ABSTRACT

GERMAIN, CASSANDRA MALLORY. Effects of Activity Level on Cognitive Change in Adulthood: A Multilevel Analysis. (Under the direction of Thomas M. Hess, and Shevaun D. Neupert).

Research supports the idea that leading an active lifestyle may help slow the negative effects of aging on cognition in older adults (McKinnon et al, 2003). However, little is known about the relationship between activity and cognitive change in younger and middle adulthood. The current study seeks to extend the literature by examining the effects of maintaining an engaged and active lifestyle on cognition throughout the adult lifespan. The goals of the current study were threefold. First, the relationship between activity and cognition in young, middle and older adults was examined. Second, the effects of activity on the trajectory of cognitive change and the rate of dementia diagnosis in late adulthood were examined. Lastly, the directionality of the relationship between activity and cognition was examined. Participants in this study were a subset of adult volunteers from the Baltimore Longitudinal Study of Aging (BLSA) with no known diagnosis of dementia or probable Alzheimer's disease at the beginning of the study. Two measures were used as indicators of cognitive ability (performance). The Benton Visual Retention Test (BVRT) and the vocabulary subtest of the Wechsler Adult Intelligence Scale (WAIS-R) were used as indicators of cognitive performance. Scores on the Activities and Attitudes Questionnaire (AAQ) were used as a measure of activity level. Both cross-sectional and longitudinal analyses were performed. Examination of current cognitive functioning was conducted using multiple regression analysis. Differential trajectories of change were also examined by activity, age, sex, education, work status and health using multilevel modeling on seven waves of data. Activity was found to be

associated both with memory performance and decreased risk of dementia diagnosis. These effects were further moderated by health status with individuals in poor health experiencing the greatest influence of increased activity. Results of the current study further suggest that the effects of activity may be domain specific, with fluid abilities potentially being more sensitive to the benefits of activity than crystallized abilities.

Effects of Activity Level on Cognitive Change in Adulthood: A Multilevel Analysis

by
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DEDICATION

To Maria I. Hazel Mondesir

1954-2002

BIOGRAPHY

Cassandra M. Germain received a Bachelors degree in Psychology from Hunter College-City University of New York in 1999. As an undergraduate she was a fellow of the National Institute of Mental Health Career Opportunities in Research (COR) Program. She earned a Masters degree in Psychology from North Carolina State University in 2003. During her time at North Carolina State University she participated in various career development programs including the Preparing the Professoriate and the Research Ethics Fellows program. Ms. Germain currently resides in Cary, NC with her husband and three children, and is a full-time caregiver to her grandmother Madeleine. She will continue to teach and pursue research on aging and cognitive change in adulthood.

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The idea that certain lifestyle factors can be beneficial in slowing the negative impact of aging on cognition and the onset of dementia has been of interest for some time (Hultsch, Hertzog, Dixon, 1999; Schooler, 1984; Scarmeas & Stern, 2003). With the rapid increase in the number of aging adults in our society, the importance of understanding the factors that may positively influence the aging process has become even more meaningful. In recent years, investigators have considered a variety of lifestyle variables that may serve as protective factors against cognitive decline including physical health (van Hooren et al., 2005), the availability and presence of social networks (Beland, Zunzunegui, Alvorado, Otero, & del Ser, 2005), socioeconomic status and education (Anstey & Christensen, 2000). One such area of investigation that is receiving increased attention in the aging literature is that of leading an active or engaged lifestyle. Whereas there are numerous variations in the manner in which "active" and "engaged" are defined (e.g., Fratiglioni, Paillard-Borg, & Winblad 2004; Lövdén, Ghisletta, & Lindenberger, 2005), the basic assertion behind this line of research is that maintaining certain levels of intellectual, physical and/or social activity may help to counteract declines in functional ability that are often associated with aging. This notion has also gained much attention in the popular culture and is often referred to as the "use it or lose it" hypothesis (Hultsch, Hertzog, Small & Dixon, 1999; MacKinnon, Christensesn, Hoffer, Korten & Jorm, 2003). Whereas this line of research has been very fruitful in aiding towards understanding the protective benefits of activity in late adulthood, little is known about the influences of activity on earlier parts of the adult lifespan (see Table 1). The current study seeks to fill this need by examining the relationship between activity and cognition across a wider age-range than has previously been considered. By improving our understanding of the effects of activity on cognition throughout the adult lifespan, we will be better able to determine whether the benefits of activity on cognitive functioning are beneficial throughout adulthood, differentially in favor of older adults or (as some have suggested) simply reflective of variability that may have been present throughout the lifespan (see Salthouse, 2006). Knowing the effects of activity on earlier parts of the adult lifespan is also important so that potentially advantageous behavioral modifications may begin earlier.

The current study also seeks to gain a better understanding of the nature of the activity-cognition relationship by examining questions concerning the directionality of the relationship between maintaining a generally active lifestyle and cognitive functioning as well as questions concerning generalizability of the effects of activity across various cognitive domains. Two specific questions were addressed, 1) Does activity help to preserve cognitive ability and/or do individuals with high cognitive ability tend to be more active? and 2) Are the protective benefits of activity on cognition generalizable to all cognitive domains or limited to certain domains?

Activity and Cognitive Change: An Overview

Research investigating the benefits of activity on cognitive functioning typically falls into two general categories. The first focuses on the effects of engagement in very specific, narrowly defined activities such as physical exercise, social engagement, or intellectual activity. The second takes a more inclusive approach towards understanding the activity-cognition link and considers the benefits of maintaining a generally active lifestyle (i.e., one that consists of regular involvement in a combination of social, physical *and* intellectual activities). Evidence in support of the “use it or lose it” hypothesis has been provided from both lines of research. For example, Lachman, Neupert, Bertrand and Jette (2006) examined the effectiveness of a strength-training program on working-memory span among a group of sedentary, community-dwelling older adults with at least one disability. Participants received a home-based intervention program that involved strength training over a 6-month period. Follow-up working memory assessments were taken at 3 and 6 months into the intervention. Evidence suggested that strength training helped to increased memory function among the older adults who participated in the strength training program as compared to those who remained sedentary. Furthermore, the benefits of strength training on memory were found to increase over time within the experimental group. Colcombe and Kramer (2003) reported similar results among participants (aged 55+) who took part in a 6 month aerobic training program. Participants of the training program demonstrated more efficient inhibitory processes than those who had not received aerobic training. A population-based study conducted by Dik, Deeg, Visser and Jonker (2003) also found that physical activity in early life preserved processing speed among community dwelling older men (aged 55-85) who participated in the LASA (Longitudinal Aging Study of Amsterdam). Benefits of physical activity have also been reported for other cognitive abilities including executive (Hillman, Motl, Pontifex, Posthuma, Stubbe, Bosma & de Geus, 2006) and attentional processes (Hawkins, Kramer, & Capaldi, 1992).

Social activity (defined as the maintenance of many social connections and/or a high level of participation in social activities) has also been shown to have positive effects on the maintenance of cognitive abilities in later adulthood. In a community based, epidemiological study of persons 65+ years of age, spanning over 12 years, Bassuk, Glass, and Berkman (1999) found that participants with limited social ties (fewer than 5 social contacts) were more likely to have incidences of cognitive decline than adults with more extensive social ties. Notably, this effect was found independent of sex, SES, education and initial cognitive functioning. Zunzunegui, Alvarado, Del Ser, and Otero (2003) found similar results among community dwelling Spanish seniors over 65 years of age. This longitudinal study also found that seniors who were socially disengaged (measured by the frequency of social interactions and number of social contacts) were at increased risk for cognitive decline as compared to those who were engaged.

Studies investigating the effects of intellectual engagement have also provided support for the “use it or lose it” hypothesis. Using data on middle-aged and older adult workers, Schooler and colleagues demonstrated that adults who are exposed to intellectually challenging and complex work environments tended to experience increases in intellectual functioning (Schooler, 1984; Schooler, Malatau & Oates, 1999). Wang, Karp, Winblad and Fratiglioni (2002) explored the relationship between leisure activities and the development of dementia among community dwelling adults aged 75 or older in Sweden. Data collection occurred at three time points over a 9 year period. Information was collected regarding type and frequency of participation in the activities reported, then divided into five categories (mental, physical, social, productive and recreational activity). Results of the study revealed a decreased risk of dementia diagnosis among community dwelling older adults who participated in social and mentally stimulating activities. The authors further reported that as frequency of participation increased, the relative risk of dementia diagnosis further decreased. This suggests that the frequency of activity may influence the degree to which benefits are experienced. Collectively, these data support the idea that engagement in some form of activity --physical, social *or* intellectual, may be protective against cognitive decline.

General Activity Studies

The second category of activity studies (those considering the relationship between maintaining a generally active lifestyle and the preservation of cognitive functioning) have also yielded positive results. One such study conducted by Christensen and colleagues (1996) investigated the relationship between activity (defined as frequency of engagement in various physical, intellectual and social activities), and various aspects of cognitive functioning including crystallized ability, fluid ability, memory and Mini Mental Status Exam (MMSE) among a group of community dwelling older adults. Eight hundred fifty-eight Australian community-dwelling adults between the ages of 70-89 provided both self and informant reports of activity. Results of this cross-sectional study indicated that inactivity was related to poorer performance across the various domains investigated independent of sex, education, sensory functioning, health, and disability status (as measured by ADL). A comparable longitudinal study by Mackinnon et al. (2003) also investigated whether engagement in general everyday activities helped to protect against cognitive decline among adults over 70 years of age.

Data were collected at three time points over a seven-year period. Results of this study also revealed a positive relationship between general measures of activity and cognition over time. Furthermore, participants with low activity levels at the beginning of the study were more likely to exhibit declines in memory and crystallized intelligence than participants with higher levels of activity. Together, results from general activity studies provide additional support for the notion that engaging in a variety of everyday activities may provide protective benefits against cognitive decline for older adults.

As previously discussed, research investigating the protective benefits of activity on cognition are examined from differing perspectives (general vs. specific activity). One key benefit of studies utilizing broader, more inclusive definitions of activity over more narrowly defined studies is that they are better able to approximate activity as it occurs in everyday life. Most people who are engaged in their environment will not limit themselves to only one type of activity, but will engage in a variety of activities that may tap multiple domains. For example, some activities may be considered both social and intellectual in nature such as being a member of a bridge club. Likewise, regularly attending a senior center may be considered a social activity. There may, however, also be a physical component if exercise is one of the club's daily activities; because of this some have argued that narrower definitions of activity "…may underestimate the potential influence of activity because it limits inter-individual variation and may overlook many activities that older adults engage in" (Newson & Kemps, 2005, p.114). More inclusive measures may also be helpful to the extent that they are more likely to capture wide individual differences that exist in the nature of activities in which people choose to (or have the opportunity in which to) engage. For these reasons, a general definition of activity was employed in this study. Interestingly enough, it does appear that results in favor of the ""use it or lose it" hypothesis are more consistently found among studies employing broader, more inclusive definitions of activity rather than those that are narrowly defined (see Table 2).

How Does Activity Protect Against Decline?

Several hypotheses have been proposed to explain how lifestyle variables might influence cognitive change. The disuse hypothesis suggests that changes in one's lifestyle -particularly in the patterns in frequency of daily activities—lead to many of the negative aging-related changes in cognitive functioning (Salthouse, 1991). In other words, we experience cognitive decline as a result of the reductions we make in daily activity as we age (reflecting concurrent effects of lack of engagement over time (Hultsch et al., 1999; MacKinnon et al. 2003). According to the disuse hypothesis, individuals who maintain active and engaged lifestyles into late adulthood should experience fewer negative changes in functional status including risk of dementia. A most attractive aspect of this theory is the implicit assumption that individuals may be able to exercise some influence over cognitive change by making behavioral modifications such as exercising, doing crossword puzzles, and so forth (Hultsch et al., 1999).

