are allowed to adopt a more conservative approach in order to improve accuracy. The researchers believed that strategic instructions increase the executive demands of the task. Results yielded no differences between activity groups for those that were given the standard instructions, but differences were apparent between activity groups for those tested given the strategic instructions. This is one possibility as to why these groups were not different on the stopping task. The difference in performance of the task based on the instructions may be a significant contribution to the lack of differences between groups.

It is also possible that because more of the swimmers were highly educated that they have higher incomes and higher cognitive functioning. There have been some studies that
suggest cognitive function is lower in people with extremely low incomes, suggesting the stress of poverty level can negatively contribute to cognitive function in later years (82). Our study may have self-selected lower income controls by offering $100 as compensation for participation in the study. This could have influenced subject’s truthful responses to the screening questionnaire; therefore the controls weren’t as inactive as hoped. It’s possible that some of the subjects could have lied to participate in the study in order to receive the compensation. Conversely, by selecting Masters Swimmers as a habitually active group, the typical demographic of Masters Swimmers are highly educated Caucasians, and earning a household income of more than $75,000 per year.

Conclusion

In conclusion, the present study demonstrates that a lifetime of engagement in physical activity provides cognitive protective benefits. A caveat to this conclusion, however, is that it’s not clear if the benefits demonstrated here are evidence of retarding the typical rate of cognitive decline and/or conversely if they are evidence of an active adaptive response. The suggested benefits might be due to differences in attention, speed of information processing, or perhaps low-level functioning. Further research is needed to identify which of these is the case. It is also possible that a combination of these factors is responsible for the cognitive benefits of life-time physical demonstrated in this study. In order to further examine these factors, future research should involve functional magnetic resonance imaging while Masters Swimmers and inactive subjects perform cognitive tasks from each relevant domain. Examining any possible functional and/or structural differences
in the brain between could give insight to the underlying mechanisms of the attenuated decline in cognitive functioning seen in active subjects.
References


80. MacDonald DJHSPJMCJ. Application and Reliability of the Retrospective Interview Procedure to Trace Physical Activity Patterns in Master Athletes and Nonactive Older Adults. *Educational Gerontology* 35: 1107-1122, 2009.


127. **Spirduso WWF, Karen L.; and MacRae, Priscilla G.** *Physical Dimensions of Aging*


Appendix A

Human Subjects Consent Form
The impact of exercise on fitness, cognition, and brain health in aging people

Substudy 4- Older Population

You are invited to participate in a research study Aging, Activity, Cognition, Balance and Brain Health. You were selected as a possible subject because you met the recruitment criteria. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

The study is being conducted by Dr. Peter Finn, Department of Psychological and Brain Sciences and Dr. Joel M. Stager, Department of Kinesiology. It is funded by Indiana University.

STUDY PURPOSE

The purpose of this study is to measure balance and cognition to examine the relationship each has with physical activity.

NUMBER OF PEOPLE TAKING PART IN THE STUDY:

If you agree to participate, you will be one of 200 subjects who will be participating in this research.

PROCEDURES FOR THE STUDY:

1. Questionnaires and interview: You will complete some questionnaires that ask about the different activities that you engage in, how much you exercise, lifetime physical activity, and some health related questions, such as medications you take, and different diseases.

2. Balance Assessment Procedure: We will assess your balance by having you stand on a force plate and look at how much your body moves while standing. For the balance assessment, you will stand on a force plate with your eyes open for 90 seconds three times and then three trials of 90 seconds with your eyes closed. A licensed physical therapist will stand near you in case you start to lose your balance. You will be free to take rest breaks between trials as needed. If you feel unbalanced or uncomfortable at any point during balance testing you can choose to discontinue testing.

