AGE DIFFERENCES AND SPATIAL NAVIGATION IN NOVEL VIRTUAL AND REAL WORLD ENVIRONMENTS

By

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To my husband, Adrian, for his absolute love and encouragement

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Normal aging is associated with a decline in a number of cognitive abilities and numerous studies document the existence of age-related changes in human spatial cognition and behavior. Recent studies using virtual navigation paradigms have shown that performance on these tasks is correlated with performance on cognitive map-based way-finding tasks. While the use of virtual environments has made it possible to study navigation performance in a controlled setting, there is limited research that evaluates how performance on virtual navigation tasks translates to real-world allocentric navigation behavior. The broad aims of this study were to empirically evaluate changes in laboratory and real world navigation associated with normal aging and to help lay the foundation for establishing the ecological validity of virtual navigation tasks.

Twenty-three healthy adults age 20-35 and twenty-seven healthy community-dwelling adults age 65 and older took part in this study. We used a 3-bedroom, 2-bathroom house to develop an ecologically valid navigation task that was based on theories of allocentric spatial navigation, as well as computer task modeled after the Morris water maze. We investigated group differences in navigation abilities and the

relationship between performance on real world and computer-generated navigation tasks. Additionally, each participant completed a neuropsychological test battery.

Consistent with previous findings, results from this study clearly demonstrated that overall, older adults do not navigate as effectively as younger adults in virtual or real world space. These data are consistent with theories that aging impairs the formation/retrieval of spatial maps of novel environments and spatial knowledge acquired from direct experience in the environment. Second, we were able to demonstrate the relationship between aging and poorer real world navigation performance was partially mediated by executive functioning. Third, while significant correlations exist between navigation in computer space and real space, results suggest that tasks with executive functioning demands are more powerful than computer navigation performance and age in predicting real world navigation.

Overall, the present report provides additional evidence that adults 65 years and older demonstrate poorer performance on virtual and real world tasks of spatial learning and memory than do their younger counterparts. This group difference appears to be markedly influenced by executive functioning. As a result, age-related changes in executive skills should be taken in consideration in future studies of spatial cognition. These data also confirm the feasibility of using a real world navigation task in adults over age 65 and emphasize the importance of utilizing real world measures for accurate assessment of cognitive functioning.

CHAPTER 1
INTRODUCTION

Normal aging is associated with a decline in a number of cognitive abilities and numerous studies document the existence of age-related changes in human spatial cognition and behavior. These age-related changes include, but are not limited to, visuospatial working and long-term memory (e.g., Park, Lautenschlager, Hedden, Davidson, Smith, and Smith, 2007), the learning of novel environmental layouts (e.g., Kirasic, 1991), the learning of routes (Barrash, 1994), and abilities on mental rotation and spatial visualization tasks (Hertzog and Rypma, 1991). One complication in studying spatial cognition in aging humans is that many distinct constructs (e.g. wayfinding, landmark knowledge, spatial cognition, sense of direction, mental rotation, point localization, route-based learning) can fall under the general rubric of “spatial abilities.” Adding to the confusion, several different methods, including psychometric tests, real-world natural environments, virtual environments, and self-report ‘sense of direction’ questionnaires, are used to study these different constructs, and the conceptual and psychometric relationships among these methods has not yet been fully elucidated.

Navigating through familiar and novel environments in order to arrive at a destination is a highly complex skill that draws upon basic abilities such as learning and recalling the layout of the environment (mental visualization), visual perception (detection of landmarks), spatial perception (determining the direction to take), and map reading (Nadolne and Stringer, 2001). Two commonly described ways of learning the layout of a novel environments are wayfinding (also referred to as cognitive mapping. allocentric navigation, or environment-dependent navigation) and egocentric navigation (also referred to as route learning, route following, or viewer dependent navigation). Egocentric navigation has its foundations in route-based knowledge. In egocentric navigation, the animal (i.e. rat, human) follows a predetermined series of directions and turns with the goal of moving toward a specific targeted location. In contrast, allocentric navigation relies on a viewer-independent, external perspective (a map-like or aerial view) that is thought to allow direct access to a representation or memory of the overall spatial layout (Shelton and Gabrieli, 2001). Clearly, the ability to remember the location of important elements of the external world (e.g., food caches, locations of predators, shelter) provides great adaptive and survival value. In humans, such abilities contribute heavily to independent function in everyday environments (e.g. navigating unfamiliar buildings, streets, and cities).

Understanding these abilities and their neuroanatomic substrates has been advanced by extensive investigations, and there exists an abundant amount of literature speculating how organisms form and retrieve cognitive maps of novel environments (O'Keefe and Nadel, 1978). One of the most reliable tests used to test allocentric spatial learning and navigation is the Morris Water Maze (MWM; Morris, 1981), a paradigm that has been mainly used with rodents. In the MWM, rats are placed in a circular pool of opaque liquid that contains a submerged platform that allows escape when the animal finds it and climbs on to it. Surrounding the circular pool are four walls, each containing a distinctive visual cue that may provide the animal information about relative platform location. Healthy young rats learn to find the platform efficiently and accurately. In contrast, rats with hippocampal damage show severe impairments in the ability to find the platform when compared to sham-operated rats (Morris, Garrud, Rawlins, and

O'Keefe, 1982; Sutherland, Whishaw, and Kolb, 1983). Further, aged rats perform more poorly on the MWM than do their younger counterparts (Wilson, Ikonen, McMahan, Gallagher, Eichenbaum, and Tanilla, 2003). While age differences in rats have been found in allocentric spatial learning skills (circular MWM), age differences in performance have not been demonstrated on an egocentric spatial task (T shaped MWM; Begaga, Cienfuegos, Rubio, Santin, Miranda, and Arias., 2001).

In humans, functional imaging and lesion studies suggest that the hippocampus and associated structures are involved in spatial memory (e.g., Astur, Taylor, Mamelak, Philpott, and Sutherland, 2002; Bohbot, Kalina, Stepankova, Spackova, Petrides, and Nadel, 1998; Frakey, 2005). Specifically, a network of structures involved in navigation, including parahippocampal and extrahippocampal regions has been identified. Using fMRI, Astur and colleagues (2005) demonstrated bilateral BOLD signal changes in the hippocampus when navigating a virtual radial arm maze. Kumaran and Maguire (2005) found preferential engagement of the hippocampus, parahippocampal, restosplenial, and posterior parietal cortices when participants navigated within their city on a computer task. Lesion studies have shown that damage to the posterior parietal cortex, hippocampus, and parahippocampal gyrus cause significant spatial impairment (Barrash, 1998). Although both egocentric and allocentric navigation recruit common networks of brain areas, allocentric wayfinding appears to be more sensitive to hippocampal and parahippocampal function (see Roche, Mangaoang, and Cummings, 2005 for review) and posterior parietal regions appear to be critical for egocentric navigation (Barrash, Damasio, Adolphs, 2000).

These findings are relevant to age-related changes in allocentric navigation in that MRI and post mortem studies of normal individuals have revealed age related decreases in brain weight and brain volume (Dekaban & Sadowsky, 1978, Hubbard & Anderson, 1981, Good, Johnsrude, Ashburner, Henson, Friston, Frackowiak, 2001, Resnick, Pham, Kraut, Zonderman, and Davatzikos, 2001). More specifically, age-related losses in the hippocampus are significantly accelerated relative to gray matter losses elsewhere in the brain (e.g. Jernigan, Archibald, Fennema-Notestine, Gamst, Bonnere, and Hesslink, 2001). Given this data, atrophy of the medial temporal lobe structures that is seen in aging may explain why older adults experienced diminished spatial memory and could find it increasingly difficult to learn and navigate (find their way) in unfamiliar environments.

Numerous age-related anatomical changes in the visual system including the lens, pupil, and at the neural level, might also contribute to age differences in spatial abilities. In fact, some researchers have claimed that these sensory changes are largely responsible for a variety of cognitive impairments in older adults (Scialfa, 2002). However, while there are a large number of age-related changes in sensory and perceptual functioning, these changes are more likely to affect tests of attention, memory, and learning, and not complex navigation (Park et al., 2007).

Adaptations of the MWM, or computer-simulated human analogues, have been developed and results obtained from humans appear to be comparable to those obtained from rats**;** older adult participants demonstrate impaired performance on this task compared to young adults (e.g. Newman and Kaszniak, 2000; Moffat, Zonderman, and Resnick, 2001). Driscoll and colleagues (2003) demonstrated age-related deficits in a virtual MWM task that were associated with decreased hippocampal volume as measured by structural MRI, as well as decreased hippocampal metabolite levels (NAA/CRE ratios) as measured by proton magnetic resonance imaging spectroscopy. In an fMRI study, Moffat and colleagues, (2006) found that hippocampal, parahippocampal, and extrahippocampal regions (parahippocampal gyrus and retrosplenial cortex) showed reduced activation in older adults when navigating a virtual MWM task. More recently Moffat and colleagues (2007) demonstrated robust age-related differences in virtual MWM performance that were associated with larger hippocampal volumes (as measured by MRI) in young, but not old participants. High performance was also associated with larger volume of the caudate nucleus and prefrontal gray and white matter in both groups.

The research study described in this proposal utilizes a computer generated adaptation of the MWM, called the Computer Generated Arena (CG Arena; Jacobs, Laurance, and Thomas, 1997; Thomas, Hsu, and Laurance, 2001). Previous studies of CG Arena suggest that data obtained from humans in this virtual environment are analogous to those obtained from rats in the MWM. As in animals, normal subjects use distal spatial cues to navigate to the target, and rearrangement of these cues produces profound impairment in ability to navigate to the hidden target (Jacobs, Thomas, Laurance, and Nadel, 1998). Subsequent findings from studies of the CG Arena with clinical populations have demonstrated that patients who had suffered mild to moderate TBI showed impaired performance when compared to normal matched controls (Skelton, Bukach, Laurance, Thomas, and Jacobs, 2000) and older adults demonstrate impaired performance when compared to younger adults. Specifically, younger adults navigate to the hidden target in less time over trials and spend a greater proportion of time in the correct quadrant during the probe trial than older adults (Thomas, Laurance, Luczak, and Jacobs, 1999; Laurance, Thomas, Newman, Kaszniak, Nadel, and Jacobs, 2002). Data from an fMRI study measuring brain activation patterns and CG-Arena have suggested that environmental learning and spatial memory are related to activation of the right hippocampus in normal healthy controls (Thomas et al., 2001). Recently, research in our lab provided additional evidence that older adults demonstrate poorer performance on the CG Arena than do their younger counterparts (King, 2006). These data confirm the feasibility of using the CG Arena task in an older population and speak to the possible utility of using this measure in the clinical setting.