Another perspective that has been presented in explanation for the effects of activity on cognitive functioning is the environmental complexity hypothesis (Schooler, 1984). Environmental complexity hypothesis argues that declines in cognitive functioning are primarily due to changes in the *complexity* of an individual's environment. On the surface, the two ideas may appear to differ. Upon closer examination however, it can be argued that while disuse theory focuses primarily on simple patterns of activity (whether or not older adults engage and how much); the environmental complexity hypothesis begins with the assumption that there is engagement but the emphasis is on the *quality* of that engagement. According to this framework, an individual who remains immersed in a complex environment is more likely to retain intellectual functioning because they will benefit from higher levels of cognitive stimulation, which in turn helps to increase mental flexibility. Conversely, continued exposure to simple environments leads to poor intellectual functioning. Support for the environmental complexity hypothesis primarily stems from studies investigating the effects of occupational conditions on psychological functioning. Schooler and colleagues found that adults who were engaged in intellectually challenging and complex work environments also experienced increases in intellectual functioning (Schooler, 1984; Schooler et al., 1999). More recently, Schooler and Malatau (2001) extended their ideas about the benefits of complex work environments to leisure time activities. They considered whether engaging in *intellectually* complex leisure activities provided similar mental benefits to younger and middle-aged adults. The relationship between intellectually complex leisure activities and intellectual functioning was moderate (as compared to those between work and intellectual functioning), but their findings did provide some support for the idea that continued engagement in one's environment may have positive effects on cognitive functioning in middle and older adulthood. Due to the limited nature of the activity measure used in the current study -the current study only captures whether or not participants engaged in activities- I was not able to specifically address questions concerning the potential influence of complexity of engagement on cognition. In accordance with the "use it or lose it" framework (and disuse hypothesis), the current study examined the relationship between engagement in general leisure activity and cognitive functioning across the adult lifespan. Because of the longitudinal design and broad age-range of participants in this study, I was in a unique position to examine interindividual as well as intraindividual influences of activity on cognitive change in order to gain a better understanding of potential influences across the lifespan.

Reciprocal Influences on Cognition and Cognitive Change

By their very nature, both the disuse and complexity hypotheses support the "use it or lose it" notion. Both suggest that the relationship between leading an engaged lifestyle and maintaining optimal cognitive functioning should occur in concert. Thus, as level of engagement is maintained (or increases), cognitive functioning should respond similarly. Unlike the unidirectional relationship implied by the original disuse hypothesis however, Schooler (1984) proposed that the relationship between continued engagement in complex activities and intellectual functioning is reciprocal rather than unidirectional. He suggested that high functioning individuals tend to lead high functioning lives, which in turn helps to further increase intellectual functioning. Questions regarding directionality were first addressed by Hultsch and colleagues (1999). In that study, the authors examined the hypothesis that maintaining intellectual engagement buffers against cognitive decline in old age. They were particularly interested in determining the effect of mental activity on cognitive change from other known influencing factors such as education, SES, gender, age and race. Although some evidence was found to suggest a relationship between participation in intellectually engaging activities and a slower rate of working memory decline, they argued against a causal relationship between activity and working memory function because they found that when they reversed the model (indicating that intellectual decline predicts intellectual activity level), it too was confirmed. In an attempt to further explore this issue, Lövdén and colleagues (2005) conducted a study addressing the following key questions: a) whether high functioning adults were more likely to lead and maintain active lifestyles, b) whether leading an engaged lifestyle alleviated cognitive decline, and c) whether the relationship between activity and cognitive function was bidirectional. Using a combination of structural equation modeling (SEM) and the dual change- score model (DCSM), the authors examined change over three time points, spanning 6 years. In that study activity was found to mediate perceptual decline in old age (70-103) thereby supporting the idea that leading an active lifestyle may positively influence cognitive change. Contrary to the study conducted by Hultsch and colleagues (1999), the reverse, (e.g., perceptual decline is mediated by an active lifestyle) was not supported. These findings lead me to conclude that perhaps the directionality of the effects may be dependent upon the way in which activity is defined (general vs. specific) or the cognitive domain being investigated (crystallized vs. fluid).

The current study considered one of these possibilities by examining the relationship between general leisure activity and cognitive functioning across measures that are presumed to tap into both crystallized and fluid abilities. Aside from those listed above, few studies have directly addressed the question of directionality, and it continues to be a topic of debate in the area (see Salthouse, 2006; Salthouse, 2007; Schooler, 2007). Most recently, Salthouse (2006) argued that although many studies have found a positive relationship between intellectual activity and cognitive functioning, “the existence of a relation between level of mental activity and level of mental functioning among adults at any given age is by itself not very informative (p.70).” In his view, causation can not be inferred because it is possible that the observed relationship can also be produced by alternate pathways that are not causal in nature such as: a) the cumulative effects of mental activity throughout one’s life contributing to an individual’s level of mental ability in later life (see Whalin, 2004); and b) the amount of mental activity being partially determined by an individual’s current level of mental ability. He suggests that much of the observed variance in cognitive performance during old age may have been present all along and not necessarily attributable to the benefits of current engagement in mental activities. On the other hand, Schooler (2007) argued that although the empirical evidence may not provide conclusive support for the “use it or lose it” hypothesis, the results among both normal and clinical populations have been congruent not only for studies investigating intellectual activity (Schooler,1996), but leisure activities as well (Bosma et al., 2002).

Schooler (2007) concluded:

“ … that Salthouse set the bar of proof too high by postulating that for a study to provide proof of the use-it-or-lose-it hypothesis, its findings must contain a significant interaction indicating that doing some form of ''mental exercise'' decreases the rate of decline more for older than for younger individuals. A more appropriate criterion would be whether doing such mental exercise increases the likelihood that a given individual's level of cognitive functioning will be better than if he or she had not done such exercise and will continue to be better for a consequential period of time." (p.24)

Schooler further concluded that the evidence presented by Salthouse (2006) does not negate the "use it or lose it" hypothesis, and the potential benefits of engaging in complex intellectual activity are likely to *at least* help older adults maintain their cognitive abilities longer than if they had not. Thus 'using it' may help you keep it longer. In line with the second goal of the current study (to gain a better understanding of the *nature* of the relationship between activity and cognitive change), questions regarding directionality were specifically addressed by examining whether the relationship between activity and cognition is reciprocal or unidirectional in nature. This allowed for the direct investigation of at least one of the key criticisms presented by Salthouse above; namely the question concerning whether the observed effects of activity are in part being determined by an individual's current mental ability.

Could the Protective Benefits of Activity Domain Specific?

Several discrepancies have been reported in the literature concerning the effects of activity on cognition and cognitive change. Christensen et al. (1996) reported varied effects of activity on cognition between the young-old (70-74) and old-old (75+). For participants under 75 years of age, inactivity predicted crystallized ability but for those 75 and older, inactivity predicted fluid ability. Although evidence for reciprocal relationship between activity and cognitive change have been reported by some investigators (Kohn & Schooler, 1978; Hultsch, 1999), Lövdén et al. (2005) failed to find evidence of such when investigating perceptual decline. These varied patterns of results illustrate a common concern among critics in the field to adopt a certain level of skepticism about the generalizability of the “use it or lose it” hypothesis (Salthouse, 2006). Some have argued that these differences stem primarily from the fact that there are inconsistencies in measurement and definition across studies (Parslow et al., 2006, Fratiglioni et al., 2004).

Another possibility that should be considered is that these outcomes may actually reflect important differences in the domains being investigated and their sensitivity to the effects of activity (Antsey & Christensen, 2000; Christensen et al, 1995). Given that crystallized abilities have been found to be more resistant to age-related declines than fluid abilities (Horn & Cattell, 1967), it is plausible to assume that fluid abilities are more flexible and therefore more sensitive to the positive effects of activity. The current study explored this possibility by examining the relationship between general leisure activity and cognitive function across measures that are presumed to tap into domains reflecting both crystallized and fluid abilities. By beginning to examine these differences, the current study sought to provide additional insight into the nature of the activity-cognition relationship.

The Case for Cognitive Reserve: Proposed Mechanisms

Although the current study is not able to empirically address questions regarding proposed mechanisms for the activity-cognition relationship, a brief discussion of Stern’s

(2002) cognitive reserve model is presented here in order to facilitate discussion of the results of the current study.

Reserve models originated from repeated observations that a disconnect frequently exists between physical brain pathology and the actual clinical evidence of that pathology among many aging adults (Stern, 2007). The general premise behind these models is that some individuals posses a certain amount of reserve (or protective buffer), and the ratio between pathology and reserve determines the degree to which clinical evidence of impairment is visible. In other words, an individual with more reserve will be able to tolerate higher levels of pathology than someone with less reserve before exhibiting symptoms related to that impairment.

Stern (2007) distinguishes between passive and active pathways for how reserve may operate. In making this distinction, it is important to note that the pathways discussed here are not independent of one another but it does help to clarify the differences in how they are proposed to operate. The passive pathway (also known as threshold model) simply reflects increases in brain size or neuronal connections. By default, an individual with more brain mass can sustain more injury before exhibiting symptoms. Stern refers to this as a passive reserve model. In the cognitive reserve (CR) model, which Stern (2007) identifies as the active model, the brain actively tries to compensate for challenges that may be brought on by brain damage or impairment. The more active model focuses primarily on *how* tasks are processed instead of the physiological networks involved. In the CR model, one may engage in two types of compensatory processing. What differs, in part, is the driving force behind the how the task is processed. Stern describes *neural reserve*, which involves the use of strategies or brain networks in order to achieve more efficient or flexible processing. This type of compensatory processing can occur within healthy or brain-damaged individuals when attempting to deal with various task demands. On the other hand, *neural compensation* occurs when an individual adopts *novel* paradigms or networks because their impairment has somehow interfered with processes that would have normally been used (Stern, 2007).

In line with the "use it or lose it" framework, Stern further suggests that certain environmental factors such as educational attainment or engagement in leisure activities may help to build reserves against cognitive decline and Alzheimer's disease (Stern, 2002; Scarmeas & Stern, 2004). One study by Scarmeas et al. (2003) considered whether pre-morbid activity in patients with early stage Alzheimer's disease (AD) provided cognitive reserve. The authors observed cerebral blood flow (CBF) of sixteen healthy older adults and nine AD patients. They found an inverse relationship between CBF and previously reported activity level among the AD patients. These results support the notion of cognitive reserve in that those with more reserve were able to withstand greater levels of pathology before the effects became evident. This relationship persisted even after the authors controlled for the severity of the disease and education. These findings are consistent with the idea that activity may help to build reserves against the effects of pathological aging. Thus by "using it", individuals may delay "losing it". The current study examined whether general engagement in activity reduced the likelihood of being diagnosed with dementia. Consistent with the use it or use it hypothesis and the reserve model, I hypothesized a decreased risk of dementia diagnosis as a function of increased activity level.

The Present Study

As previously discussed, research supports the idea that leading an active and engaged lifestyle may help slow the effects of aging on cognition (McKinnon et al., 2003). Little is known, however, about the effects of activity on cognitive change in younger and middle adulthood. Though much research in this area is focused on improving the quality of life in old age, it is important to know the effects of activity on earlier parts of the adult lifespan so that potentially advantageous behavioral modifications may begin earlier. This could also inform the question as to whether engagement effects are specific to later life as some have argued (Salthouse, 2006) or are more general in nature. In light of this, the current study seeks to extend the existing literature by investigating both cross sectional and longitudinal relationships between activity and cognition across the adult lifespan. Because of the wide age range and the time span available in these data, the current study was able to conduct examinations of interindividual and intraindividual change in order to more closely examine the differential effects of activity on cognitive functioning at different ages as well as possible cumulative effects of activity on the rate of change in cognition.