3. Cognitive assessment tests:
   a. Task Switching: This test asks you to look at a letter and number and judge whether or not the letter is a consonant/vowel and if the number is odd/even. The letters and numbers will be presented at the top of a square or at the bottom of the square. If the letter/number is on the bottom you’ll decided if it’s odd/even. If it’s on top you’ll decide if its consonant/vowel. Please answer as quickly and accurately as possible. You will have practice before starting the task to make sure you know how to properly do the task.
   b. Stopping: You will sit at a computer for this test and wear headphones. This task asks you to press a key on the computer keyboard as quickly as possible after seeing a stimulus (green box). Sometimes you will hear a tone when you see the stimulus. When you hear the tone, DO NOT press the key on the keyboard. You’ll have some practice on this test before doing the trials to make sure you understand the test.
c. Flanker Task: You will be seated at a computer for this test, too. You'll be read instructions prior to starting the task. You will be shown a letter in the middle of the screen. If it’s X you will press the F key on the keyboard. If it’s S you will press the J key. Sometimes the center letter will sometimes be shown with an extra letter to either side. The main goal is to respond as accurately and quickly to the center letter. You’ll have trials to practice on before embarking on the task.

The entire time for testing procedures will be between 1 and 1.5 hours.

RISKS OF TAKING PART IN THE STUDY:

There is a risk of loss of confidentiality.

In the motor nerve conduction task, the electrical stimulation may be uncomfortable. You also may feel some muscular discomfort similar to that of a muscle cramp.

Completing the Health History Form: You may be uncomfortable completing the questions about the dosage of your medications and the conditions for which they are used.

Balance assessment: You may feel uncomfortable standing for 90 seconds with your eyes closed because your balance may not feel as steady.

Cognitive assessment: you may feel some mental fatigue from completing the tasks, that is similar to very focused concentration.

BENEFITS OF TAKING PART IN THE STUDY:

There are no known benefits to your participation in this study. Your participation will aid in understanding the relationship between exercise and its effects on fitness, cognition, aging and brain health.

ALTERNATIVES TO TAKING PART IN THE STUDY:

An alternative to participating in the study is to choose not to participate.

CONFIDENTIALITY

Efforts are made to ensure that the information collected from you in the study is kept confidential. These efforts include coding your data using a numeric code and securely storing the link between your name and your numeric code in a locked file cabinet on a password protected file stored on a separate drive. The link between your name and numeric code will be kept for one year after the entire project has been completed (the fall of 2013), if you agree in the consent statement below to be contacted in the future for a follow-up study. If you do not want to be contacted for follow-up studies, the link between your numeric code, your name and contact information will be destroyed within two months of completing the study.

We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. Your identity will be held in confidence in reports in which the study may be published. No reference will be made in oral or written reports which could link you to the study.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the IU Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP) etc., who may need to access your research records.
PAYMENT

You will receive a $20 gift card for participating in this study.

CONTACTS FOR QUESTIONS OR PROBLEMS

For questions about the study or a research-related injury, contact the researcher Dr. Peter Finn at (812) 855-9548.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IU Human Subjects office, 530 E Kirkwood Ave, Carmichael Center, 203, Bloomington IN 47408, 812-856-4242 or by email at irb@iu.edu

VOLUNTARY NATURE OF STUDY

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to withdraw from the study you will be paid for your time. If your decision whether or not to participate in this study will not affect your current or future relations with the investigator(s).

SUBJECT’S CONSENT

In consideration of all of the above, I give my consent to participate in this research study.

I will be given a copy of this informed consent document to keep for my records. I agree to take part in this study.

Subject’s Printed Name: ________________________________

Subject’s Signature: ________________________________ Date: ______

Printed Name of Person Obtaining Consent: ______________________________

Signature of Person Obtaining Consent: ________________________________ Date: ______

CONSENT FOR FOLLOW-UP

I agree to be contacted before the fall of 2015 to be invited to participate in a study that follows up this study. If I agree to be contacted, I understand that my name will remain linked with my data (in a confidential and secure file) at least until that follow up period. I also agree to complete a form asking for contact information. If you indicate that you do not want to be contacted, then your name will no longer be linked with your data.