In clinical practice, neuropsychologists commonly measure “spatial ability,” but rarely engage the patient in actual navigational tasks of any sort. Computer-generated environments (e.g. CG Arena) allow for navigation through space without losing experimental control while preserving features of real-world environments that are lacking in traditional neuropsychological tests. Virtual environment technology also permits accessibility to more diverse populations who may otherwise be incapable of participation (e.g., non-ambulatory individuals). While the claim has been made that these methods are more ecologically valid than traditional tests, and translate into real world abilities, such real-world correspondence has not been adequately established. There have been a number of studies that have investigated the acquisition of spatial knowledge in real-world situations such as streets (e.g. Titov & Knight, 2005), buildings (e.g. Barrash, 1998; DeIpolyi, Hamilton, Petropoulos, Yeo, Brooks, Baumgartner, et al., 2007; Ruddle, Payne, and Jones, 1997) and towns (e.g. Maguire, Burke, Philips, and

Staunton, 1996). In one such study, investigation of navigation in a virtual and real-world 2-level outlet mall, found that when compared to unexposed controls, both young and old participants were able to transfer understanding of the spatial layout of a virtual representation of the outlet mall to successful performance in the real world equivalent (Foreman, Stanton-Fraser, Wilson, Duffy, and Parnell, 2005). In addition, younger experimental participants remembered the location of specific targets better than did older participants. While this study demonstrated virtual technology is not a barrier to examining the ecological validity of computer navigation tasks in the elderly, there have been few studies that examine the ecological validity of virtual human analogs of animal models (e.g. virtual MWM) and even fewer that study environments that older adults frequently encounter.

As the focus of assessment in the elderly population has shifted from a diagnostic to a more functional approach (e.g. answering questions about living independently, making financial decisions, driving, or continuing at work), some considerable problems with the generalizibilty of the testing situation to the real world have come to light. These include, but are not limited to the sterility of the testing environment, the obstruction of compensatory strategies, non-cognitive factors that may interfere with testing performance, and the abilities that the tests are designed to measure might not represent skills that are used in everyday functioning (Sbordone, 1996). In a limited number of studies, age-related differences in real-world spatial navigation have been investigated and normal older individuals experience significant deficits. Results from a real-world supermarket navigation study (Kirasic, 1991) indicated that while younger adults acquire spatial information in a novel environment more quickly than do older adults, no age-related differences were found in the execution of a familiar route. In contrast, Monacelli and colleagues (2003) found significant age differences on a more complicated hospital route execution task in a familiar setting. In another route-learning study in a novel environment, older participants had relatively greater difficulty retracing the route and ordering landmarks through a two-level medical setting, but were equally good at recognizing the landmarks occurring on the route (Wilkniss, Jones, Korol, Gold, and Manning, 1997).

To further validate human analogs of the MWM, several real-world large scale designs have been tested. Older adults have been found to demonstrate impaired performance when compared to younger adults (Newman & Kaszniak, 2000) and patients with lesions to the medial temporal lobes (selective thermocoagulation to alleviate intractable epilepsy) demonstrate that the right parahippocampal cortex is critical for successful performance on a “dry” MWM task. More recently, Kalov and colleagues (2005) found that similar results can be obtained from a real-world MWM and a map view computer version when comparing performance between normal controls and individuals with AD. While performance on these real-life analogue tasks can aid in drawing conclusions from rat performance, they have not yet firmly established links with “real-life” abilities. Overall then, investigation into allocentric navigation age differences in natural real-world settings is still needed.

Our previous research correlated CG Arena performance with real life navigation performance (hospital route learning task) and demonstrated a significant positive relationship of CG Arena performance and real world performance (King, 2006). However, as with the studies mentioned above, this task was a measure of egocentric or route-learning ability. A better way to establish the ecological validity of the CG Arena would be to demonstrate that performance on this task is similar to performance on a real-life measure of allocentric navigation. This is a key aim of the current investigation.

Logistical factors are largely responsible for the lack of research evaluating age related differences in spatial navigation in everyday settings (i.e. other than hospitals or office buildings). By not evaluating performance in naturalistic environments that older adults are ikely to encounter in everyday life, we may be missing decrements in cognitive functioning that have a great impact on real life functioning. In contrast, we may be overemphasizing age differences that are found in the laboratory (especially with computerized tasks) that actually are not critical in everyday life. In keeping with the emphasis on *application* of spatial skill (function), instead of *description* (ability), the House Navigation Task (HNT: See methods section for details) was developed. The HNT provides a real world natural measure of allocentric spatial navigation within a home environment. The HNT incorporates key procedural conditions of supermarket tasks developed by Kirasic (1991), but extends the focus to measuring map-based (allocentric) wayfinding, as opposed to route-based navigation. It also incorporates aspects of the Apartment Test or Memory in Reality Test (MIR: Johansson, 1988/1989), an ecologically valid alternative to declarative memory tasks, by using everyday items that are placed within a meaningful context.

The HNT has more face validity than navigation tasks commonly used in research protocols. It requires participants to participate in a real life scenario of packing for a trip and remembering the location of things in their house. As a result, older adults may be more inclined to participate (with maximum effort) in the HNT as it is more relevant to everyday functioning and contains a rich array of stimuli. In addition, it not only employs isolated components of abilities (i.e. attention, language, etc.) but also draws on a combination of skills simultaneously (e.g. object memory, spatial memory, navigation, spatial mapping, etc.).

One other advantage of measuring spatial ability in a naturalistic environment is that participants can use compensatory or adaptive strategies they normally use in tasks of this type. Typical standardized testing does not allow for use of compensatory strategies that older adults may utilize in the real world, and thus whatever age differences exist in underlying abilities may be magnified. Therefore, traditional standardized tests may not accurately be measuring the degree of cognitive age differences (or lack thereof) that older adults are experiencing in everyday abilities. We believe that the HNT is more generalizable to real-life navigation, because it is conducted in a natural setting and participants are engaging in an activity that is a common occurrence (packing for a trip to family's house, doctor's appointment, school, work, vacation, etc.)

The main goal of task development was to determine whether participants employ the use of a created spatial map to remember the location of the objects in the house. The objects and landmarks were designed to be more meaningful to older adults than pictures on a wall (i.e. as in real-world MWM analogues) or arbitrary routes through hospital corridors. The HNT measures how participants (young and old) learn and remember (route vs. spatial map), as well as navigate in novel environments. The goal of development was to further evaluate age differences that are found in virtual MWM task performance that may be attributed to several other factors (e.g. cohort effects- lack of experience with technology, thereby leading to motivational factors, etc.).

A large body of data (e.g., Nadolne & Stringer, 2000) suggests that traditional psychometric tests of spatial ability (e.g. tools that measure visualization, spatial orientation, mental rotation, and map reading) tap into domains of visuospatial skills that are not necessarily crucial to spatial navigation ability (as above, the ability to move around a new environment and learn the layout). For instance, Sonnenfeld (1985) demonstrated that paper and pencil spatial performance was not related to true wayfinding ability. In this study, participants from Southeast Alaska, including professional guides, fishing boat captains and pilots, were found to have some of the poorest performances on a battery of paper and pencil spatial tests, yet were expert navigators in real life. Kirasic (1991) also demonstrated no correlation between cognitive task performance in a laboratory and performance in a real-world novel environment, as well as no significant relationship between performance on traditional paper- and pencil-based psychometric measures and navigation ability in elderly individuals (Kirasic, 1989). More recently Hegarty and colleagues (2006) found relatively low positive correlations of paper and pencil measures of spatial abilities with measures of learning from direct experience with the environment (campus building route execution task). DeIpolyi and colleagues (2007) found that while a real-world route execution task through an ambulatory care center could distinguish AD and MCI individuals from normal controls, standard neuropsychological measures could not differentiate those who “got lost” from those who did not.

Relationships among virtual environments and paper and pencil measures have also been examined. Moffat and colleagues (1998) found significant positive correlations between scores on psychometric tests of mental rotation, map learning, and spatial orientation, and performance on egocentric virtual maze learning in humans. Our previous work (King, 2006) demonstrated that while some psychometric paper-and-pencil measures were significantly correlated with CG Arena performance, a majority of the measures were not. The significant correlations that were found were of modest proportions, and suggest that while some tests may tap some overlapping spatial ability, CG Arena appears to measure a unique skill that is not otherwise accounted for by our current clinical measures (King, 2006). The results of our previous work also demonstrated significant positive correlations between performance on the mental rotation task and overall CG Arena performance, suggesting that the two tests share overlapping information processing demands. This result is consistent with findings that demonstrate significant correlations with the probe trial on a virtual MWM task and mental rotation (Astur, Tropp, Sava, Constable, and Markus, 2004) and suggests that age related differences in computer navigation might also be explained by changes in other cognitive processes.

Influences on spatial navigation from outside the medial temporal lobe have been investigated and evidence that virtual MWM tasks are mediated by frontal systems has been found. In one study, Moffat and colleagues (2007) found that gray and white matter volumes of the prefrontal cortex was positively associated with task performance and two measure of executive functioning were also associated with virtual MWM. In addition, measures of executive functioning have been shown to make unique (and independent) contributions to decline in everyday functioning in older adults (Farias, Cahn-Weiner, Harvey, Reed, Mungas, Kramer, et al., 2009). Specifically, this suggests that age related differences in real world abilities can be somewhat accounted for by cognitive measures of executive functioning.

The relationship between performance on a virtual MWM and age-related structural brain changes has been demonstrated in several studies, and is not the purpose of this investigation. Successful Morris water maze performance is dependent on the hippocampus and surrounding medial temporal lobe structures in animal studies. In humans, older adults with age-related hippocampal atrophy have consistently been found to demonstrate age-related deficits on virtual MWT and individuals with structural temporal lobe damage also demonstrate impaired performance. Therefore, we can draw conclusions that vMWM task performance is also sensitive to medial temporal lobe insult. Based on these findings, we would therefore expect the underlying brain changes seen in aging to be associated with poorer real world allocentric navigation performance as well. Older adults demonstrate spatial navigation impairment in a laboratory setting, and we know that they demonstrate impaired performance when compared to younger adults in the real world egocentric navigation (e.g. route learning). However, we still do not have adequate information about group differences in real-world spatial mapping tasks (allocentric navigation), and we know very little about the correlation between laboratory MWM tasks and real world performance. While the use of virtual environments has made it possible to study wayfinding performance in a controlled setting, and capture abilities that are not otherwise measured by standard clinical psychometric instruments, to our knowledge, there is no research looking at how performance on virtual MWM tasks translates to real-world allocentric navigation behavior. The CG Arena is so unlike everyday situations, we cannot really generalize performance on this task to everyday life spatial navigation. Examining this relationship is a crucial step that must be taken in the development of clinical virtual navigation tasks. Therefore, this study will help lay the foundation for establishing the ecological validity of virtual MWM tasks.