The present study had three specific goals. The first was to examine the cross-sectional relationship between activity and cognition in young, middle-aged and older adults. Cross-sectional analyses allowed me to determine whether the benefits of activity varied with age. If there are differential effects of activity in favor of particular age-groups, perhaps middle or late adulthood, we can argue more definitively in favor of the use it-or-lose it hypothesis.

The second goal was to examine the effects of activity on the trajectory of cognitive change. I was particularly interested in understanding how--if at all--activity influences the rate of negative change in adulthood. The current study examined the effects of activity on intraindividual cognitive change. I also examined whether activity is a protective factor in the development of dementia. I hypothesized that higher activity levels would be associated with slower rates of cognitive decline, as well as decreased risk of being diagnosed with dementia over time, than those with lower activity levels.

The third goal of the current study was to examine the nature of the relationship between activity and cognitive change. Two specific questions were addressed. I examined whether the relationship between activity and cognitive function is reciprocal or unidirectional in nature. I also examined whether the relationship between activity and cognitive change differed based on the cognitive domain being investigated. Existing research suggests that the effects of activity are reciprocal and the direction of these effects may be further influenced by the domain being investigated (Hultsch et al., 1999; Lovdén et al., 2005; Schooler, 2007; Schooler & Malatu, 2001). Thus, I hypothesized a reciprocal relationship between activity and cognitive function. I also hypothesized that there would be differential effects of activity between measures that reflect crystallized ability versus fluid ability. Specifically, I predicted that fluid ability would be more influenced by activity than crystallized ability.

Methods

Participants

Participants in this study were a subset of adult volunteers from the Baltimore Longitudinal Study of Aging (BLSA) who also completed the Attitudes and Activity Questionnaire (Burgess, Cavan & Havighurst, 1948) as part of their battery of psychological measures (n = 2093). The BLSA is a longitudinal study designed to investigate the effects of aging in healthy adults which began in 1958. Participants in the larger data set are a convenience sample of community-dwelling men and women ages 17 or older. Early recruitment of women into the BLSA sample began in 1978 and was partial to the wives of existing male participants. As a whole, earlier participants of the BLSA represent a fairly homogeneous sample. Ninety-one percent of the participants were classified as White, 8% percent Black, and .7% other. Fifty-nine percent were working at least part-time and 41% were not working. Most of the male participants were highly educated professionals or employed in management positions and married (Rasmusson, Zonderman, Kawas & Resnick, 1998; Shock et al, 1984). Given that early participants of the BLSA study represent a highly selective sample, results of this study may have limited generalizability to other less affluent or educated populations. Additional demographics concerning the participants at first and last measurement are reported in Table 3.

The complete data set contains repeated assessments of various biological, physical, psychological and lifestyle measures. Assessment intervals of the larger study initially occurred every two years on site at the National Institute of Aging (NIA). As the

BLSA is an ongoing longitudinal study, various changes in protocol (e.g., instruments and assessment intervals) have been made in order to better capture developmental change (see Shock, Greulich, & Andres, 1984). Currently, testing occurs every four years for participants under 50, every two years for those 50-79 and annually for those 80 and older.

The subset of data used in this study contained up to 7 time points at which data were collected over a 36-year period (1958 -1994) at varying intervals. For purposes of this study, participants with a diagnosis of known or probable dementia at the beginning of the study were excluded from the sample due to negative effects on measurements of cognitive functioning (Rosen, 1980). Participants with fewer than two activity measurements were also eliminated. The final number of participants available for analysis were $n = 1468$.

Detailed information concerning drop-out rates were not systematically recorded during the earlier years of the BLSA. In addition, participants involved in the BLSA were (and continue to be) permitted to exit and reenter into the larger study at various data collection points. Based on information currently available, Table 4 presents information regarding the frequency of repeat observations available for participants with AAQ data during the course of the current study.

Measures

Activity index. For purposes of this study, activity was defined as participation in a variety of physical, social and intellectual activities. By utilizing a broader, more inclusive definition of activity, I hope to capture individual differences in choice of activities -or opportunity to engage in certain activities- that may not have been revealed using less inclusive measures.

Participants completed the Activities and Attitudes Questionnaire (AAQ) (Burgess, Cavan, & Havighurst, 1948), as part of the battery of measures administered at every fourth visit between 1958 and 1994. The activity subscale of the AAQ consists of a list of 20 leisure activities. The questions on the list reflected activities from physical, social and intellectual domains (e.g., play golf or other sports, read, attend clubs, lodges, or other meetings). In response to the question "What do you do in your free time?" participants placed a check next to each activity in which they engaged (see Appendix A). As is customary in this line of research (Fratiglioni et al., 2004; Parslow, Christensen & Mackinnon, 2006), a summary score was created using the total number of items checked to pertaining to leisure activity on the AAQ. Initial scores on the activity index ranged from 0-20. Due to the uncertainty in interpreting activity scores equal to "zero" however, only activity scores of 1 and above were included in the current analyses (n = 1230).

While this method of measuring activity can be limited in that inferences concerning the minimum amount of activity (or the quality of activities) that are necessary in order to reap cognitive benefits are not possible, several studies have found effects using summary scores which suggests that the effects are robust enough to be detected using imperfect measures (Fratiglioni et al., 2004; Parslow, Christensen, & Mackinnon, 2006).

Information concerning the frequency of responses for each activity item on the AAQ is presented in Table 5. In the context of this study, higher activity scores were presumed to be associated with higher levels of engagement in the environment.

Memory. The BVRT is a widely used measure that assesses visual perception, visual memory, and visuo-constructive abilities (Benton, 1946). Previous research has also demonstrated that changes in performance on the BVRT are associated with cognitive decline and Alzheimer's type dementia (Zonderman, Giambra, Arenberg, Resnick, Costa, 1995). The BVRT was administered as part of the BLSA battery of cognitive tests at 6 year intervals beginning in 1960. In 1990, participants over 50 years of age began to receive the measure annually. After studying each design for 10 seconds, participants were asked to replicate the design from memory at his/her own pace. Forms C, D and E were rotated at each administration of the measure. Each form is made up of 10 designs containing one or more figures. Scores on the BVRT range from 0-36 and reflect the number of total errors in reproduction. In this case, higher scores reflect poorer visual memory performance. Error scores greater than 4 are generally considered an indication of impairment. Both reliability and validity for the BVRT are quite high with inter-rater reliability above of .95. Alternate form reliability has also been reported to be between .79 to .84 between the three forms C, D and E (see Spreen & Strauss, 1998). Among nonclinical populations, the BVRT has also been shown to be modestly correlated with intelligence .7, and thus is a fair approximation of generalized ability (see Spreen & Strauss, 1998). Measures of visual acuity were not available in the current data set and as a result, I was unable to control for the potential effects of visual acuity on performance on this measure.

Vocabulary. The vocabulary subtest of the WAIS (Wechsler, 1958) was used as a measure of verbal ability. It is a multiple choice vocabulary test where participants are asked to select the closest synonym to the target word. The WAIS was administered every six years as part of the BLSA cognitive battery between 1960 and 1989. Scores on the vocabulary subtest range from 0-80. Higher scores on the vocabulary measure are associated with better verbal knowledge.

Dementia Diagnosis. Prevalence as well as incidence of dementia was examined in the current study. Diagnosis of dementia status was introduced to the BLSA in 1985. Active participants over 65 years of age who demonstrated negative changes in two or more neuropsychological tests were identified for further dementia screening. Medical records, laboratory tests, and informant questionnaires were obtained and evaluated for participants who exhibited cognitive problems. Dementia status of each subject was determined during a multidisciplinary conference on the basis of all available information. A clinical diagnosis of dementia was established using the Diagnostic and Statistical Manual of Mental Disorders 3rd ed.-Revised (APA, 1987). For purposes of the current study, dementia status was coded to indicate the absence or presence of dementia (0 = no dementia, 1= dementia).

Covariates

Age. Baseline-age (i.e., age of participant when he or she entered the study) was included in the models as a covariate in order to examine age related differences on the influence of activity on cognition and cognitive change.

Health. A self-report assessment of health was used in this study. Previous research has found self-report measures of health status to be fairly congruent with physician assessments (Maddox & Douglass, 1973). At each visit, participants were asked to rate their health in response to the question: "How would you rate your health at present?" The responses were scored from 1 to 5, with 1 = very poor health, 2 = poor, 3 = fair, 4 = good, and 5 = excellent health. Prior to its inclusion in the analyses, the relationship between health and activity was examined. Changes in health were positively associated with changes in activity ($\gamma_{10} = .27$, $t = 2.22$, $p < .03$). Therefore health status was included as a covariate in the analyses in order to allow me to examine changes in cognition that may be related to activity level, independent of changes in health status.

Work Status. Due to the fact that change in work status may also potentially influence participation in leisure activities, work was included as a covariate in the analysis. This allowed me examine changes in cognition that may be related to activity level independent of changes in work status. Participant responses were coded 0 if they were not working and 1 if they were working. Participation in leisure activities tended to decrease as work status increased ($\gamma_{10} = -.95$, $t = -5.71$, $p < .0001$). This means occasions of employment were characterized by decreases in activity. Thus, work status was included as a Level 1 covariate in future analyses in order to determine the effects of activity independent of those associated with changes in work status.

Education. Education is defined as total years of education completed as of 1992. Research in the area suggests that there may be a relationship between educational attainment and cognitive change (Anstey & Christensen, 2000). Including education as a covariate enabled me to determine whether any of the variability attributable to activity level on cognitive change (and vice versa) is independent of educational attainment.

Gender. The relationship between gender and activity was examined in order to determine whether there were any gender differences in activity level. The results indicate that there were gender differences in activity level in this sample with men reporting moderately lower levels of leisure activity than women (r = -.15, p < .0001). Therefore, gender was included as a covariate in order to control for potential gender effects. Gender is coded as (0 = female, 1 = male).

Results

Cross Sectional Analyses

Multiple regression analyses were used in order to examine the cross-sectional relationship between activity and cognition. Activity and all the covariates were examined as predictors of BVRT and vocabulary scores. Activity and all the covariates were also entered into a logistic regression analysis in order to examine their influences on the prevalence of dementia. Age was also included as a covariate in the models in order to address the first goal of the study (i.e., whether benefits of activity varied with age). All predictors were centered prior to being entered into the model in order to reduce multicollinearity. Detailed parameter estimates for the models can be found in Table 6.

Visual Memory. The overall model was statistically significant (R^2 = .28, F [13, 1116] = 32.70, p < .0001), accounting for 28% of the variance in memory scores. Memory performance was significantly related to age (b = .08, t = 16.17, p < .0001) and education (b = -.15, t = -5.30, p < .0001). Overall, older adults committed more memory errors than younger adults, and higher education was associated with fewer memory errors. Contrary to expectations, activity alone was not found to be related to memory performance (b = -.01, t = -.14, p < .89). I also failed to find the predicted interaction between age and activity on memory performance (b = -.002, t = -.91, p =-.91), which suggests that the effects of activity do not differ by age. Analyses did reveal a significant Activity x Gender interaction on memory performance (b = -.14, t = -2.33, p =.02), indicating that the relationship between activity and memory is dependent on gender. More activity in men was associated with fewer memory errors, but this effect was not evident in women (Figure 1).

Vocabulary. The overall model for vocabulary performance was statistically significant (R^2 = .27, F [13, 934] = 26.82, p < .0001), accounting for 27% of the variance in vocabulary scores. As expected and consistent with the literature, age (b = .07, t = 4.21, p < .0001) and education (b = 1.78, t = 15.52, p < 0001) were positively related to vocabulary performance. Work status was also found to be positively associated with vocabulary (b = 1.37, t = 2.01, p < .05), such that vocabulary performance was higher for participants who were currently working than for those who were not. Activity was not related to vocabulary performance, nor was gender or health status. The interaction observed for memory performance did not emerge for vocabulary.