I agree to be contacted: Signature: _______________ Date: __________

I do not wish to be contacted: Signature: _______________ Date: __________

Form date: May 3, 2013
Appendix B

Historical Physical Activity Survey
BACKGROUND INFORMATION

1. Age: ______________

2. Date of birth: __________

3. Sex (Please circle one): Male Female

4. Years of school completed
   a. Some high school
   b. High school graduate
   c. Some college
   d. College graduate (B.S. or B.A.)
   e. Some graduate school
   f. Completed Post-Graduate (M.A., M.D., PhD)

5. Which of the following would you say is your race?
   a. White – not Hispanic
   b. Black – not Hispanic
   c. Hispanic or Latino
   d. Asian
   e. Native Hawaiian or Pacific Islander
   f. American Indian or Alaska Native
   g. Other (please specify ______________)

6. What is your current marital status?
   a. Married
   b. Living with significant other
   c. Divorced
   d. Separated
   e. Widowed
   f. Never Married
7. Please indicate your current household income in U.S. dollars
   a. Less than $20,000
   b. $20,000 - $34,999
   c. $35,000 - $54,999
   d. $55,000 - $74,999
   e. Greater than $75,000

8. Height __________ feet __________ inches

9. Current Weight __________ pounds

10. Weight at age 18 __________ pounds
1. How often did you regularly participate in sports and leisure time physical activity, *excluding walking*? (Please check the appropriate box)

<table>
<thead>
<tr>
<th></th>
<th>0-1 hour/week</th>
<th>2-3 hours/week</th>
<th>4-7 hours/week</th>
<th>&gt;7 hours/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>During high school and college (years 14-21)?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 22-34?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 35-50?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 51-64?</td>
<td></td>
<td></td>
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<tr>
<td>During years 65 and &gt;</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

2. Were you considered more active than others your age and sex…

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>During years 14-21?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 22-34?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 35-50?</td>
<td></td>
<td></td>
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<tr>
<td>During years 51 – 64?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 65 and &gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. How many miles did you normally walk each day…

<table>
<thead>
<tr>
<th></th>
<th>&lt; 1 mile</th>
<th>1-2 miles</th>
<th>3-5 miles</th>
<th>&gt;5 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>During years 14-21?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 22-34?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>During years 35-50?</td>
<td></td>
<td></td>
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<tr>
<td>During years 51 – 64?</td>
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<tr>
<td>During years 65 and &gt;</td>
<td></td>
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</tbody>
</table>

REMEMBER: 12 blocks or 20 minutes of brisk walking is equivalent to approximately 1 mile.

4. Please indicate next to each activity whether you have participated in the activity more than 10 times during your lifetime. For those activities you have participated in, proceed to the right answering the questions in the top of the column. If no regular participation in the activity in a particular time period, please indicate this by drawing a line through that time period.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Have you participated in an activity more than 10 times in your lifetime?</th>
<th>During Past year</th>
<th>Age Period 65 or Greater</th>
<th>Age Period 51 – 64 (a 15 year span)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Mo/Yr</td>
<td>Hrs/Wk</td>
</tr>
<tr>
<td>Swimming</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking for exercise</td>
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</tr>
<tr>
<td>Cardio machines</td>
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<tr>
<td>(e.g. elliptical)</td>
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<tr>
<td>Running/jogging</td>
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<tr>
<td>Doubles tennis</td>
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</tr>
<tr>
<td>Singles tennis</td>
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<tr>
<td>Golf</td>
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<tr>
<td>Rowing</td>
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<tr>
<td>Hiking</td>
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<tr>
<td>Aerobic dance</td>
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</tr>
<tr>
<td>Bicycling</td>
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<td></td>
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<tr>
<td>Skating/ice, roller</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiking</td>
<td></td>
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</tr>
<tr>
<td>Softball/baseball</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basketball</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Racquetball/squash</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Skiing cross-country</td>
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<tr>
<td>Skiing downhill</td>
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<tr>
<td>Social dancing</td>
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</tr>
<tr>
<td>Volleyball</td>
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</tr>
<tr>
<td>Weight lifting</td>
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</tbody>
</table>
Please indicate next to each activity whether you have participated in the activity more than 10 times during your lifetime. For those activities you have participated in, proceed to the right answering the questions in the top of the column. If no regular participation in the activity in a particular time period, please indicate this by drawing a line through that time period.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Age Period 35-50 (A 15 year span)</th>
<th>Age period 22-34 (13 years total)</th>
<th>Age Period 14-21 (8 years total)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>If younger than 35, skip to next column</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yrs</td>
<td>Mo/Yr</td>
<td>Hrs/Wk</td>
<td>Yrs</td>
</tr>
<tr>
<td>Swimming</td>
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<td>Walking for exercise</td>
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<tr>
<td>Cardio machines (e.g. elliptical)</td>
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<tr>
<td>Running/jogging</td>
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<td>Doubles tennis</td>
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<tr>
<td>Singles tennis</td>
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<td>Hiking</td>
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<td>Bicycling</td>
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<tr>
<td>Skating/ice, roller</td>
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<tr>
<td>Hiking</td>
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<tr>
<td>Softball/baseball</td>
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<tr>
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<td>Skiing downhill</td>
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<tr>
<td>Activity</td>
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<td>Social dancing</td>
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<td>Volleyball</td>
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<tr>
<td>Weight lifting</td>
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Appendix C