In sum, our previous research (King, 2006) sought to evaluate various forms of spatial cognition and navigation in young and old adults and to examine the relationship to real world measures of spatial navigation impairment. It served as an initial step in characterizing particular abilities, and a few of the limitations will be addressed in this study. The two major aims of the study are to empirically determine (1) whether there are age-group differences in real-world natural spatial navigation performance and if so, what cognitive factors mediate these differences; (2) the relationship with navigation in real space with that in virtual space.

Specific Aim 1

To characterize differences in real-world spatial navigation performance between two healthy age groups (20-35 and 65 and older). Based on previous real-world large scale navigation studies (e.g. route execution in hospital corridors and supermarkets), we predicted that elderly participants would show impaired map-based navigation performance when compared to healthy young participants. Contributions of domain-specific processing capacity (executive functioning and mental rotation) to spatial navigation were also investigated.

Specific Aim 2

To examine the relationship between navigation in a natural environment with navigation in a virtual environment (C-G Arena). It is predicted that better performance on a real world navigation task will be associated with better performance on the C-G Arena. Contributions of other cognitive processes to this relationship were also examined.

CHAPTER 2
RESEARCH DESIGN AND METHODS

Participants

Participants were fifty individuals (27 aged sixty-five and older, and 23 aged twenty to twenty-eight) recruited from Gainesville, Florida and surrounding areas. Recruitment for the older group took place via community advertisements (e.g. newspaper, flyers, and newsletters). Recruitment strategies for young healthy adults focused mainly on University of Florida advertisements (e.g. flyers). The main goal of recruitment was to obtain a heterogeneous and representative sample of community-dwelling older adults, without cognitive impairments, and a sample of younger adults matched on the basis of gender and education. Both the young and old groups were cognitively intact and had no history of neurological insult or psychopathology.

All potential participants were screened via telephone in order to exclude individual participants based on the following criteria: (1) dementing illness or other neurological disease (e.g. Alzheimer’s disease, Parkinson’s disease, epilepsy), (2) history of significant head injury, or a mild head injury with any loss of consciousness within the past year (3) stroke or TIA, (4) heart attack or myocardial infarction within the past year, (5) orthopedic or heart surgery within the past year (e.g. hip replacement, CABG), (6) cancer treated with cranial radiation or chemotherapy, (7) history of learning disability or developmental disability, (8) severe uncorrected vision or hearing impairments, (9) history of inpatient psychiatric treatment, (10) history of drug or alcohol abuse sufficient to affect health, work, or family functioning, (11) unwillingness to participate in two testing sessions, or (12) inability or unwillingness to walk five minutes without rest, five separate times within an hour time period. Participants gave written informed consent according to university and federal regulations. All participants who completed the research protocol received $50.

A total of fifty-one participants were initially enrolled in the study and completed all study procedures. The data from one participant was not included in the final analysis due to not meeting criteria for being cognitively intact (significantly impaired memory, language, visuospatial, and executive functioning performance on testing).

Demographic variables for the remaining 50 participants (16 females and 11 males in the older group and 14 females and 9 males in the younger group) are shown in Table 2-1. The racial/ethnic composition of the sample was 17 Caucasian and 6 Hispanic males and females for the younger group and 100% Caucasian for the older group. The two groups did not differ in education [$t(48) = .402$, $p > .05$] or IQ [$t(48) = .946$, $p > .05$]. Groups did differ statistically in MMSE score [$t(48) = .-2.68$, p .01], however, the mean difference is not large (29.39 in young group and 28.67 in old group) and not clinically meaningful.

Table 2-1. Demographic characteristics of experimental participants by group

Measure	Young Adults Mean (SD)	Older Adults Mean (SD)
Number of Participants	N = 23	N = 27
Age	22.83 (2.25)	75.78 (7.55)
Education	15.26 (1.42)	15.51 (2.95)
IQ	109.52 (6.29)	111.41 (7.59)
MMSE	29.39 (.72)	28.67 (1.11)

Note: IQ= Intelligence quotient as measured by the Wechsler Test of Adult Reading (WTAR)

Experimental Procedures

Following the completion of the telephone screening and consent procedures, all eligible participants were invited into the psychology laboratory. Testing was conducted over two sessions.

First testing session. At this session, the participant's overall cognitive functioning was assessed using the Neuropsychological Screening and Spatial Cognition battery and the computer-generated navigation task described below. Additionally, participants completed mood inventories and provided lists of their current medications.

Second testing session. Within one month of the first testing session, participants completed a real-world navigation task, as well as self-report measures of spatial navigation impairment and tests of spatial cognition.

Neuropsychological Screening and Spatial Cognition

This battery of tests consisted of standardized tests of neurocognitive functions in several domains. The elements of the battery are listed below (Table 2-2) and are described in Appendix A. All tests are from peer-reviewed sources, and each measure a particular domain of neuropsychological function commonly recognized in the neuropsychological literature. The composition of this test battery was determined with three goals in mind. First, we wanted to be able to distinguish healthy older adults from older adults with significant cognitive impairment, paying particular attention to verbal and nonverbal memory functioning. Second, with recent findings of vMWM tasks being somewhat dependent on contributions from frontal lobe areas and with numerous findings of age-related changes in this region, tasks thought to utilize higher order frontal/executive skills were included to mediate age related variance on navigation performance. Third, the particular spatial cognition assessment instruments represent either experimental measures specially developed to evaluate the domains of interest, or are well established and widely used measures of those domains. Tests of mental rotation were therefore included.

Table 2-2. Cognitive Test Battery

Measure	Source
Mini Mental State Exam (MMSE)	Folstein et al., (1975)
Clinical Dementia Rating Scale (CDR)	Morris, (1993)
Memory Assessment Centers-Questionnaire (MAC-Q)	Crook et al., (1992)
Repeatable Battery for Assessment of Neuropsychological Status (RBANS)	Randolph, (1998)
Wechsler Abbreviated Scales of Intelligence (WASI) - Vocabulary, Similarities, Block Design, Matrix Reasoning	Wechsler, (1999)
Wechsler Test of Adult Reading (WTAR)	The Psychological Corporation, (2001)
Boston Naming Test-2nd Edition (BNT)	Goodglass & Kaplan, (2001)
Controlled Oral Word Association (COWA)	Spreen & Benton, (1977)
D-KEFS Trail Making Test Condition	Delis, Kaplan, & Kramer, (2001)
Finger Oscillation Test	Reitan (1969)
Grooved Pegboard test	Klove (1963); Reitan (1969)
Wechsler Memory Scale-III -Spatial Span	Wechsler, (1997)
Mental Rotation Test	Vandenberg & Kuse (1978)
Space Thinking-Flags	Thurstone & Jeffrey (1984)
Neuropsychological Assessment Battery (NAB) - Spatial Module: Map Test	PAR, Inc. (2003)
Geriatric Depression Scale (GDS)	Yesavage et al., (1983)
Beck Depression Inventory -2nd Edition (BDI-II)	Beck, Steer & Brown, (1996)

Self-Report Environmental Spatial Ability and Computer Game Experience

In evaluating age differences in spatial cognition, it is important to take into consideration the likelihood that age groups may differ in “spatial experience.” This difference in spatial ability could be due to a variety of other cohort factors such as access to education, socio-economic status, and cultural expectancies (e.g. males traditionally “trained” more in spatial abilities, mathematical, and engineering sciences, etc.). By incorporating these measures, it may be possible to clarify some of the cohort effects that may be present in the older group of individuals (e.g. lack of spatial navigation and computer experience).

The Santa Barbara Sense of Direction Scale (SBSOD) is a 27-item self-report measure of environmental spatial ability or "sense of direction." The scale has demonstrated good psychometric properties (Hegarty, Richardson, Montello, Lovelace, and Subbiah, 2002).

The Everyday Spatial Questionnaire (Skelton et al., 2000) is a 13-item self-report measure that assesses the frequency of various problems in wayfinding (e.g. 'Do you feel disoriented when you come out of an unfamiliar building?') and locating objects left in the environment (e.g. 'Do you have trouble finding your car in a parking lot?'). Responses were rated on a 10-point scale anchored at opposite ends by 'Never' and 'Always'/'Every time.'

The frequency of playing computer-games was rated on a 4-point scale (''never'', ''rarely'', ''often'', ''very often''). In addition, the questionnaire included a single item worded ''I have never played computer-games at all'' which participants could check or not (based on Quaiser-Pohl et al. 2006). Joystick experience was also rated using this same 4-point scale.

House Navigation Task

The House Navigation Task (HNT) is a real-world natural environment navigation task developed for use in this study. The HNT assesses learning the spatial layout of a one-story, 3-bedroom, 2-bathroom home environment, previously unfamiliar to subjects, and rich with visual cues. The home has a kitchen, den, living room, and back patio; and is located in Gainesville, Florida (Figure 2-1). Participants located 16 items needed for a hypothetic trip. Four of the items were placed in commonly found locations within the house (e.g. sunscreen in medicine cabinet in bathroom), and 12 of the items were placed in unusual locations (e.g., gauze pads in kitchen cabinet; See Appendix B for list of items). Most of the items were not in plain view so the participants could not just “bump” into them on their way to other items in the house. In addition, there were several other “foil” items scattered throughout the house that were not on the list.