Dementia Diagnosis. The relationship between activity level and prevalence of dementia (i.e., the total number of dementia cases observed in this sample) was examined using logistic regression. Logistic regression is appropriate in this case because the dependent variable (diagnosis of dementia [coded as 1] vs. no diagnosis of dementia [coded as 0]) is dichotomous. Fifteen percent of the population observed were diagnosed with dementia (*n* = 123 [82 women, 41 men]). However, only 10 of the 123 participants diagnosed with dementia had a sufficient number of data points to be included in the model. Therefore, the results from this analysis should be interpreted with some caution. The full model, which included all of the covariates, revealed that older age (OR = 1.09, x^2 = .01, LCI = 1.02, UCI = 1.17) and higher education (OR = 1.54, x^2 = .02, LCI = 1.08, UCI = 2.19) were related to an increased likelihood of dementia diagnosis. Gender was also related to likelihood of dementia diagnosis, with males being less likely to be diagnosed with dementia than women (OR = .072, x^2 = .04, LCI = .005, UCI = .87). A significant Activity x Gender interaction also emerged, suggesting that the relationship between activity and dementia diagnosis is dependent on gender (OR = 2.70, $p < .004$, LCI = 1.36, UCI = 1.18). Contrary to expectations, higher activity in men appeared to be associated with was an increased likelihood of dementia diagnosis (Figure 2). Note however, that these results have limited interpretability due to the low number of individuals who were diagnosed with dementia in this sample. Based on the ratio of men to women in whom dementia was observed, it can also be presumed that the majority of the occurrences of dementia in this sample were women. Whether the association between activity and increased likelihood of dementia diagnosis reflects spurious results or is related to unique processes occurring in men merits further investigation, but cannot be determined at this time.

Longitudinal Analyses

Multilevel Modeling (MLM) was used to examine the trajectory of cognitive change as a function of activity level over time. MLM is typically used for the analysis of data with complex patterns of variability, and its use allowed me to determine variability due to intraindividual (within-person) and interindividual (between-person) differences. In the context of the current study, using MLM allowed me to examine differences in the trajectory of change due to time, activity and work status (Level 1), as well as those due to between-person differences such as gender, education and baseline age (Level 2) (Snijders & Bosker, 1999). I chose to use MLM to examine the trajectory of change over other commonly used methods such as repeated measures analysis of variance (ANOVA) or multiple regression analysis primarily because of the nature of these data. First, the repeated assessments that are characteristic of longitudinal studies violate the independence of observations assumption of ordinary least squares (OLS) regression. Second, participants in the current data set were measured at varying time points and intervals during the course of this study and third, the current data set contained incomplete data. Because MLM is not dependent on the completeness of the data set as with repeated measures ANOVA, I was able to use all available data from each participant in order to estimate the trajectory of change. MLM was also able to control for the irregular timing of individual measurements (Snidjers & Bosker, 1999). I used MLM in order to examine the trajectory of cognitive change as a function of activity level over time. At Level 1, the differences in the trajectory of change due to time, activity, work status and health were examined. At Level 2, the between-person differences in baseline age, education and gender were also examined.

Prior to analysis, a fully unconditional model was tested for each dependent variable that was to be used in the multilevel models in order to estimate the ratio of between and within person variance in cognition and dementia diagnosis. The unconditional model helped to determine whether sufficient variability existed between and within individuals to justify full model specification. At Level 1, r_{it} represents the variability within persons in BVRT scores with no predictors in the model. At Level 2, γ_{00} represents the grand mean in BVRT scores with no predictors in the model and u_{0i} is the between person variability in cognition scores. Results of the null model indicated that 58% of the variability in BVRT scores was due to between person differences (τ_{00} = 9.38, z = 26.18, p < .0001) and 42% of the variability in BVRT scores is due to within person fluctuations (σ^2 = 6.90, z = 57.24, p < .0001).

Fully Unconditional Model (BVRT): (1)

Level 1: $BVRT_{it} = \beta 0_{it} + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

Results of the null model for WAIS vocabulary (below) indicated that 62% of the variability in WAIS scores was due to between person differences (τ_{00} = 90.91, z = 29.34, p < .0001) and 38% of the variability in vocabulary scores is due to within person fluctuations (σ^2= 12.62, z = 33.48, p < .0001). The unconditional models for BVRT and vocabulary indicated that there was sufficient variability to justify further analyses.

Fully Unconditional Model (WAIS): (2)

Level 1: $WAIS_{it} = \beta 0_{it} + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

Results of the null model for dementia diagnosis (below) indicated that 98% of the variability in the likelihood of being diagnosed with dementia was due to between person differences ($\tau_{00} = 7.95$, $z = -64.97$, $p < .0001$) and only 2% was due to within person fluctuations ($\gamma_{00} = -6.5$, $\sigma^2 = .11$). The low estimate of within person variability primarily reflects the fact that there were only eight people (2 men, 6 women) with sufficient data for analyses.

Fully Unconditional Model (DementDx): (3)

Level 1: $DementDx_{it} = \beta 0_{it} + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

Results of the null model for activity (below) indicated that 52% of the variability in the likelihood of transitioning into dementia status was due to between person differences ($\tau_{00} = 5.65$, $z = 10.21$, $p < .0001$) and that 48% of the variability was due to within person differences ($\sigma^2 = 5.07$, $z = 11.38$, $p < .0001$). The unconditional models for Activity indicated that there was sufficient variability to justify further analyses.

Fully Unconditional Model (Activity): (4)

Level 1: $Activity_{it} = \beta0_{it} + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

The first full model (below) examined changes in activity over time as a function of health (Level 1). Activity level for person *i* at time *t* is a function of the intercept, $\beta0_{it}$ which refers to activity for person *i* controlling for the effects of health. γ_{00} represents the grand mean for activity, whereas $\beta1_{it}$ represents the relationship between activity and health and is tested with the fixed effect of γ_{10} in the second Level 2 equation. Changes in health were positively associated with changes in activity ($\gamma_{10} = .27$, $t = 2.22$, $p < .03$). Therefore health was included as a Level 1 covariate in order to determine the effects of activity independent of health status.

Model 1: (5)

Level 1: $Activity_{it} = \beta0_{it} + \beta1_{it}\ (Health) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

$\beta_{1i} = \gamma_{10}$

The second full model (below) examined changes in activity over time as a function of work status (Level 1). Activity level for person *i* at time *t* is a function of the intercept, $\beta0_{it}$ which refers to activity for person *i* controlling for work status, $\gamma_{00,}$ which represents the grand mean for activity, and $\beta 1_{it,}$ which represents the relationship between activity and work status. The relationship between activity and work status is tested with the fixed effect of γ_{10} in the second Level 2 equation. Work status was found to be related to changes in activity level. Participation in leisure activities decreased as work status increased ($\gamma_{10} = -.95$, $t = -5.71$, $p < .0001$). This means that occasions of employment were characterized by decreased leisure activity. Thus, work status was included as a Level 1 covariate in future analyses in order to determine the effects of activity independent of those associated with changes in work status.

Model 2: (6)

Level 1: $\text{Activity}_{it} = \beta 0_{it} + b \square_{it} (\text{Work}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

$\beta_{1i} = \gamma_{10}$

Change in visual memory as a function of activity. The third full multilevel model examined changes in cognition (as measured by BVRT) as a function of time, activity, work status, and health (Level 1). BVRT scores for person *i* at time *t* is a function of the intercept, $\beta 0_{it}$ which refers to memory score for person *i* at baseline (time = 0) when there is no activity (activity = 0) and when work (work = 0) and health status (health = 0) are not included in the model. $\beta 1_{it}$ represents the relationship between memory and time, $\beta 2_{it}$ represents the relationship between cognition and activity, $\beta 3_{it}$ represents the relationship between memory and work status, $\beta4_{it}$ represents the relationship between memory and health, and $\beta5_{it}$ represents the relationship between memory and the combined effects of activity and health. At Level 2, the potential influence of age (γ_{01}), educational attainment (γ_{02}), gender (γ_{03}), and combined effects of age and gender (γ_{04}) on memory were controlled for. The grand mean for memory is represented by $\gamma_{00.}$ The relationship between time and memory is represented by $\gamma_{10.}$ The relationship between activity and memory is represented by $\gamma_{20.}$ The following main and interaction effects were also examined and are represented in the equations as follows: (a) γ_{21} examines whether the relationship between activity and memory is dependent on age, (b) γ_{22} examines whether the relationship between activity and memory is dependent on gender, (c) γ_{23} examines whether the relationship between activity and memory is simultaneously dependent on age and gender, (d) γ_{30} represents the relationship between work status and memory, (e) γ_{40} represents the relationship between health status and memory, (f) γ_{50} examines whether the relationship between activity and memory is dependent on health status, and (g) γ_{51} examines whether the relationship between activity and memory is simultaneously dependent on health and gender.

Model 3 (7)

Level 1: $BVRT_{it} = \beta0_{it} + \beta1_{it}(\text{Time}) + \beta2_{it}(\text{Activity}) + \beta3_{it}(\text{Work}) + \beta4_{it}(\text{Health}) + \beta5_{it}(\text{Activity*Health}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \gamma_{02}(\text{Educ}) + \gamma_{03}(\text{Gender}) + u_{0i}$

$\beta_{1i} = \gamma_{10} + u_{1i}$

$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Age}) + \gamma_{22}(\text{Gender}) + \gamma_{23}(\text{Age*Gender}) + u_{2i}$

$\beta_{3i} = \gamma_{30}$

$\beta_{4i} = \gamma_{40}$

$\beta_{5i} = \gamma_{50} + \gamma_{51}(\text{Gender})$

The results of the above model indicate significant declines in memory over time (γ_{10} = .08, t = 3.78, p = <.0004). Older age (γ_{01} =.08, t =6.66, p < .0001) and being male (γ_{03} = 5.23, t =1.95, p < .05) were also associated with poorer memory at baseline, but higher education was related to fewer memory errors at baseline (γ_{02} = -.15, t = -4.36, p < .0001). An Activity X Gender interaction also emerged (γ_{22} = -.76, t = -2.25, p < .03) suggesting that the relationship between activity and memory is dependent on gender (Figure 3). Just as in the cross sectional analyses, the 2-way interaction revealed that increased activity was associated with better memory performance over time among men but not women. A 3-way Activity X Health X Gender interaction also emerged, suggesting that the relationship between activity and memory is simultaneously dependent on health status and gender (γ_{24} = .15, t = 2.0, p < .05). Consistent with expectations, increased activity was significantly associated with better memory performance. This effect was further moderated by health status such that the influence of activity was greatest among individuals with poor health. Active individuals with poor health saw greater memory improvements over time than active individuals who were healthier (Figure 4). Work status was not associated with changes in memory performance over time (see Table 7). This model accounted for 52% of within-person variability in memory performance and 87% of variability between persons.

Change in verbal ability as a function of activity. Attempts to run the proposed model resulted in uninterpretable estimates; most of the *df* were at 0. Therefore, a simpler model was tested. In order to be able to address specific questions related to differential effects of activity level on cognitive domains, I tried to keep the models as similar as possible. I began by eliminating interaction effects that were not significant from Model 3.

The fourth full multilevel model (below) examines changes in verbal ability (as measured by WAIS vocabulary) as a function of time, activity, work status and health (Level 1). The full model is represented below. Vocabulary score for person *i* at time *t* is a function of the intercept, $\beta 0_{it}$ which refers to vocabulary score for person *i* at baseline when there is no activity. $\beta 1_{it}$ represents the relationship between vocabulary and time, $\beta 2_{it}$ represents the relationship between vocabulary and activity, $\beta 3_{it}$ represents the relationship between vocabulary and work status, and $\beta 4_{it}$ represents the relationship between vocabulary and health status. At Level 2, the potential influence of baseline age (γ_{01}), years of education (γ_{02}) and gender (γ_{03}) were controlled for, γ_{00} represents the grand mean for cognition, γ_{10} represents the relationship between time and vocabulary, γ_{20} represents the relationship between activity and verbal ability, γ_{30} represents the relationship between activity and work status, γ_{40} represents the relationship between activity and health. Several interaction effects were also examined and are represented by the following: (a) γ_{21} examines whether the relationship between activity and vocabulary is dependent on age, (b) γ_{22} examines whether the relationship between activity and vocabulary is dependent on gender, (c) γ_{23} examines whether the relationship between activity and vocabulary simultaneously depends on health and gender.