Data Tables
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<tr>
<th>SubID</th>
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<th>SwitchCost</th>
<th>Incongruent</th>
<th>Congruent</th>
<th>RC</th>
<th>NSrt</th>
<th>SSrtMean</th>
<th>SSrtInt</th>
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Appendix D

Beck Depression Inventory
Beck's Depression Inventory
This depression inventory can be self-scored. The scoring scale is at the end of the questionnaire.

1. 0 I do not feel sad.
    1 I feel sad
    2 I am sad all the time and I can't snap out of it.
    3 I am so sad and unhappy that I can't stand it.

2. 0 I am not particularly discouraged about the future.
    1 I feel discouraged about the future.
    2 I feel I have nothing to look forward to.
    3 I feel the future is hopeless and that things cannot improve.

3. 0 I do not feel like a failure.
    1 I feel I have failed more than the average person.
    2 As I look back on my life, all I can see is a lot of failures.
    3 I feel I am a complete failure as a person.

4. 0 I get as much satisfaction out of things as I used to.
    1 I don't enjoy things the way I used to.
    2 I don't get real satisfaction out of anything anymore.
    3 I am dissatisfied or bored with everything.

5. 0 I don't feel particularly guilty
    1 I feel guilty a good part of the time.
    2 I feel quite guilty most of the time.
    3 I feel guilty all of the time.

6. 0 I don't feel I am being punished.
    1 I feel I may be punished.
    2 I expect to be punished.
    3 I feel I am being punished.

7. 0 I don't feel disappointed in myself.
    1 I am disappointed in myself.
    2 I am disgusted with myself.
    3 I hate myself.

8. 0 I don't feel I am any worse than anybody else.
    1 I am critical of myself for my weaknesses or mistakes.
    2 I blame myself all the time for my faults.
    3 I blame myself for everything bad that happens.

9. 0 I don't have any thoughts of killing myself.
    1 I have thoughts of killing myself, but I would not carry them out.
    2 I would like to kill myself.
    3 I would kill myself if I had the chance.

10. 0 I don't cry any more than usual.
    1 I cry more now than I used to.
    2 I cry all the time now.
    3 I used to be able to cry, but now I can't cry even though I want to.
11. 0 I am no more irritated by things than I ever was. 1 I am slightly more irritated now than usual. 2 I am quite annoyed or irritated a good deal of the time. 3 I feel irritated all the time.
12. 0 I have not lost interest in other people. 1 I am less interested in other people than I used to be. 2 I have lost most of my interest in other people. 3 I have lost all of my interest in other people.
13. 0 I make decisions about as well as I ever could. 1 I put off making decisions more than I used to. 2 I have greater difficulty in making decisions more than I used to. 3 I can't make decisions at all anymore.
14. 0 I don't feel that I look any worse than I used to. 1 I am worried that I am looking old or unattractive. 2 I feel there are permanent changes in my appearance that make me look unattractive 3 I believe that I look ugly.
15. 0 I can work about as well as before. 1 It takes an extra effort to get started at doing something. 2 I have to push myself very hard to do anything. 3 I can't do any work at all.
16. 0 I can sleep as well as usual. 1 I don't sleep as well as I used to. 2 I wake up 1-2 hours earlier than usual and find it hard to get back to sleep. 3 I wake up several hours earlier than I used to and cannot get back to sleep.
17. 0 I don't get more tired than usual. 1 I get tired more easily than I used to. 2 I get tired from doing almost anything. 3 I am too tired to do anything.
18. 0 My appetite is no worse than usual. 1 My appetite is not as good as it used to be. 2 My appetite is much worse now. 3 I have no appetite at all anymore.
19. 0 I haven't lost much weight, if any, lately. 1 I have lost more than five pounds. 2 I have lost more than ten pounds. 3 I have lost more than fifteen pounds.
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<td>I am so worried about my physical problems that I cannot think of anything else.</td>
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<td>I have not noticed any recent change in my interest in sex.</td>
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<td>I have almost no interest in sex.</td>
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<td>I have lost interest in sex completely.</td>
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CURRICULUM VITAE