Figure 2-1. Gator Tech Smart House, Gainesville, Florida (HNT)

At the beginning of the task, participants were told to imagine they are packing for a trip, and that they will need to remember the location of a number of items. At a leisurely pace, the examiner led the participants through the house giving a tour of the layout and pointing out the items participants needed to locate for their trip. The presentation of the items was conducted in such a way as to not represent the shortest or most efficient route to reach all of the items; however it was not presented in a manner that would confuse or trick participants. The examiner pointed out two items per room/area of the house at a time starting in the master bedroom and continuing towards the other end of the house. When the other end of the house was reached, the examiner then led the participant through the remainder of the house to identify/point out the remaining items needed for the trip. Participants were then given the list of items presented in random order and asked to locate the items as efficiently as possible, as the examiner would be following them with a contractor's measuring wheel. Participants were also required to tell the experimenter the item or location they would be travelling to next before going to get it. This task was repeated for a total of three trials, starting from a different location around the house on each trial, and with the list of items in different order. If the participant was unable to locate all of the items (using the list) on any of the trials, the examiner showed the participant the location of any unlocated item on each trial. Without being previously told about the delay, participants were asked to repeat the task two more times 25-35 minutes after completion of the last trial. The first delay trial was completed without the assistance of the list of items and the fifth trial (or second delay) was completed with the use of the list. The starting points for all five trials (learning and delay) were different. After completion of the entire task (including recognition and reconstitution measures), participants were asked to walk through a specific route throughout the house (one hundred feet in length) in order to obtain a trial measuring baseline walking speed. This enabled us to reference speed of ambulation to a common metric for each participant. HNT scoring was based on 1) number of correctly identified locations 2) number of correctly identified objects and 3) Path length (total distance ambulated in completing the task).

After the delay trial, participants were administered two cognitive measures related to the HNT: a house object recognition task (HORT) and a house reconstitution map task (HRMT). The house object recognition task (HORT) required participants to correctly identify and distinguish photographs of objects that were in the house from some that were not (Figure 2-2). Following completion of the HORT, participants were then led into an area of the house where they had not yet been (the very large walk-in master bedroom closet), and they completed the house reconstitution map task (HRMT). The HRMT required participants to appropriately place laminated photographs (approximately 1.5 squared inch in size) of the items on a large (approximately 3 feet by 4 feet) floor plan style map (Figure 2-3). To test whether the placement of the items was based on a developed spatial map, the furniture/appliance arrangement on the HRMT task map was altered so that it did not exactly match the actual arrangement in the house (i.e. some of the furniture/appliances were not included and some were placed in a different location within the room). Participants were asked to place the objects where they were located in the house (including correct relation to other items) regardless of the placement of the furniture and the appliances. The exact locations of the item placements were recorded on a small version of the floor plan map by the examiner.

Figure 2-2. House Object Recognition Task (HORT)

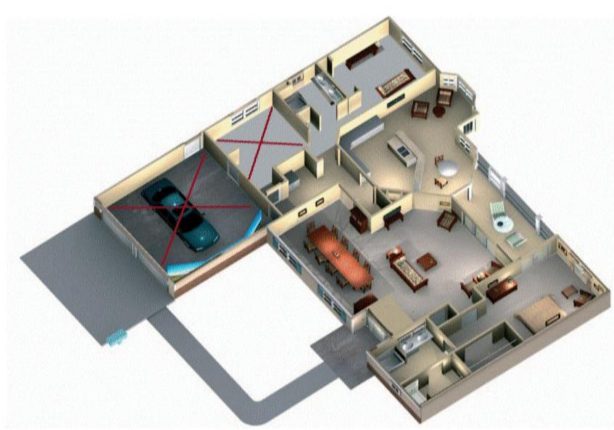

Figure 2-3. House Reconstitution Map Task (HRMT).

Computer-Generated Arena

The Computer-Generated Arena (CG Arena; Jacobs et al., 1997, 1998) is a computer-based analogue of the Morris Water Maze task (MWM) that is administered on a desktop or laptop computer. The participant is asked to use a joystick to navigate through a virtual MWM in order to find a hidden target. The stimulus environment consists of a circular arena wall located within a small square “room.” This virtual room is analogous to the circular tank placed within a square room used in Morris’ original experiments. Each of the room’s four walls contains a unique item, such as a picture, a door, a window, or a pattern that together serve as distal cues to assist the participant in navigating toward the hidden platform target (Figure 2-4). The placement of the walls relative to the target remains constant over all the experimental trials. The target is a small square located on the floor of the Arena. The task itself is modeled after the classic MWM paradigm. On each trial, the participant starts from a different point in the circular arena.

The CG Arena protocol began with a set of practice trials. During these trials, the target was visible, and the participant was asked to use the joystick to navigate to it as quickly as possible. The target was in a different place in the room on each practice trial. Over the course of the practice trials, participants were exposed to a minimum of five minutes practice time in order to familiarize themselves with the use of the joystick. Participants were administered the appropriate number of practice trials until the examiner judged that all participants were starting the experimental trials with an equivalent level of understanding of the task, as well as familiarity with the joystick.

Immediately after completing the set of practice trials, participants were administered a set of acquisition trials. During these trials, the participants entered into a new virtual room for eight trials. The target was invisible, but remained in the same location across acquisition trials. During the first trial, the participant navigated through the environment until the invisible target was found. Once this occurred, the target became visible (Figure 2-5) and was paired with an auditory clicking-sound. The target also “trapped” the participant and made it impossible to move off by use of the joystick, forcing the participant to look around the Arena environment. This procedure was repeated for the remaining seven trials. In the event that the participant was unable to independently locate the target within 120 seconds, the examiner assisted the participant. Such assistance was given only on the first two acquisition trials.

The starting position within the Arena was randomized for the first six acquisition trials. In order to measure learning in the data analysis, Trial 7 had the same starting position as Trial 2, and Trial 8 had the same starting position as Trial 1.

Immediately following the 8 acquisition trials, the participant was administered a probe trial. On this trial, the hidden target was removed from the virtual room, unbeknownst to the participant. This final trial is an analogue of the standard probe trial in MWM research, in which the animal, knowing where the target “should be,” repeatedly swims around the anticipated target location, searching for it. Upon completion of the probe trial, the participant was presented with a blank screen, indicating the end of the CG Arena portion of the testing session. Participants were then immediately debriefed about the removal of the target on the probe trial.

For each trial, several dependent measures, including the length of the navigation path, the latency to find the hidden target, the time spent in each quadrant of the arena, and whether the target was actually found, were automatically recorded by the CG Arena software.

After the probe trial, participants were administered two paper-and-pencil measures related to the CG Arena task: an arena reconstitution task (ART) and an object recognition task (ORT). The ART required participants to reconstruct the CG experimental room by appropriately placing icons representing the four walls of the room, the objects on those walls, and the target onto a sheet of paper. The ORT required participants to correctly identify and distinguish objects that were on the walls in the experimental room from a group of objects, some of which were in the room and some of which were not. The entire CG Arena protocol, including the ART and ORT tasks, took approximately 30-45 minutes to complete.

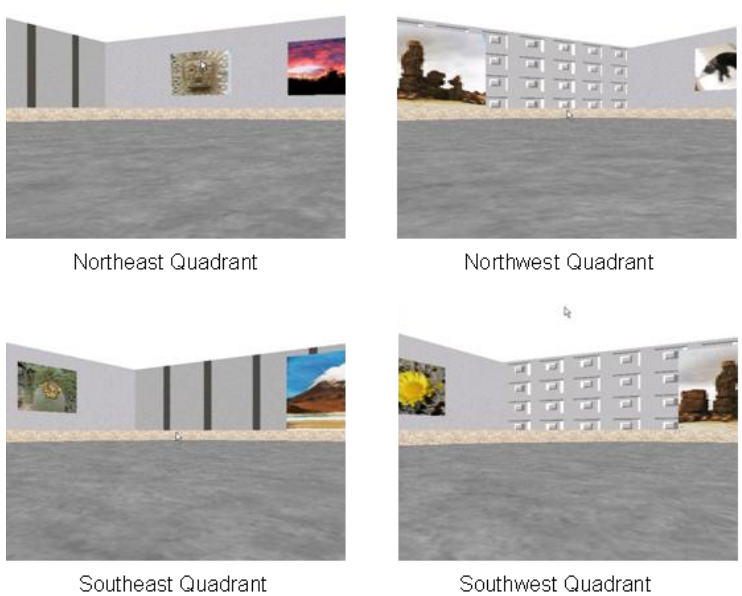

Figure 2-4. Representations of the C-G experimental room as seen by the participants

Figure 2-5. Representation of target once it is successfully acquired

Data Reduction

House Navigation Variables

The number of correct locations and number of correctly identified objects were recorded. For each trial, a participant could score a total of 16 points for number of correctly identified locations and number of correctly identified objects. This scoring procedure was in place to distinguish memory for objects from memory for location in space. Path length was measured in feet using a contractor’s measuring wheel. The examiner followed participants as they navigated through the task in order to collect distance travelled. The “ideal” path length, or the distance of the length to acquire the items as efficiently as possible, was calculated a priori from each starting point for interpretive purpose use. This length was consistent across starting points and varied by only 10 feet (278-288 feet). If all items were not located on a given trial, the path length score was calculated as a proportion of the number of items found (X) so that participants would not have shorter path lengths if they did not locate all items.

$$\frac{\text{Number of items found}}{\text{Path length}} = \frac{16}{X}$$

The house object recognition task (HORT) consisted of 42 recognition items: Sixteen of the items were the items located during the experiment, ten were items that were in plain view throughout the house located near the target items, and sixteen items were not located in the house. Two scores were derived for this task. One was a total recognition score based on correctly distinguishing items that were in the house (both critical and incidental) from those that were not. The second was based on correct identification of incidental items.

Two scores were derived from the house reconstitution map task (HRMT). One score was based on the following criteria: 1) item in correct room, 2) item in correct relation to other items, and 3) item in correct location. A point was awarded for each criterion for each item, for a total of 48 points. The second score for this task was based on deviation of the item from the correct location, measured in centimeters.

In order to weigh the various HNT dependent variables equally, a composite dependent variable (DV) was created from the mean of the z scores earned on each variable (path length (trials 1-3), path length delay; correctly identified locations (trials 1-3), correctly identified locations delay, correctly identified objects (trials 1-3), and correctly identified objects delay, HORT total recognition and incidental score, HRMT total score and deviation). The basic statistical procedures we used to create a composite DV are outlined in Rosenthal (1991).

Computer – Generated Arena Variables

Path Length was recorded by the distance travelled over the course of the trial, either when the target was found or until the trial ended. The sum of target acquisitions was recorded by counting the number of times the participant found the invisible target over the course of the acquisition trials. Dwell time on the probe trial was created by calculating the proportion of time the participant spent in the target quadrant (the quadrant where the invisible target had previously been located) during the probe trial. The ORT score was created by summing up the total number of correctly identified objects and correctly discerning objects that were not located in the room. The ART score was created by using a template that awards points to objects placed correctly in the room relative to the actual location.