Model 4 (8)

Level 1: $WAIS_{it} = \beta0_{it} + \beta1_{it}(Time) + \beta2_{it}(Activity) + \beta3_{it}(Work) + \beta4_{it}(Health) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(Age) + \gamma_{02}(Educ) + \gamma_{03}(Gender) + u_{0i}$

$\beta_{1i} = \gamma_{10} + u_{1i}$

$\beta_{2i} = \gamma_{20} + \gamma_{21}(Age) + \gamma_{22}(Gender) + \gamma_{23}(Health*Gender) + u_{2i}$

$\beta_{3i} = \gamma_{30}$

$\beta_{4i} = \gamma_{40}$

Results of this model showed a significant increase in vocabulary over time (γ_{10} = .36, t = 4.46, p < .05). Education was also positively related to vocabulary performance (γ_{02} =1.61, t =11.85, p < .0001). Activity was not found to be associated with verbal ability over time (γ_{10} =.09, t =.27, p < .83), but there were significant differences in rates of change between persons (τ_{11} = .42, z = 2.39, p < .01). Neither age nor work status was found to be associated with changes in vocabulary performance (see Table 8). This model accounted for 36 % of variance within persons and 48% of the variance between persons.

Change in dementia status as a function of activity. The fifth model (below) examines the incidence of dementia diagnosis as a function of activity level (Level 1).

This model differs from the previous two models in several ways. First, the model was simplified to include activity as the only predictor because the number of individuals transitioning to dementia during the course of the study who had both activity data and dementia diagnosis was very low (*n* = 8). Second, the outcome variable is dichotomous (having a diagnosis of dementia or not) rather than continuous. Therefore, results of this model are reported in terms of odds ratios. At Level 1, dementia status for person *i* at time *t* is a function of the intercept, $\beta 0_{it}$ which refers to dementia status for person *i* when there is no activity. $\beta 1_{it}$ represents the relationship between dementia status and activity and is tested with a fixed effect of γ_{10}. At Level 2, β_{00} represents the grand mean for dementia status, and γ_{10} represents the relationship between activity and dementia diagnosis.

Results of this model indicated that the likelihood of transitioning into dementia is significantly related to changes in activity (OR= .000003780, LCI = .000003778, UCI = . 00003781, $p < .0001$). As predicted, increased activity was associated with decreased likelihood of transitioning into dementia.

Model 5: (9)

Level 1: Dementdx = $\beta 0_{it} + \beta 1_{it}$ (Activity) + r_{it}

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

$\beta_{1i} = \gamma_{10} + u_{1i}$

Reciprocal Influences on cognitive change. In order to examine whether a reciprocal relationship exists between activity and cognition, the previous models were reversed such that activity became the dependent variable. In Models 3 thru 5, the intercept and rate of change in cognition were free to vary between people in order to get an estimate of how much variability exists in the slope (τ_{00}). In the subsequent models (6 and 7), the association between time, cognition and activity was constrained to be equal across people by removing u_{1i} and u_{2i} from subsequent analysis because the previous analysis found that the random effect term approached zero (people did not significantly vary in their rates of change).

Prior to analyses, a fully unconditional model was tested in order to estimate the relation of between- and within-person variance in activity. At Level 1, r_{it} represents the variability within persons in activity with no predictors in the model. At Level 2, γ_{00} represents the grand mean in activity with no predictors in the model and u_{0i} is the between-person variability in activity. Results of the null model indicated that 53% of the variability in activity scores was due to between-person differences (τ_{00} = 5.66, z = 10.21, p < .0001) and 47% of the variability in activity scores is due to within-person fluctuations (σ^2 = 5.07, z = 11.38, p < .0001).

Change in activity as a function of memory. Model 6 (below) examined the relationship between changes in activity as a function of time, memory and health status at Level 1. Influences of age, education and gender on average activity were controlled for at Level 2. Activity scores for person *i* at time *t* is a function of the intercept, $\beta0_{it}$ which refers to activity level for person *i* at baseline (time = 0) when there is no BVRT (BVRT = 0). $\beta1_{it}$ represents the relationship between activity and time, $\beta2_{it}$ represents the relationship between activity and BVRT, and $\beta3_{it}$ represents the relationship between activity and works status. $\beta4_{it}$ examines the relationship between activity and health status and $\beta5_{it}$ examines whether the relationship between activity and memory simultaneously depends on gender and health status. At Level 2, the potential influence of age (γ_{01}), educational attainment (γ_{02}), and gender (γ_{03}) were controlled for with γ_{00} representing the grand mean for memory, γ_{10} representing the relationship between time and memory, and γ_{20} representing the relationship between activity and memory. Additional main and interaction effects were examined and entered into the equation as follows: (a) γ_{21} examines whether the relationship between activity and memory is dependent on age, (b) γ_{22} examines whether the relationship between activity and memory is dependent on gender , (c) γ_{23} examines whether the relationship between activity and memory is dependent on gender and age, (d) γ_{30} represents the relationship between work status and activity, (e) γ_{40} represents the relationship between health status, (f) γ_{50} examines whether the relationship between activity and memory is dependent on health status and γ_{51} examines whether the relationship between activity and memory is simultaneously dependent on gender and health.

Model 6 (10)

Level 1: $\text{Activity}_{it} = \beta0_{it} + \beta1_{it}(\text{Time}) + \beta2_{it}(\text{BVRT}) + \beta3_{it}(\text{Work}) + \beta4_{it}(\text{Health}) + \beta5_{it}(\text{Activity*Health}) + r_{it}$

Level 2: $\beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \gamma_{02}(\text{Educ}) + \gamma_{03}(\text{Gender}) + u_{0i}$

$\beta_{1i} = \gamma_{10} + u_{1i}$

$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Age}) + \gamma_{22}(\text{Gender}) + \gamma_{23}(\text{Age*Gender}) + u_{2i}$

$\beta_{3i} = \gamma_{30}$

$\beta_{4i} = \gamma_{40}$

$\beta_{5i} = \gamma_{50} + \gamma_{51}(\text{Gender})$

The results indicate that changes in work status and mean level of education were significantly related to activity level. Increases in work status were associated with decreases in leisure activity (γ_{30} =.-1.20, t =.-4.26, $p < .0001$) but higher education was associated with higher activity (γ_{02} =.14, t = 2.98, $p < .01$). A 2-way interaction emerged between memory performance and gender (γ_{22} = -.38, t = -2.69, $p < .01$). Consistent with previous analyses, higher memory scores were associated with more activity in men. The pattern appeared to be reversed in women, however, with women showing a slight decrease in activity with better memory (Figure 5). The previously observed 3-way interaction was also replicated at the within-person level (γ_{51} =.14, t = 2.98, $p < .01$). Again, the within-person relationship between activity and memory performance was moderated by changes in health, such that the relationship was stronger for occasions of poorer health (Figure 6). This effect was most salient among men with poor health who showed significant increases in activity as a function of memory performance. Although it appeared that women with better memory performance had slightly lower activity, a test of slopes revealed no significant difference in slopes for women (t = .94, p = .35). These results provide strong evidence for the idea that the relationship between activity and cognitive performance are reciprocal in nature.

Change in activity as a function of vocabulary. Model 7 (below) examined the relationship between changes in activity as a function of time, vocabulary, work and health at Level 1. Influences of age, education and gender on average activity level were controlled for at Level 2. The slopes for the associations between time and vocabulary were constrained to be equal across people by removing u_{1i} from subsequent analyses because previous analyses found that the random effect terms were zero. The activity score for person *i* at time *t* is a function of the intercept, $\beta 0_{it}$ which refers to activity level for person *i* at baseline (time = 0) when there is no activity (activity = 0). $\beta 1_{it}$ represents the relationship between activity and time, $\beta 2_{it}$ represents the relationship between activity and vocabulary, $\beta 3_{it}$ represents the relationship between activity and work status and $\beta 4_{it}$ represents the relationship between activity and health. At Level 2, the potential influence of age (γ_{01}), education (γ_{02}) and gender (γ_{03}) on activity was controlled for; γ_{00} represents the grand mean for activity, γ_{10} represents the relationship between time and activity, and γ_{20} represents the relationship between vocabulary and activity. Additional main and interaction effects were examined and entered into the equation as follows: (a) γ_{21} examines whether the relationship between activity and vocabulary is dependent on age, (b) γ_{22} examines whether the relationship between activity and vocabulary is dependent on gender, (c) γ_{23} examines whether the relationship between activity and vocabulary is simultaneously dependent on health and gender, (d) γ_{30} represents the relationship between activity and work status, (e) γ_{40} represents the relationship between activity and health.

Model 7 (11)

$$\text{Level 1: Activity}_{it} = \beta 0_{it} + \beta 1_{it}(\text{Time}) + \beta 2_{it}(\text{WAIS}) + \beta 3_{it}(\text{Work}) + \beta 4_{it}(\text{Health}) + r_{it}$$

$$\text{Level 2: } \beta_{0i} = \gamma_{00} + \gamma_{01}(\text{Age}) + \gamma_{02}(\text{Educ}) + \gamma_{03}(\text{Gender}) + u_{0i}$$

$$\beta_{1i} = \gamma_{10} + u_{1i}$$

$$\beta_{2i} = \gamma_{20} + \gamma_{21}(\text{Age}) + \gamma_{22}(\text{Gender}) + \gamma_{23}(\text{Health*Gender}) + u_{2i}$$

$$\beta_{3i} = \gamma_{30}$$

$$\beta_{4i} = \gamma_{40}$$

The results of the model found work status and health to be significantly related to activity. Occasions of work were associated with less activity (γ_{30} = -1.15, t =-4.81, p <.0001) and increases in health status were associated with increased activity (γ_{40} = .28, t = 1.98, p=.05). There was no association found between activity and vocabulary performance, nor were any significant interactions observed in this model. This model accounted for .05% of the within-person variance in activity and .06% of between-person variance in activity.

Discussion

The current study sought to contribute to the existing literature by conducting a closer examination of the nature of the effects of activity on cognition across the adult lifespan. Three specific questions were addressed. First, I conducted an examination of age-related differences in the effects of activity on cognition in order to gain a better understanding of how activity influences cognition and cognitive change throughout the adult lifespan. Second, I sought to expand existing knowledge of how activity might influence the rate of cognitive change by examining within person fluctuations. Third, I also sought a clearer understanding of the nature of the activity-cognition relationship by addressing questions concerning directionality as well as potential differences in domain responsiveness.

Cross Sectional Analysis

Aim 1: Do the effects of activity on cognition vary by age? There is an assumption in the area that the cognitive benefits of activity are disproportionately in favor of older adults. However, most of the research investigating the activity-cognition relationship to date generally excludes younger and middle aged adults, and very little is known about how activity influences cognition in the earlier part of the lifespan. The current study sought to contribute to the existing literature by conducting a closer examination of the effects of activity on cognition across a wider age range than has been previously investigated in order to gain a better understanding of how activity operates in earlier parts of the adult lifespan. The first question of interest examined whether there were differential effects of activity on cognition across age-groups. Consistent with the "use it or lose it" hypothesis, it was expected that participants with higher levels of activity would have higher performance on cognitive measures. It was further hypothesized that the nature of these benefits would be greater for older adults than younger adults. Contrary to expectations however, no age-effects emerged suggesting that the benefits of activity are not limited to older adults but may operate similarly across the lifespan.