Colleen M. McCracken

EDUCATION

Indiana University, Bloomington, IN 2015
PhD., Human Performance
Area of Study: Exercise Physiology Minor: Gerontology
School of Public Health, Department of Kinesiology
Advisor: Dr. Joel M. Stager

Indiana University, Bloomington, IN 2009
M.S., Kinesiology
Area of study: Exercise Physiology
School of Health, Physical Education, and Recreation; Department of Kinesiology
Advisor: Dr. Joel M. Stager

Indiana University, Bloomington, IN 2004
B.S., Kinesiology
Major: Exercise Science
Minor: Chemistry

TEACHING EXPERIENCE

Academic:
Adjunct Lecturer,

*Indiana University Dept. of Kinesiology, Bloomington, IN* 2014-Present
Course Taught: Personal Fitness

*Ivy Tech Community College, Bloomington, IN* Spring 2014
Course Taught: Advanced Principles of Human Physiology
Guest Lecturer, *Indiana University Dept. of Kinesiology*, Bloomington, IN 2010-present

Courses Taught: Exercise Physiology and The Art of Meaningful Work

Associate Instructor, *Indiana University Dept. of Kinesiology*, Bloomington, IN 2004-2010

Courses Taught: Exercise Physiology, Structural Kinesiology, and Living Well

Elective:

Associate Instructor, *Indiana University Dept. of Kinesiology*, Bloomington, IN 2004-present

Courses Taught: Beginning & Intermediate Swimming and Introduction to Swim Coaching

Other Instruction and Leadership:

Yoga Instructor; *Vibe Yoga and Pilates Studio*, Bloomington, IN 2009-2014

Styles Taught: Vinyasa Yoga, Hot Yoga, Hot Vinyasa, Yoga Sculpt, and Restorative

Water Exercise Instructor; *Indiana University Outdoor Pool*, Bloomington, IN 2005-2011

Formats Taught: Deep & Shallow Water Exercise

Age-Group Swim Coach, *Counsilman Center Swim Team*, Bloomington, IN 2006-2008

Group Exercise Leader, *Campus Recreational Sports*, Bloomington, IN 2004-2008

Classes taught: Cycle-fit, Water Exercise, Strength/Core, and Trekking

PROFESSIONAL EXPERIENCE

Magnetic Resonance Imaging Technologist, 2011-2013

*Imaging Research Facility, Department of Psychological and Brain Sciences*, Indiana University, Bloomington, IN

Research Associate, 2004-present
Assessments:

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HONORS AND AWARDS

**HPER Dissertation Fellowship ($5,000)** 2011

*School of Health Physical Education and Recreation, Indiana University Bloomington*

Best Poster Presentation 2010

*XIIIth Biomechanics and Medicine in Swimming International Symposium; Oslo, Norway*

Hal Morris Summer Research Fellowship 2009

*School of Health Physical Education and Recreation, Indiana University Bloomington*

Graduate Student Teaching Assistantship 2004-2009

*School of Health Physical Education and Recreation, Indiana University Bloomington*

Alpha-Beta Student-Athlete Honor Society 2000-2003

*Indiana University Athletics, Indiana University Bloomington*
CERTIFICATIONS AND PROFESSIONAL MEMBERSHIPS

Health IU Campus Wellness Coalition 2012-present
American Heart Association Heartsaver® CPR & AED 2012-present
American College of Sports Medicine, Member 2005-2012
Hot Fusion Yoga Instructor 2012-present
Vinyasa Yoga Instructor 2009-present
American Red Cross CPR & First Aid 1996-2010
American Red Cross Lifeguard 1997-98; 2008-2010
American Red Cross Swim Coaches Safety 2006-2008
American Council on Exercise, Fitness Professional 2003-2008
Indiana University Women’s Swimming Team, Member 1999-2003