In order to weigh the various CG Arena dependent variables equally, a composite dependent variable (DV) was also created from the mean of the z scores earned on each variable (path length; total target acquisitions across invisible trials; dwell time on probe trial; ORT score; ART score).

Cognitive Test Variables

A cognitive flexibility (frontal executive functioning) variable (FE) was created from the mean of the z scores on DKEFS Letter Number Sequencing (switching-connecting circles alternating between numbers and letters with DKEFS motor control portion time substracted from time) and WAIS-III Digit Span-Backward (working memory-reciting increasingly longer strings of numbers in reverse). Raw scores on each of these measures were first converted to standardized scores based on the mean and standard deviation of the entire group.

A psychomotor skill and speed variable was created using the same procedures as above with the Finger Tapping dominant hand and the DKEFS motor control portion raw scores.

Mental rotation was measured using Space Thinking - Flags (Thurstone & Jeffrey, 1984). This test requires participants to view a picture of a flag and judge which of the six alternative test figures are planar rotations of the flag. The score was based on the number of items answered correctly within five minutes. The Mental Rotation Test (Vandeberg & Kuse, 1978) was not used in calculation of this variable. Most of the old adults and a few of the young adults were unable correctly answer any of the practice items and therefore it is not considered an accurate representation of mental rotation ability.

CHAPTER 3
RESULTS

Smart House Navigation Task Performance

We began data analysis by evaluating differences in young and old adult performance on the real world navigation task. In examining age group differences using a MANOVA, with age group as the independent variable and performance on the House Navigation Task (HNT) as dependent variables, a significant main effect for age was found, Wilks Lambda $F(10,39) = 7.358$, $p < .001$, $\eta^2 = .65$. Univariate comparisons confirm that the young group found the items in shorter distance (length) $F(1,48) = 25.56$, $p < .001$, $\eta^2 = .35$, and more often (number of correctly identified locations $F(1,48) = 36.02$, $p < .001$, $\eta^2 = .43$, and number of correctly identified items, $F(1,48) = 55.27$, $p < .001$, $\eta^2 = .54$, on the acquisition trials (1-3). Age differences were also seen on the delayed recall trial, in which the young group again found the items in a shorter distance, $F(1,48) = 19.13$, $p < .001$, $\eta^2 = .29$, navigated to the location more often, $F(1,48) = 17.79$, $p < .001$, $\eta^2 = .27$, and correctly identified the item in that location more often, $F(1,48) = 23.21$, $p < .001$, $\eta^2 = .33$. The old and young group differed in their performances on the House Object Recognition Task (HORT) total score, $F(1,48) = 5.19$, $p = .016$, $\eta^2 = .11$, HORT incidental item score $F(1,48) = 7.55$, $p = .008$, $\eta^2 = .14$, on the House Reconstruction Map Task (HRMT), $F(1,48) = 18.05$, $p < .001$, $\eta^2 = .27$, total score, and on the HRMT Error Measurement score $F(1,48) = 6.26$, $p = .016$, $\eta^2 = .12$.

The composite HNT variable, which represented overall performance, was then subjected to an independent samples *t*-test to test for group differences in allocentric navigation. Significant group differences were found $t(29.74) = -7.21$, $p < .001$, $d = -$

2.74. Overall, older participants performed significantly worse on the HNT composite than did their younger counterparts (Figure 3-1).

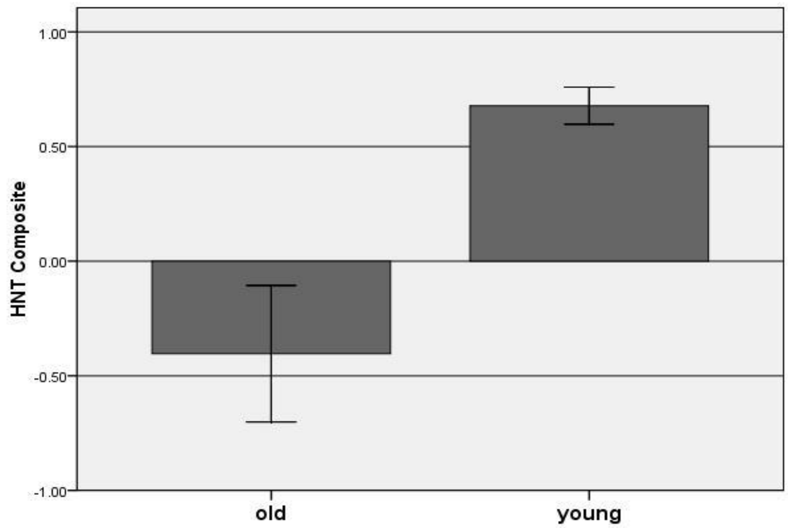

Figure 3-1. Mean HNT composite performance by group, $t(29.74) = -7.21$, $p < .001$, $d = -2.74$.

To further examine age group differences in House Navigation Task (HNT) performance, the old group was broken into 'young old' (65-74) and 'old old' (75 and older). Demographic variables for the 27 old participants are shown in Table 3-1.

Table 3-1. Demographic characteristics of old and old old groups

Measure	Young Old Adults Mean (SD)	Old Old Adults Mean (SD)
Number of Participants	N = 13	N = 14
Age	69.15 (2.45)	81.93 (4.90)
Education	15.00 (3.03)	16.00 (2.90)
IQ	109.31 (7.45)	113.36 (7.59)
MMSE	28.69 (.94)	28.64 (1.28)

Note: IQ= Intelligence quotient as measured by the Wechsler Test of Adult Reading (WTAR)

An analysis of variance (ANOVA) was used to test for differences among the three age groups with the composite HNT variable as the dependent variable and age group as the independent variable. Overall performance on the HNT differed significantly across the three age groups, $F(2, 47) = 39.18$, $p < .001$, $\eta^2 = .63$. There was a significant linear trend, $F(1, 47) = 77.83$, $p < .001$, indicating as age group increased (young<young old<old old), overall house navigation task performance decreased proportionately (Figure 3-2). Furthermore, the planned contrasts revealed that both old groups demonstrated significantly decreased HNT performance compared to the young group, $t(29.84) = -8.19$, $p < .001$, and the old old group demonstrated significantly poorer performance when compared to the old group, $t(24.98) = -3.20$, $p = .002$.

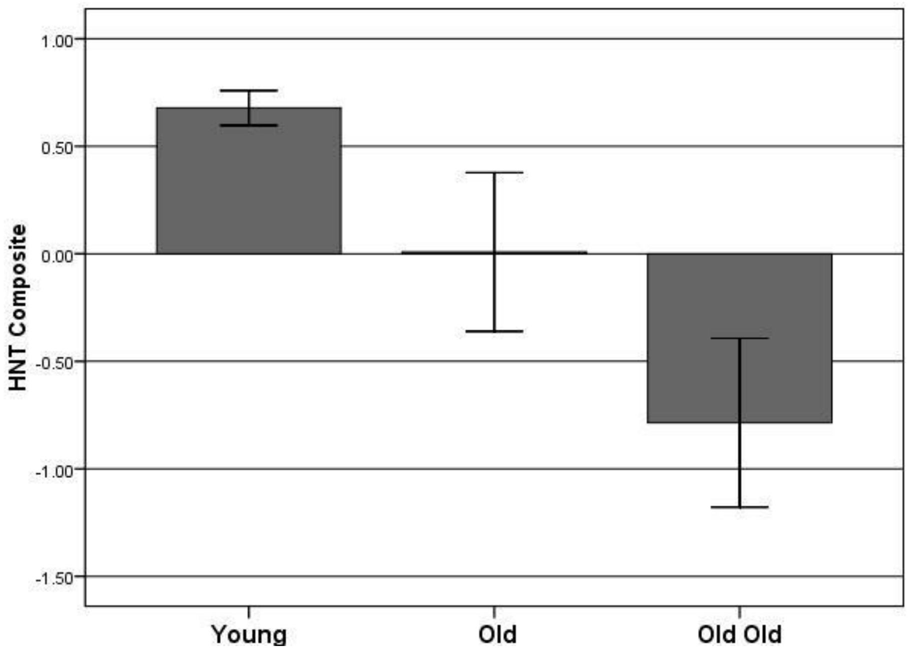

Figure 3-2. Mean HNT composite performance by group, $F(2, 47) = 39.18$, $p < .001$, $\eta^2 = .63$

Analyses of baseline time revealed expected significant age group differences in ambulation speed, $F(2, 47) = 6.86$, $p = .002$, $\eta^2 = .140$, with a significant linear trend, $F(1, 47) = 13.63$, $p = .001$, indicating as age group increased (young<young old<old old), baseline time increased (i.e. slower speed) (*M* young = 34.43 seconds, *SD* = 5.66; *M* old = 35.54 seconds, *SD* = 4.37; *M* old old = 40.50, *SD* = 6.60). Accordingly, even though time was not a measure of HNT performance, an analyses of covariance (ANCOVA) with baseline time as a covariate was conducted. Baseline speed was not a

significant covariate $F(1, 47) = 1.43$, $p = .238$, and therefore significance was maintained when controlling for it $F(2, 47) = 26.63$, $p < .001$, $\eta^2 = .53$.

Table 3-2 provides the mean scores for each of the HNT variables broken down by age group. The mean scores are highest in the young participants, as expected, and a ceiling effect is evident. Figure 3-3 shows the age differences in correctly identified locations across the three trials and on the delay recall trial. All age groups showed learning over trial, losing very little information on the delayed recall trial. A paired-samples t-test was conducted to compare the number of correctly identified locations in the delay recall trial to trial 3. There was a not a significant difference in any of the age groups (Young: $t(22) = -1.00$, p = .3.28; Old; $t(12) = 1.00$, $p = .337$; Old Old: $t(13) = -.79$, $p = .444$). In addition, the oldest old were able to remember an average of 92% of the locations on the learning trials and remember 88% of the locations on delay recall. No significant differences (p's >.05) between the delay recall trial and trial 3 were found in any of the age groups for correctly identified items (Fig 3-4) or path length (Fig 3-5).