Consistent with extant literature, memory declined with time, memory performance was poorer for older adults than for younger adults, and participants with more education made fewer memory errors than participants with less education (Anstey & Christensen, 2000). Unexpectedly, but consistent with the "use it or lose it" hypothesis, an Activity x Gender interaction emerged for memory. In this sample, higher activity was associated with better memory performance in men but not women. The failure to find significant effects of activity in women in this sample may reflect cohort effects related to working habits as well as gender differences in the types of activities that men and women choose engage in. It may be that the benefits of activity were magnified for men when combined with the intellectual engagement they received from the *type* of work they engaged in. This idea is supported by reports from previous research which suggest that continued engagement in complex intellectual activities (associated with one's work environment) helps to increase mental flexibility (Schooler, 1984; Schooler & Malatu, 1999). This argument is particularly plausible if one considers the possibility that both quality and frequency of activities are important factors in determining the minimum threshold at which the benefits of activity become protective. Although the current study was not able to examine this directly, additional research examining the potentially moderating influences of complexity of activities would be beneficial in gaining a better understanding of the nature of this relationship.

Another possible explanation for the observed gender-difference may be related to inherent differences in the types of activities that men and women choose to participate. These differences may in turn, point to important variations in how specific types of activity may influence cognition. Although it has been suggested that both frequency of participation (Salthouse, 1991) as well as complexity (Schooler, 1984) of activities may moderate the influence of activity on cognition, few studies have considered whether specific types of activity have differential effects on cognitive change. It is possible that the previously observed relationship between general activity and cognitive functioning is being driven primarily by just one domain (such as physical or intellectual activity). Conversely, it may be that the protective benefits of activity require participation in a breadth of physical, intellectual and social activities in order to reap cognitive benefits. Rationale for this hypothesis also comes from earlier research by Wang and colleagues (2002) revealing a decreased risk in dementia as a function of both frequency and type of activity. Future research examining potential differential effects (and/or mechanisms) of various types of activity on cognitive will be particularly important in gaining a clearer understanding of how activity influences cognitive change.

Collectively, the results of the cross-sectional analyses provided inconclusive support for the idea that higher activity is associated with improved cognitive ability. The positive effects of activity on memory performance (as measured by the BVRT) were fairly clear, but the influence of activity on likelihood of dementia diagnosis were less so. The current results also suggest that further investigation into the differential effects of activity across domain types is worthwhile given the noticeable lack of influence of activity on vocabulary in contrast to the effects observed on memory performance.

Longitudinal Analysis

Aim 2: What are the effects of activity on the rate of change? The second goal of the current study was to examine the effects of activity on the trajectory of cognitive change and likelihood of transitioning into dementia. Consistent with the "use it or lose it" hypothesis and the reserve model, I hypothesized that higher activity would be associated with slower rates of decline in cognitive performance as well as a reduced risk of dementia diagnosis over time. The longitudinal analyses provided results that extended the cross-sectional analyses (and expectations), but also gave additional information concerning within-person change.

As expected, changes in activity were significantly related to changes in memory performance, but the effects were moderated by changes in health status and gender. The significant interaction between activity and gender on changes in memory performance replicated findings from the cross-sectional analyses such that the influence of activity on memory was stronger and more consistent among men than women. As discussed in the previous section, the failure to find main effects of activity in women may actually elucidate important differences in the types of activities that are protective against cognitive decline. It is also possible that trajectories of change could not be adequately assessed among women in this sample because of the limited number of time points that were available for analyses among women during the course of the study. Recall that women were introduced into the larger BLSA sample 20 years later than men and that activity assessments occurred at every 4th visit. Thus, the opportunity to measure within-person change was limited in women in this sample as compared to men.

The emergence of a 3-way interaction between health, gender and activity provided an opportunity to more closely examine the nature of the activity-cognition relationship. Changes in activity continued to be associated with changes in memory, but the influence of increased activity were stronger for individuals with poorer health. This suggests that health status is a significant factor in considering who may benefit most from activity interventions. It may be that activity is more influential among individuals with poorer health since they are also likely to have lower activity levels overall, or to ceiling effects since individuals with better health are more apt to be performing at (or closer to) their best cognitively. Although the 3-way interaction helped to further elucidate the results, gender differences in the effects of activity persisted. While the trajectory of change is clearly defined among men, there were no significant differences detected between slopes for women as a function of health. As I have previously speculated, it is very likely that the opportunities to capture concurrent changes in health and among women were limited as compared to men in this sample due to the staggered nature of data collection and the delay of women entering into the study. Analysis of within-person standard deviations across gender supports this thought as there was evidence of more variability among health scores for men than for women ($F = 1.36$, $p = .0001$). These results further suggest that the effects of activity may operate both concurrently as well as cumulatively (Colcombe & Kramer, 2003; Lachman et al., 2006

Examining the relationship between changes in activity and verbal ability, only education was significantly related to changes in verbal ability in this sample. There was no relationship between activity and change in verbal ability. If we accept the notion that effects of activity are indeed cumulative as previous research suggests, then I would have expected to see some evidence of activity influences on verbal ability emerging over time

(Lachman et al., 2006). The failure to find a strengthening of the relationship as I did with memory provides additional support for the idea that activity may not have the same effect on verbal ability as it does on memory performance, and that the effects of activity vary across domains–for which I did find support in later analyses.

Consistent with expectations and previous research, activity was associated with a lower likelihood of transitioning into dementia over time (Scarmeas & Stern, 2003; Stern 2002). Again, because of the small sample size, these results should be interpreted with caution. This particular model was further limited due to the inability to include other key predictors into the analysis. Although not specifically addressed in the context of this study, another consideration in interpreting the current results concerns the potentially reciprocal relationship between dementia diagnosis and activity level. This is particularly plausible given that moderate to severe dementia is typically associated with negative changes in functional status and, most likely, changes in activity. It should also be considered that accuracy of measurement may also be compromised since individuals with memory impairment are likely to forget to report some of their past activities.

Collectively, the examination of the effects of activity on the rate of individual change has provided evidence consistent with "use it or lose it" and reserve theory (Schooler, 2007; Stern, 2002), which argue that activity protects against the negative effects of aging on cognition and changes in functional status over time. Conversely, previous criticisms suggesting that reported effects of activity on cognitive functioning primarily reflect within-person variability that may have been present throughout the lifespan (Salthouse, 2006) were not supported.

Aim 3a: Are the effects of activity domain specific? The third goal of the current study was to gain a better understanding of the nature of the relationship between activity and cognitive change by examining potential moderators. The first question examined whether the observed relationship between activity and cognition might be domain specific. In order to examine this possibility, I selected cognitive measures that reflected crystallized as well as fluid abilities.

I hypothesized that there would be differential effects of activity on cognition that reflect characteristics of the cognitive domains being measured. Traditionally, crystallized ability—as reflected in vocabulary measures—is more resistant to age-related declines, whereas more fluid abilities—as reflected in the memory measure—tend to be more susceptible to age-related declines (Cattell, 1987). As noted earlier in this manuscript, even among studies that have employed similar definitions of activity (e.g., Christensen et al., 1996; MacKinnon et al., 2003), the results often vary based on the domain being investigated. The idea of domain-specific responses to the effects of activity becomes more plausible when we consider the nature of these abilities. It has long been presumed that fluid abilities are more susceptible to decline primarily because of their neurobiological underpinnings (Schaie & Willis, 1996). For example, as brain volume and certain brain structures atrophy with age, it is generally expected that there is an associated cognitive decline. .In a sense, one may argue that this makes fluid processes more flexible than crystallized abilities, and therefore more susceptible to natural biological processes that may take place during the course of the aging processes. Conversely, one can argue that fluid processes would also be more susceptible to the protective benefits of activity because it may help to preserve neurological architecture. As the current findings suggest, it may be that the effects of activity are limited to domains that are more susceptible to age-related declines. The fact that effects of activity differed across measures of crystallized and fluid ability upon cross-sectional and longitudinal examination is noteworthy and provides converging support for the idea that the effects of activity may very well be limited by domain characteristics. In addition, previous research suggests that these effects can be further influenced by age of the participants, as well as by how activity is defined (Christensen et al., 1996; Mackinnon et al, 2003). Collectively the current findings provide at least partial insight into other contributing factors that may moderate the relationship between activity and cognition. More systematic research is still needed however, in order to gain a clearer understanding of this complex relationship.

Aim 3b: Is the relationship between activity and cognition reciprocal? The current study also examined the directionality of the relationship between maintaining a generally active lifestyle and cognitive functioning. Specifically, I examined whether there was evidence to support the notion of a reciprocal relationship between activity and cognitive change (Hultsch et al., 1999; Schooler, Maltau, & Oates, 1999). Consistent with expectations and results of the predictive analyses, higher memory scores were associated with more activity in men. Interestingly, however, the pattern was reversed in women, who showed a slight decrease in activity with better memory. The previously observed 3-way interaction was also replicated such that the relationship between activity and memory was stronger for those with poorer health. These results are in line with previously reported research (Hultsch, 1999; Kohn & Schooler, 1978) and provide stronger evidence for the idea of a reciprocal relationship between cognition and activity as presented by Schooler's (1984) complexity hypothesis.

It is important to mention that the strength of the effects differed for the reversed models. In examining the association between activity and memory, the reversed model accounted for 29% of within person change and 25% of between person change as opposed to 52% of within person change and 87% of between person change in the predictive model. This suggests that there may be other factors influencing change in activity that were not considered within the analyses. Despite these limitations, a positive interpretation toward confirming the idea of reciprocal influences is further encouraged by the fact that the pattern of results for both memory and vocabulary performance remained consistently different in their susceptibility to the influence of activity across cross-sectional and longitudinal analyses.

Caveats

Several limitations should be noted concerning the generalizability of the current study. First, the BLSA subsample used in this study represent a very select and homogenous group of individuals who were predominately white (91%), highly-educated (M = 16.9 years) professionals who were high functioning individuals, thus generalizability of the current results are limited to similar populations. In addition, many of the earlier participants of the BLSA were spouses or associates of one another which could have compounded concerns regarding non-independence of observations in this sample. Both of these concerns may have influenced variability estimates and my ability to detect certain effects (especially those relating to intraindividual variability among women over time).

Although it can be argued that continued findings of a positive relationship between activity and cognition among various studies using similar measures have been useful (see Fratiglioni et al, 2004), there were noteworthy limitations with using a measure that was too general. Due to the existing measures inability to provide specific information (i.e., frequency, duration or complexity of various activities) on cognitive change, I was unable to address key questions that arose during the context of the study. For example, it would have been advantageous for me to dig deeper into the persistent differences in engagement patterns between men and women in order to gain a clearer understanding of what was driving the observed gender differences. This question, as well as others that have arisen during the context of this study, illustrate the need for more precise measures of activity in the field which will allow for more systematic investigations into underlying mechanisms of the activity-cognition relationship

Conclusion and Future Directions

Taken together, the current results make several important contributions to the literature. First, the results of both cross-sectional and longitudinal analysis support the general notion that engagement in activity is related to memory performance and may provide protective some benefits against negative declines. The results also provide firm evidence that the effects of activity are beneficial throughout the lifespan and not limited to older adults as has been previously believed. Therefore, introducing interventions earlier in the lifespan for those who are identified as being at higher risk for cognitive dysfunction may prove to be beneficial.

Second, the current results demonstrate that the influence of activity on cognition operates concurrently (as theory suggests), as well as cumulatively. As a result, it should be expected that significant statistical associations may not always emerge when conducting cross-sectional analyses, and one should be careful not to discount the influence of activity on cognition simply because inconsistencies appear in the literature. Furthermore, the current study provides emerging evidence against the view that the relationship between activity and cognitive change primarily reflects inherent differences between individuals rather than true activity effects.