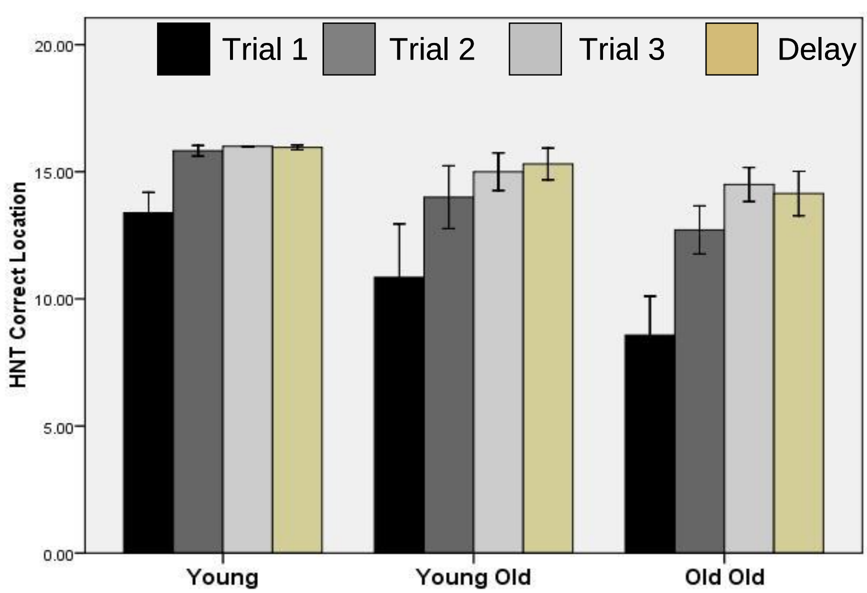

Figure 3-3. Correctly identified HNT locations by group

Table 3-2. Mean scores for HNT variables

Age Group	*n*	HNT Trial 1-3 Path Length	HNT Trial 1-3 Correct Location	HNT Trial 1-3 Correct Item	HNT Trial 4 Path Length	HNT Trial 4 Correct Location	HNT Trial 4 Correct Item	HNT ORT	HNT ORT Incidental	HNT HRMT	HNT HRMT Error
Young	23	324.82 (20.95)	15.07 (.71)	14.86 (.91)	301.80 (12.04)	15.96 (.21)	15.78 (.67)	35.22 (2.76)	5.39 (2.08)	47.57 (.90)	.98 (2.79)
Old	13	406.84 (93.06)	13.28 (2.05)	11.15 (2.52)	334.43 (32.40)	15.31 (1.03)	14.23 (2.09)	34.0 (2.42)	4.46 (2.67)	43.38 (7.08)	2.11 (3.06)
Old Old	14	464.93 (109.89)	11.93 (1.47)	8.93 (3.96)	396.07 (82.58)	14.14 (1.51)	11.29 (3.07)	32.64 (2.84)	2.71 (2.23)	34.79 (10.18)	3.83 (2.54)

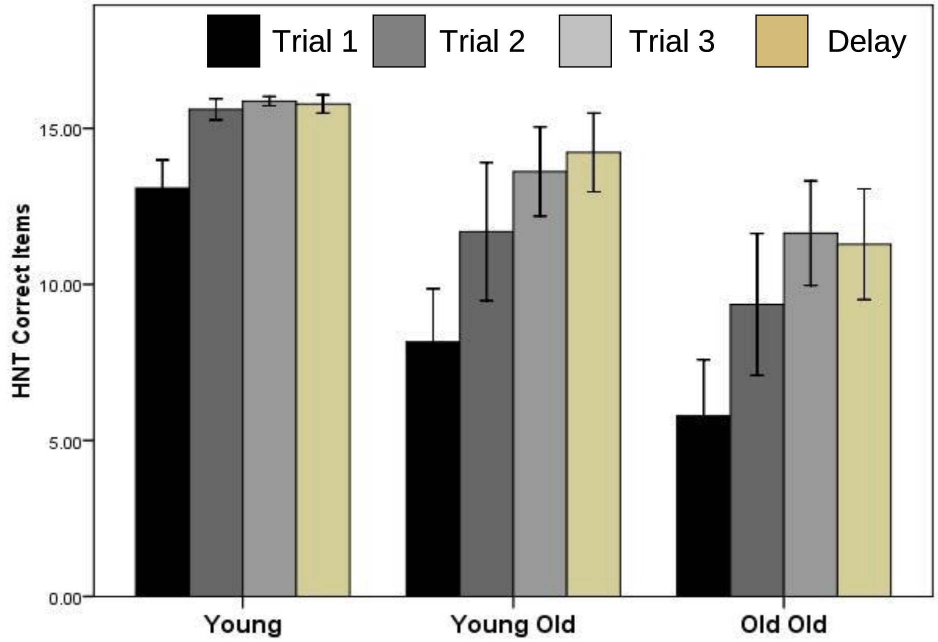

Figure 3-4. Correctly identified HNT items by group

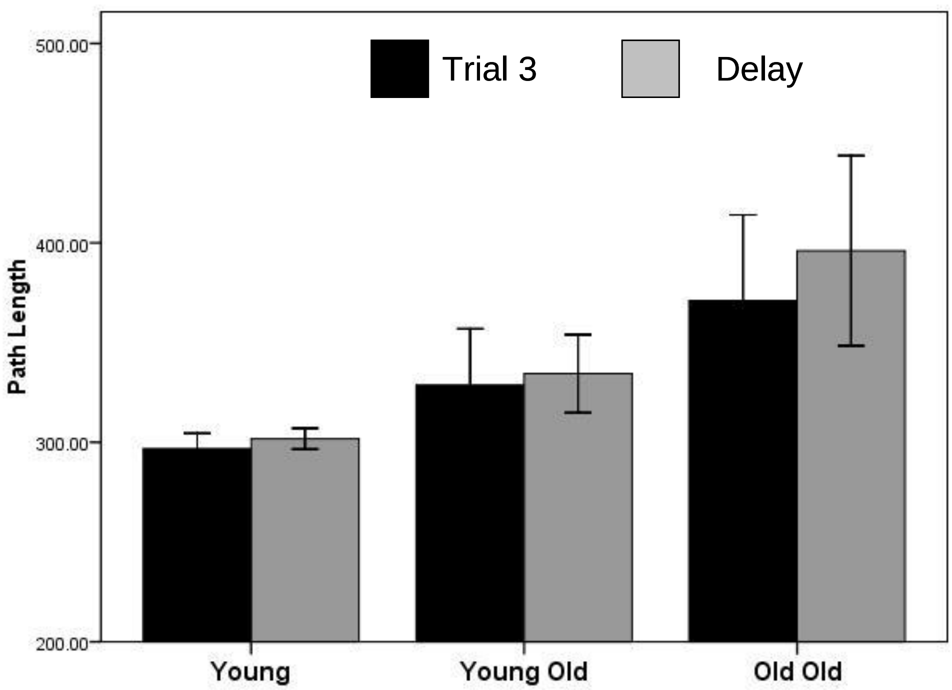

Figure 3-5. HNT path length for trial 3 and for delayed recall

Smart House Navigation Task Performance and cognition

Mediation analyses were conducted to examine whether performance on the neuropsychological screening and spatial cognition battery was associated with performance on the HNT. In previous studies, mental rotation and executive functioning (mental flexibility) abilities have been found to influence both virtual and real world environmental layout learning.

First evaluating frontal/executive cognitive performance (FE), formal significance tests of the indirect effect of the indirect effect of mental rotation were conducted by means of the Sobel test and a bootstrap approach (explanation and macro can be found in Preacher and Hayes, 2004). Results of both procedures indicated that frontal/executive cognitive performance exerted a significant ($p < .05$) indirect mediational effect on the relationship between age and HNT performance. To further examine the degree of mediation, we employed a four-step, ordinary least squares approach (Baron and Kenney, 1986). Step 1 indicated a significant total effect of age on house navigation (HNT; $\beta = -.73$, $p <.001$); Step 2 indicated a significant effect of age of FE ($\beta = -.58$, $p <.001$); and step 3 indicated a significant effect of FE on HNT, while controlling for age ($\beta = .21$, $p = .03$). Thus, the first three steps in establishing mediation were satisfied, supporting the results of the tests of the indirect effect. Step 4 revealed that although HNT performance decreased with increasing age when controlling for FE, it remained significant ($\beta = -.60$, $p <.001$), indicating that FE partially mediates this relationship. These results demonstrate that age and FE collectively account for 65% of the variance ($R^2 = .65$) in house navigation performance.

Formal significance tests of the indirect effect of mental rotation did not find a significant indirect effect of age on navigation performance through mental rotation (p >

.05). A significant effect of age on mental rotation was found (β = -22.13, $p < .001$). When controlling for age, the significant effect of Mental Rotation on HNT did not remain significant (β = .0043, $p = .1734$). However, the significant negative relationship between age and HNT (β = -.73) does becomes smaller when controlling for mental rotation (β = -.63, p< .001)

CG Arena Performance

The next part of our statistical analysis examined differences in overall CG Arena performance between older and younger adults. Using a MANOVA with age group as the independent variable and individual variables of CG Arena performance as the dependent variables, a significant effect of age group was found, Wilks' Lambda, $F(7,42) = 1120.02$, p < .001, $\eta^2 = .83$. Univariate analyses showed that the young group found the target in shorter distance (path length), $F(1,48) = 67.95$, $p < .001$, $\eta^2 = .59$, more often (number of target acquisitions, $F(1,48) = 50.59$, $p < .001$, $\eta^2 = .51$, and spent a greater percentage of time in proximity to the target on the acquisition, $F(1,48) = 141.97$, $p < .001$, $\eta^2 = .75$, and probe trials, $F(1,48) = 49.19$, $p < .001$, $\eta^2 = .51$. On measures administered after completion of the computer task, the young group demonstrated significantly better overall performance on the Arena Reconstruction Task (ART), $F(1,48) = 13.87$, $p = .001$, $\eta^2 = .22$, and placed the target in the correct quadrant more often than the old group, $F(1,48) = 5.25$, $p = .023$, $\eta^2 = .10$. The old and young groups did not differ in their performances on the Object Recognition Task (ORT), $F(1,48) = 1.01$, $p = .319$; *M* young = 12.67, *M* old = 13.17.

Both the young adult and older adult groups found the target consistently when the target was visible on the practice trials. To exclude the possibility that the group differences observed in CG Arena performance was secondary to greater joystick experience and computer familiarity in the young group, a mean path length score was calculated for all visible practice trials. This variable did not reveal reliable age group differences, $t(48) = .783$, $p = .438$. Joystick experience as assessed by questionnaire also did not reveal reliable age group differences, $t(48) = -.384$, $p = .702$. Computer game experience as assessed by questionnaire did reveal reliable age group differences, $t(33.21) = -.4.50$, $p < .001$, and was therefore used as a covariate in the following analyses.

An analysis of covariance (ANCOVA) was performed with CG Arena composite as the outcome variable, age group as the fixed factor, and computer game experience as the covariate. The results of the ANCOVA indicated that computer game experience was not a significant covariate, $F(1,47) = .105$, p = .747, and did not predict CG Arena performance. There was a significant effect of age on overall CG Arena performance, $F(2, 47) = 47.41$, $p < .001$, $\eta^2 = .74$, in that older participants performed significantly worse on the CG Arena composite than did their younger counterparts (Figure 3-6).

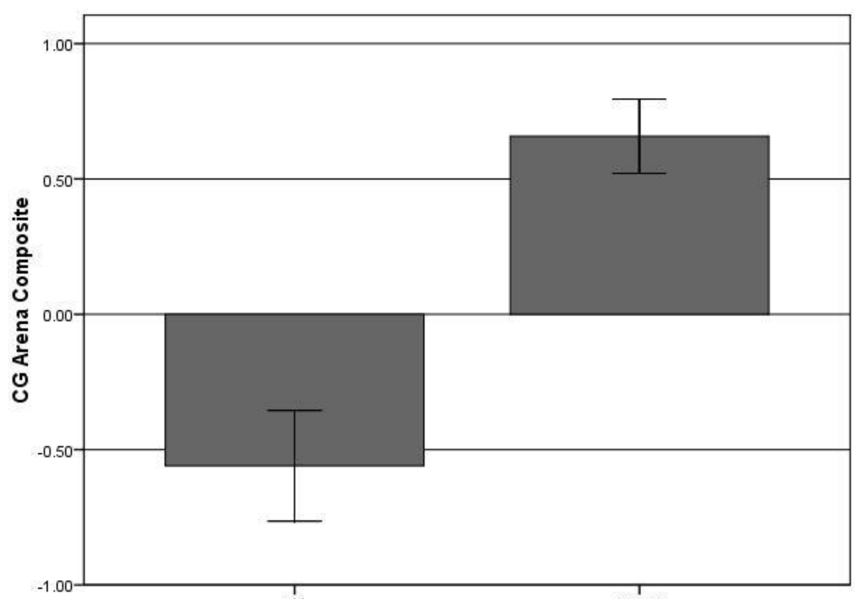

Figure 3-6. Mean CG composite performance by group $F(2, 47) = 47.41$, $p < .001$, $\eta^2 = .74$.

To further examine differences in age group CG Arena performance, the old group was again divided into 'young old' and 'old old.' An analysis of variance (ANOVA) was used to test for differences among the three age groups with the composite CG variable as the dependent variable and age group as the independent variable. Overall performance on the CG Arena differed significantly across the three age groups, $F(2, 47) = 65.89$, $p < .001$, $\eta^2 = .74$. There was a significant linear trend, $F(1, 47) = 122.58$, $p < .001$, indicating as age increased (young<young old<old old), overall house navigation task performance decreased proportionately. (Figure 3-7). Furthermore, the planned contrasts revealed that (old) age significantly decreased CG Arena performance compared to young adults, $t(44.45) = -11.08$, $p < .001$, and the old old group performance was significantly worse than the old group, $t(24.46) = -3.07$, $p = .005$.

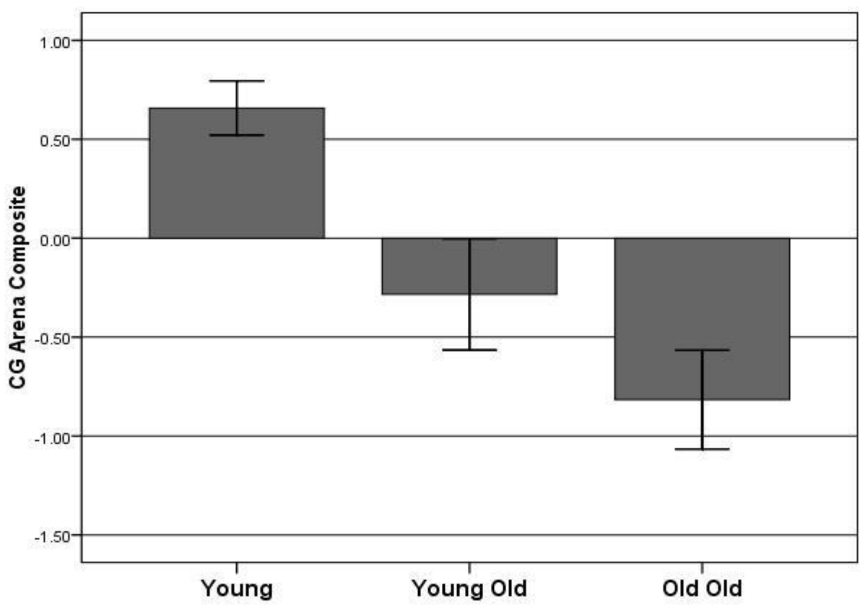

Figure 3-7. Mean Group CG Arena composite performance F(2, 47) = 65.89, p < .001, η2 = .74

To further account for age group differences that can be attributed to known age group differences in motor skill (slowing) and accompanying joystick manipulation, baseline motor testing was examined. Analyses of psychomotor skill and speed (MS) revealed expected significant age group differences, $F(2, 47) = 20.69$, $p < .001$, with a significant linear trend, $F(1, 47) = 38.126$, $p < .001$, indicating as age increased (young<young old<old old), psychomotor skill/speed (Composite *Z* Score) decreased (*M* young = .59, *SD* = .54; *M* old = -.29, *SD* = .65; *M* old old = -.74, *SD* = .76). Accordingly, an analyses of covariance (ANCOVA) with motor speed (MS) as a covariate and CG Arena composite as the dependent variable was conducted. MS was not a significant covariate F(1, 47) = 1.95, p = .169 and therefore significance was maintained when controlling for it $F(2, 47) = 29.17$, $p < .001$, $\eta^2 = .565$.

Relationship between navigation in CG Arena Space and Real Space

In line with our second aim, the next part of our statistical analysis examined the relationships with real world spatial navigation (HNT performance) and computer navigation performance. Preliminary analyses focused on bivariate correlations between the HNT, CG Arena, and FE composite scores considered separately for each of the three age groups. Table 3-3 and Figure 3-8 shows the mean scores obtained by each group. When looking at the groups separately, no significant correlations exist, although near significant correlations between HNT and FE and HNT and CG Arena exist in the old group (Table 3-4). However, when combining the two old groups, there exists a significant positive correlation between CG Arena and HNT ($r = .439$, $p < .02$), accounting for 19% of the variance.

Table 3-3. Composite Scores by age group *M (SD)*

Age Group	*n*	Frontal Executive Composite Score	HNT Composite Score	CG Arena Composite Score
Young	23	.44 (.65)	.68 (.19)	.66 (.32)
Old	13	-.02(.64)	.008 (.61)	-.28 (.47)
Old Old	14	-.73 (.80)	-.79 (.68)	-.82 (.43)

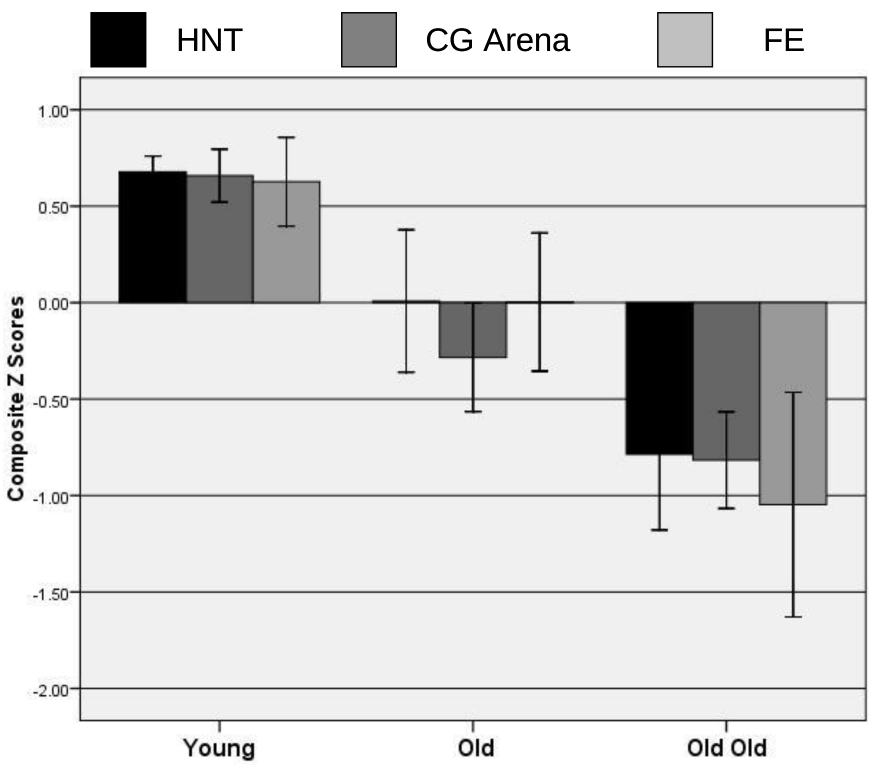

Figure 3- 8. Composite scores by age group

Table 3-4. Correlation of composite scores by group

Age Group	**HNT-Arena**	**Arena-FE**	**FE-HNT**
Young	0.181	-0.128	0.074
Old	0.481*	0.258	0.525**
Old Old	-0.012	0.243	0.308

Note: * p = .096, ** p = 0.066

To determine the relative contribution of CG Arena, age, and FE to HNT performance, this relationship was examined further by using hierarchical multiple regression analyses. At the first step, we entered the composite CG Arena variable. Second, we entered age. Based on the evidence of frontal executive functioning (FE) partially mediating the effects of age on HNT, we also entered FE in the second step. Using this method, a significant model emerged in the first step with CG Arena predicting HNT, $F(1, 48) = 55.03$, $p < .001$. The second model also significantly predicted the outcome variable, HNT, $F(3, 46) = 30.084$, $p < .001$, accounting for 67% of the variance in HNT performance. Once age and FE were added to the model, CG Arena no longer significantly predicted HNT performance. This, along with the significant large correlation of age and FE ($r = -.58$, $p < .001$), suggests that FE does a better job of predicting real world navigation than does computer navigation. Results are given in Table 3-5.