Finally, the present study provides clear evidence supporting the consideration that differential effects of activity previously reported in the area may not be spurious in nature, but potentially reflective of key differences in how activity influences various cognitive abilities. Combined with the added possibility that specific types of activities may have varying degrees of influence on cognitive change, the current study clearly illustrates the need for more systematic investigations into the complex mechanisms of the activity-cognition relationship. Together these findings provide some insight into potential causes of the inconsistencies that continue to resurface in the literature concerning the nature of the relationship between activity and cognition.

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Table 1.

Age Ranges of Participants in General Activity Studies

Study	Age Range
Christensen et al (1996):	70-80
Lovden et al (2005)	70-103
McKinnon et al (2003):	70 +
Newson & Kemps (2005):	77.4

Note: Research focusing on specific types of activity are not included

general activity studies only.

Table 2.

Review of Research Findings by Type of Activity Studied

Study	Activity	Results
Aartsen et al (2002)	Soc/Int	Mixed
Christensen et al (1996)	General	Positive
Hultsch et al (1999)	Intellectual	Mixed
Lovden et al (2005)	General	Positive
McKinnon et al (2003)	General	Positive
Newson & Kemps (2005)	General	Positive
Schooler & Malatu (2001)	Intellectual	Positive
Schooler et al (1999)	Intellectual	Positive

Note: General activity includes components of physical, social and intellectual activities; Positive/Unclear results refer to the observed relationship found between activity and cognitive functioning.

Table 3.

Participant Demographics (N =1525)

	First Visit	Last Visit	
	M (SD)	*M* (SD)	*p*
Age	51.2 (17.8)	64.5 (18.6)	.0001
Health	2.7 (1.5)	3.1 (1.3)	.0001
Activity	7.7 (3.3)	7.2 (3.5)	.20
BVRT	4.4 (3.3)	6.6 (5.3)	.0001
Vocabulary	63.2 (10.4)	62.2 (11.3)	.01
Education	16.6 (2.8)	16.6 (2.8)	
Gender			
Males	70%	70%	
Females	30%	30%	
Work Status			
Working	59%	4%	
Not Working	41%	96%	
Occupation Status			
Professional/Mgmt	16%	2%	

Note. Demographics are reported on participants' first and last visits for individuals with at least two measurements of AAQ data (paired t-test).

Table 4.

Frequency of Observations for Participants with AAQ Data

N = 2093

No. of Visits	*n*
1	1062
2	439
3	222
4	187
5	126
6	45
7	12

Table 5.

Frequency of "Yes" Responses by AAQ Item

Work in and around the house	1102
Work in garden or yard	876
Work on some hobby	620
Listen to radio	557
Farm work	45
Write letters	602
Write books, articles, poems	201
Attend movies	517
Attend theatre, lectures, concerts	399
Attend club, lodges, other meetings	692
Shop	850
Participate in community or church work	639
Play golf or other sports	490
Play cards or other table games	450
Take rides	429
Visit or entertain friends	944
Sew crochet or knit	238
Read	1152
Just sit and think	330
Other	340

Note. All responses ranged from 0 (did not participate) to 1 (participated.)

Table 6.

Unstandardized Regression Coefficients for BVRT and WAIS

Variable	*B*	SE	*t*
		Model 4 (BVRT)	
Activity	-.01	.05	-.14
Age	.08***	.00	16.17
Gender	-.09	.21	-.43
Work Status	-.21	.17	-1.24
Health	.08	.11	.71
Activ* Age	-.00	.00	-.91
Activ * Gender	-.14*	.06	.33
Activ* Health	-.00	.03	-.12
Activ*Age*Gender	.00	.00	.94
Activ* Health*Gender	.15*	2.0	2.0
		Model 5 (WAIS)	
Activity	.13	.19	.52
Age	.08****	.02	4.21
Gender	.76	.80	.95
Work Status	1.31*	.68	2.01
Health	-1.04**	.41	-2.53
Activ* Age	-.00	.00	-.52
Activ * Gender	.35	.23	1.56
Activ* Health	.13	.13	1.02
Activ* Age*Gender	.01	.01	.45
Activ*Health*Gender	-.22	.14	-1.50

Note. * $p < .05$, **$p <.01$***$p <.001$, ****$p < .0001$

Table 7.

Multilevel Modeling Estimates (and Standard Errors) for Memory Errors

Fixed Effects	
Intercept, $\beta 0$	
Overall memory errors ($\gamma 00$□)	4.17 (2.1)
Time($\gamma 10$)	.08 (.02) ***
Activity ($\gamma 20$)	-.04 (.25)
Work status ($\gamma 30$)	-.31 (.21)
Health ($\gamma 40$)	-.35 (.45)
Age ($\gamma 01$)	.08 (.01) ****
Education (γ 02)	-.15 (.03) ****
Sex ($\gamma 03$)	5.2(2.6) *
Activ*Age ($\gamma 21$)	-.00 (.00)
Activ *Gender ($\gamma 22$)	-.76(.34) *
Activ* Health ($\gamma 40$)	.02 (.05)
Activ*Age*Gender ($\gamma 23$)	-.00 (.00)
Activ*Health*Gender ($\gamma 24$)	.15 (.08) *
Random Effects	
Intercept ($\tau 00$)	1.22 (1.13)
Change over time ($\tau 11$)	.01 (.02)
Residuals	3.31

Note. * $p < .05$, **$p <.01$***$p <.001$, ****$p < .0001$

Table 8.

Multilevel Modeling Estimates (and Standard Errors) WAIS

Fixed Effects	
Intercept, $\beta 0$	
Overall memory errors ($\gamma 00$)	28.88 (4.55)
Time ($\gamma 10$)	.36 (.08) *
Activity ($\gamma 20$)	.15 (.31)
Work status ($\gamma 30$)	2.1 (.82)
Health ($\gamma 40$)	-.17 (.66)
Age ($\gamma 01$)	.08 (.05)
Education ($\gamma 02$)	1.6 (.14) ****
Sex ($\gamma 03$)	.11 (1.7)
Activ*Age ($\gamma 21$)	.00 (.00)
Activ * Gender ($\gamma 22$)	.02 (.52)
Activ*Health*Gender ($\gamma 23$)	.00 (.11)
Random Effects	
Intercept ($\tau 00$)	134.1 (27.4) ****
Change over time ($\tau 11$)	.42 (.18) **
Residuals	8.06 (6.4)

Note. * $p < .05$, ** $p < .01$ *** $p < .001$, **** $p < .0001$

Figure Captions

Figure 1. Low BVRT scores = fewer memory errors (better memory).

Figure 2. Increasing scores represent increased risk of dementia diagnosis.

Figure3. Low BVRT scores = fewer memory errors (better memory).

Figure 4. Test of slopes for men (t =2.99, p < .01); test of slopes for women (t =1.49, p = .136).

Figure 5. Low BVRT scores = fewer memory errors (better memory).

Figure 6. Test of slopes for men (t = 3.24, p < .001); test of slopes for women (t = .94, p = .35).

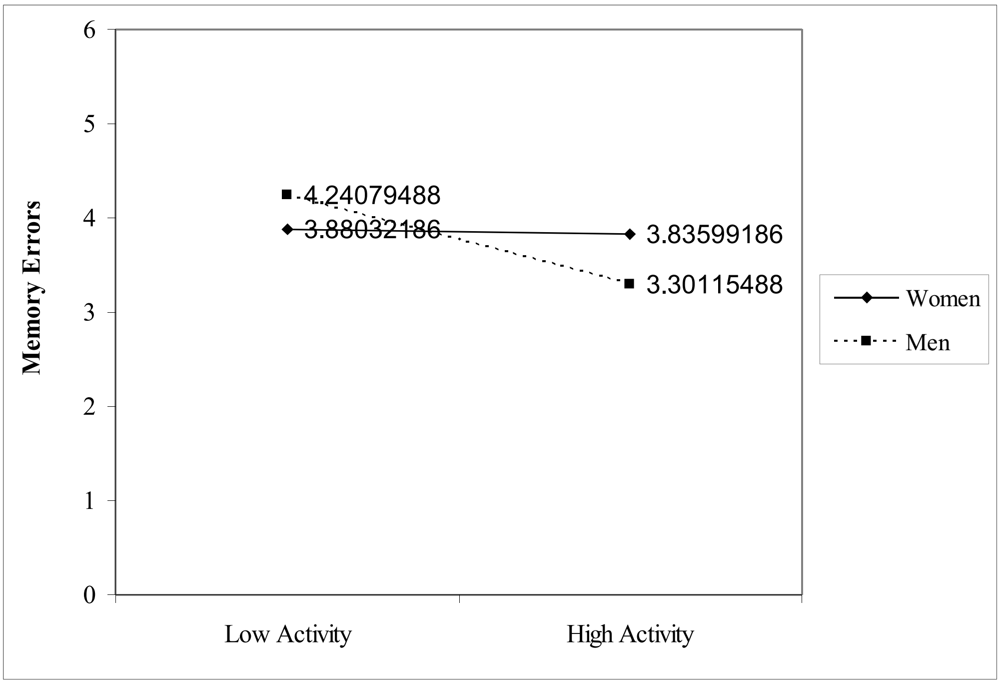

Figure 1. *Cross Sectional Activity x Gender Interaction for Memory Errors*

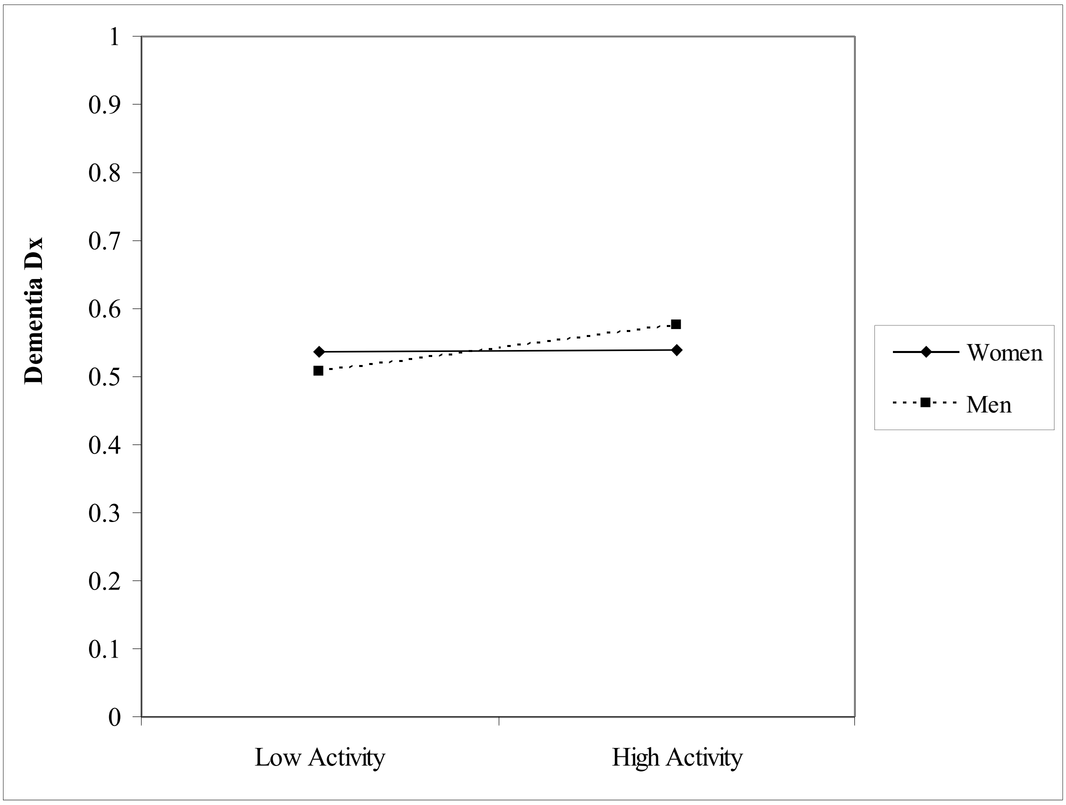

Figure 2. *Cross Sectional Activity x Gender Interaction for Dementia Diagnosis*

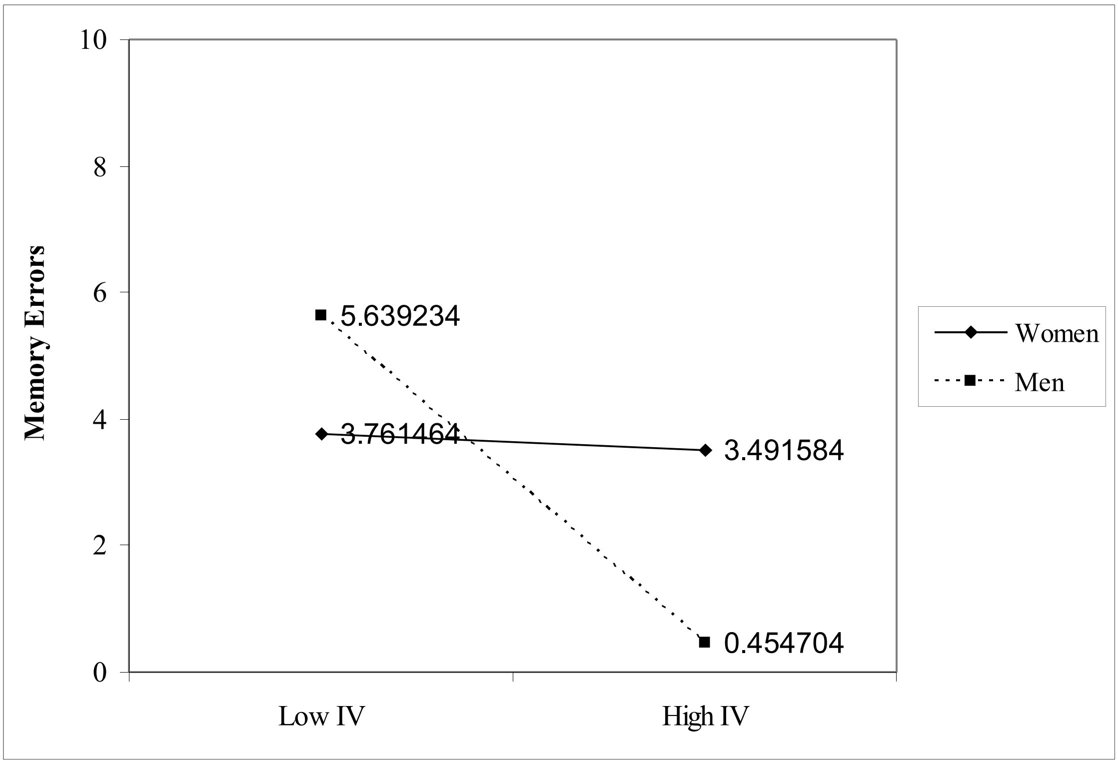

Figure 3. *MLM Activity x Gender Interaction for Memory Errors*

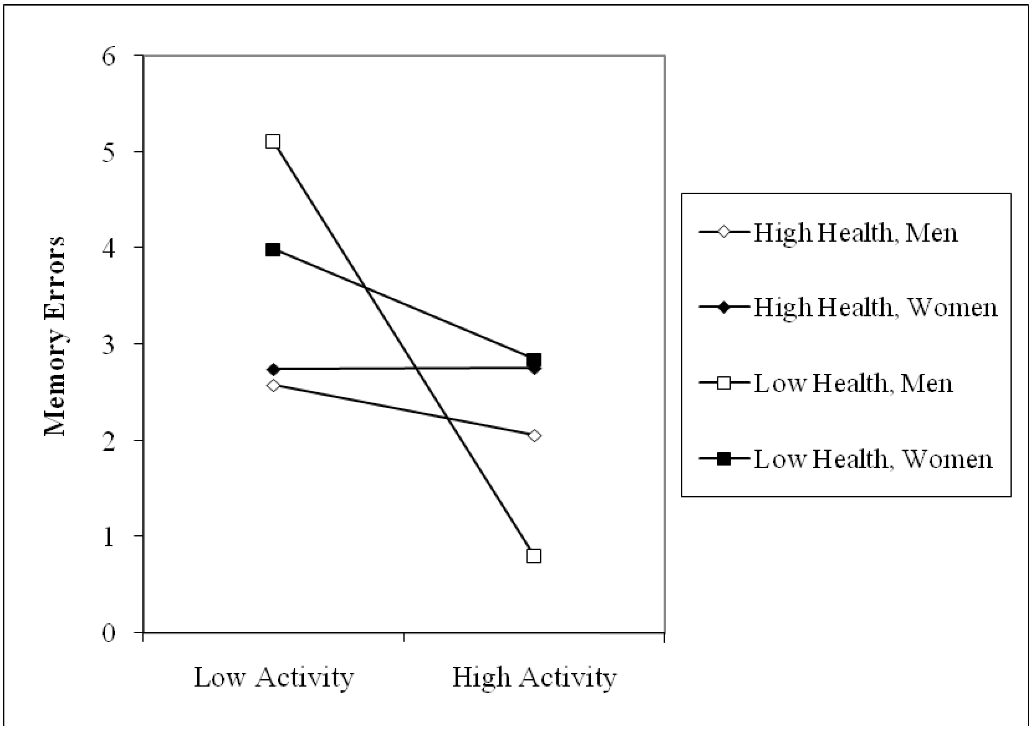

Figure 4. *MLM Activity x Health x Gender Interaction for Memory Errors*

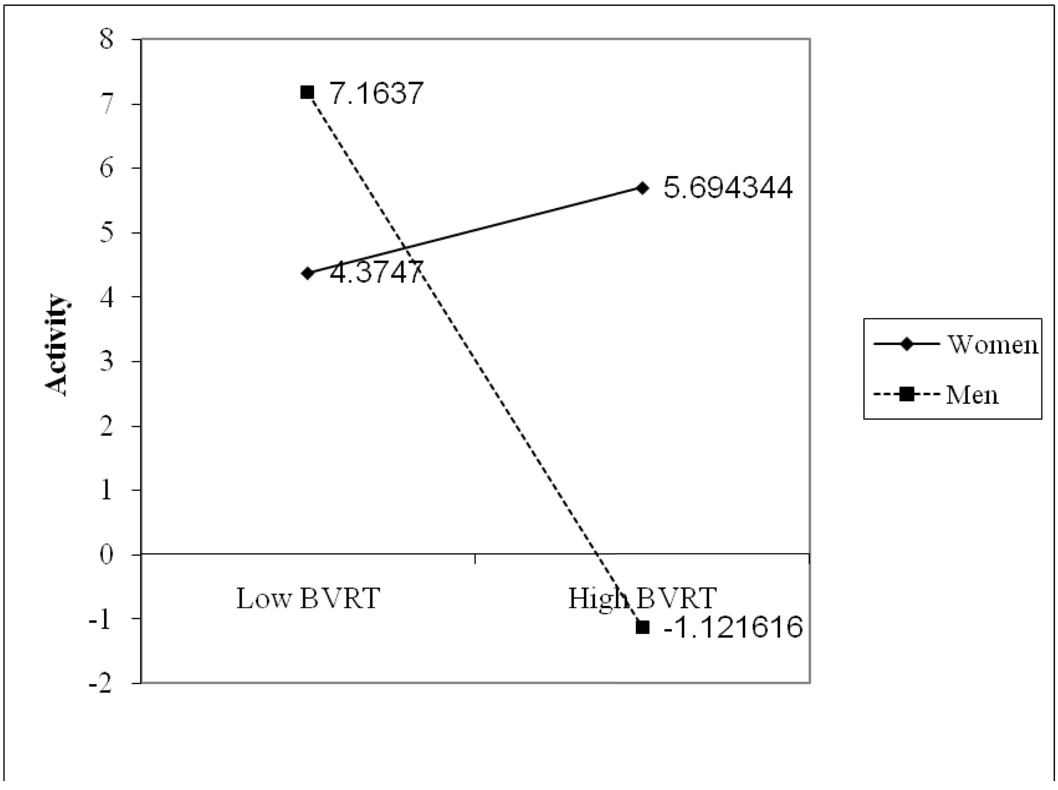

Figure 5. *2- Way BVRT x Gender Reciprocal Interaction Effect for Activity*

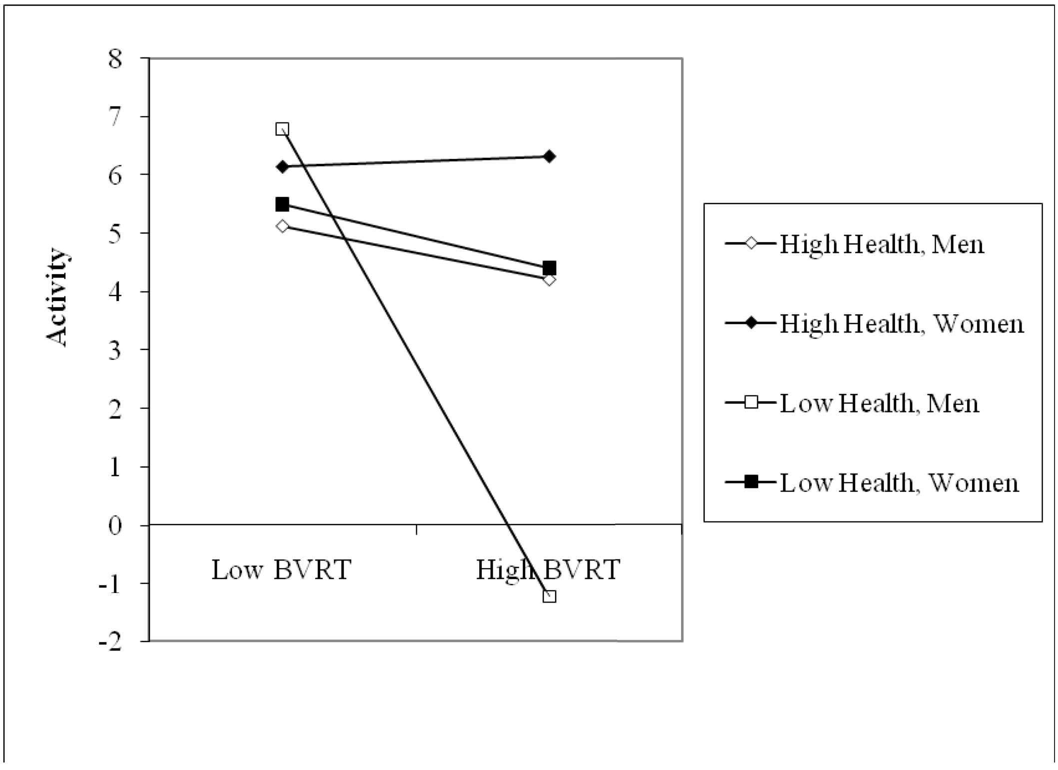

Figure 6. *3-way BVRT x Health x Gender Reciprocal Interaction Effect for Activity*

APPENDIX

APPENDIX A

AAQ Activity Subscale

2. What do you do in your free time?

Work in and around the house . . . ______
Work in garden or yard . . . . ______
Work on some hobby . . . . ______
Listen to the radio . . . . ______
Farm work . . . . ______
Write letters . . . . ______
Write books, articles, poems, etc. ______
Attend movies . . . . ______
Attend theaters, lectures, concerts
Attend clubs, lodges, other
meetings . . . . ______
Shop . . . . ______
Participate in community or
church work . . . . ______
Play golf, other sports . . . . ______
Play cards or other table games . ______
Take rides . . . . ______
Visit or entertain friends . . . . . ______
Sew, crochet, or knit . . . . ______
Read . . . . ______
Just sit and think . . . . ______
Other (what?) ______________________