Table 3-5. Summary of multiple regression analyses examining contribution of CG Arena, age, and FE on HNT performance.

		b	*SE b*	β
Step 1				
	Constant	.094	.076	
	CG Arena	.763	.103	.731***
Step 2				
	Constant	.482	.143	
	CG Arena	.184	.170	.176
	Age Group	-.473	.155	-.513**
	Frontal Executive	.204	.098	.218*

Note. $R^2 = .534$ for Step 1: $\Delta R^2 = .134$ for Step 2 (p < .05). * $p < .05$ ** $p < .01$ *** $p < .001$

CHAPTER 4
DISCUSSION

The broad aim of this study was to evaluate changes in spatial memory and cognition associated with normal aging. The results of the present study demonstrate that real world environments can be used to assess age effects in spatial navigation performance. We used a 3 bedroom, 2 bathroom house to develop an ecologically valid task modeled after theories of allocentric spatial navigation (House Navigation Task; HNT). This environment was easily understood, well organized, and thereby was predicted to elicit optimal performance. The performance of young, old, and old old adults improved with each trial, each locating more items with shortened distance travelled over trials. These results provide evidence that real world environmental support may enhance memory performance (especially in older adults). However, despite improvement in performance over time and retention of this information on delayed recall, the two groups of older adults were clearly impaired in overall performance relative to the young group, with increasing impairment in the old-old group compared to their young-old counterparts. Moreover, on the delayed recall portion of the HNT, 96% of young adults, 65% of old adults, and 14% of old old adults were able to correctly identify all 16 locations.

When examining individual variables of the HNT, some interesting patterns emerged. As represented by overall path length, an increase in age was accompanied by more frequent repeat visits to locations already visited within a trial and less efficient acquisition of the items (i.e. going back and forth between rooms). Older adults would frequently back track between rooms when they realized they had forgotten an item (or not gone to a location) in a room they had already visited.

This effect was further illustrated when looking at performance on number of correctly identified locations and correctly identified items. Scoring for HNT was based on the well documented relationship between aging and decline in memory functioning including spatial memory (e.g., Park, et al., 2007) and verbal memory (e.g. Salthouse, 1998), as well as evidence that spatial and object memory are two different systems (e.g. Courtney, Ungerleider, Keil, & Haxby, 1996). It was expected that older adults would not be able to remember the objects as well as younger adults, but memory for location in a real world setting was of interest. While there was a significant age group difference in the number of correctly identified locations, old adults on average correctly remembered almost all (14-15 out of 16) of the locations (old: M = 15.31, SD = 1.03; old old: M = 14.14, SD = 1.51). However, they did not efficiently navigate to these locations resulting in longer path lengths. Contributions to this inefficiency were explored even further using a mediation model approach.

The significant age group differences found in path length, correctly identified locations, and correctly identified items even on Trial 1 further suggest that age differences in navigational ability are not restricted to learning and memory. These gaps narrow over trial, but significant group differences still exist. These age differences in our study then could not simply be due to differences in general spatial ability, but can be explained by other factors as well.

The data also demonstrated group differences in the house object recognition task (HORT), an independent paper-and-pencil recognition task administered after the completion of the delay trials. While significant group differences were found, closer investigation reveals that these differences were fairly small with no participant (young or old) correctly recognizing or differentiating all 48 items (Total HORT score young: *M* = 35.22, *SD* = 2.76; old: *M* = 34.00, *SD* = 2.42; old old: *M* = 32.64, *SD* = 2.84). The finding of significant group effects on correct identification of incidental items was opposite to what was predicted. Based on the relationship between age and distraction (or inability to suppress irrelevant information) (e.g. Andres, Parmentier, & Escera, 2006; Chao & Knight, 1995), it was predicted that the older adults would be more accurate in the identification of items placed in the house that were not needed for the experiment (i.e. items not located on the list needed to "pack for the trip"). In other words, they would attend to incidental items as much as they would to critical items. This did not prove to be the case and in fact the opposite was found. Younger adults performed best on accurate identification of incidental items, followed by old adults and then the old old adults (Total HRMT score young: *M* = 47.57, *SD* = .90; old: *M* = 43.38, *SD* = 7.08; old old: *M* = 34.79, *SD* = 10.18). Although the HORT measures recognition of objects that were located in the house, it does not measure reconstruction of the spatial relationships among the objects, and likely taps different memory representations than those used for successful spatial navigation.

Analysis of the house reconstitution map task (HRMT), which required participants to place the 16 items used in the experiment on a floor plan of the house revealed significant group differences. Younger adults placed the items in the correct room and in correct relation to the other items more often than old adults. When looking at accuracy (deviation measurement), young adults again performed significantly better. This, taken together with the mean number of items correctly identified on the HORT suggests that while older adults are able to recognize objects in their environments, they are unable to reconstruct a cognitive map of the relationship of these items in the environment. On the HRMT, older adults were frequently observed to place items on the misarranged pieces of furniture that were not located in the correct room or in correct relation to other items in the same vicinity. It could be the case that older adults were either encoding the information using a verbal or visual object memory strategy rather than encoding the information using a spatial map (i.e. “the keys are on the desk”). This strategy led to the large discrepancy in deviation scores between groups and suggests older adults were not effectively encoding the layout of the environment. Younger adults appear better able to accurately remember the precise spatial layout of an environment than older adults.

We then sought to examine other cognitive factors mediating the relationship between age and spatial navigation. Specifically, based on previous research, we predicted that the expected age-related differences in real world navigation would be accounted for by mental rotation ability and executive functioning (cognitive flexibility). We were able to demonstrate the causal relationship between aging and poorer real world navigation (HNT) performance was partially mediated by executive functioning. This finding suggests that executive functioning may be the driving critical cognitive contributor to successful navigation, mostly independent of age. This result fits well with the correlation of normal aging and accompanying age related effects on neuropsychological tests of executive functioning (e.g. Salthouse, Atkinson, and Berish, 2003). Indeed, approximately 35% of the variance in the direct effect of age on HNT remains unexplained. It is plausible that this relationship may be partially mediated by other cognitive factors, or factors not measured in this study. Mental rotation was not found to mediate the significant causal relationship between age and HNT.

Consistent with previous findings, results from this study clearly demonstrated that overall, older adults do not navigate as effectively as younger adults in virtual space (CG Arena). Performance on all visible practice trials was comparable, all participants reported they understood the instructions, and all participants were trained until they mastered the use of the joystick. Furthermore, young adults did not report significantly more experience with use of a joystick than older adults.

Young adults did report significantly more computer game experience than older adults. However, in the analyses, this experience did not have an impact on performance. It can therefore be concluded that the age differences found were not a function of lack of experience with the computer or joystick. While time was not included in measuring age group differences, known age effects of psychomotor processing speed were still considered. Despite the joystick control being relatively simple (gross motor skill- forward, left, right), changes in motor skill that accompany aging, could make it harder for older adults to manipulate the joystick, thereby impacting performance. Therefore, the age group differences in psychomotor skill and speed were examined and in this analyses did not have an impact on performance. In addition, no age related differences were found on the practice trials of the experiment. We can therefore conclude that this age difference found in CG Arena performance cannot be accounted for by generalized psychomotor slowing associated with age.

We also examined CG Arena variables independently and our findings confirmed previous work done in our laboratory. This data demonstrated that young adults found the target more often and with shorter traveling distance than did older adults. Additionally, on the probe trial, young adults spent a greater proportion of time searching the target quadrant than older adults. Consistent with previous studies, this pattern of results indicated that young adults learned, remembered, and navigated to the invisible target more effect than older adults (King, 2006, Laurence et al., 2002).

Age group differences were also demonstrated on the arena reconstitution task (ART), but not the object recognition test (ORT). Both are paper and pencil tests administered after completion of the CG Arena. The older group placed the target in the correct quadrant on the ART significantly less often than the younger group, further supporting the idea that they did not have an accurate memory representation for the location of the invisible target. These data suggest that older adults are not able to reconstruct virtual cognitive maps of their environments as well as younger adults or remember a particular place in that environment as accurately as younger adults. However, they are able to recognize objects that were in the virtual environment as well as younger adults (ORT).

A third important outcome of the present study emerged from examining the relationship of performance on CG Arena with that of HNT. The focus of the present study was to evaluate how virtual navigation predicts real world navigation, especially in older adults. CG Arena turned out to have less impact on HNT performance than age and executive functioning. While CG Arena has a significant positive correlation with HNT, when age and executive functioning are entered into the model, this significant correlation no longer exists. In addition, there is a large significant negative correlation between age and executive functioning. This is all good evidence to suggest that tasks with executive functioning demands are more powerful than computer navigation performance and age in predicting real world navigation. Therefore, while significant correlations exist between navigation in computer space and real space, this present study expands on this finding even further by evaluating other factors contributing to this relationship.

One explanation for the lack of impact from computer navigation is the cognitive flexibility demands of HNT, as mentioned above. In addition to the spatial learning components of the HNT, there exists a large working memory and planning component. One must visualize the location of the items, and then decide the order of item location so that the most efficient path is taken. If this is not done successfully, then it leads to inefficiency (i.e. travelling back and forth between rooms). The high execution demands of this real world navigation task could be contributing to the decrease in shared variance with the CG Arena and both measures most likely rely on executive functions systems. As reviewed earlier, it has been demonstrated that vMWM performance is influenced by frontal systems and that cognitive measures that are thought to tap these systems are correlated with vMWM performance (Moffat, et al., 2007).

The limitations of the current study will be addressed in further studies. First, one recognized limitation of the design is that, by not performing the task in the person's home and having it be so structured, it does not completely generalize to the individual participant's environment (Burgess, Alderman, Forbes, Costello, Coates, Dawson, et al., 2006). Despite the task not being "open ended" in nature, there are several methodological gains that are believed to make this a valuable measure. These include the ability to control the stimuli in the environment (e.g. familiarity and range of exploration – both of which could not be accomplished in an individual's home or supermarket), standardization of the test demands, and safety and privacy of the participants (Titov & Knight, 2005). Despite the benefits of methodological control, future studies focusing on navigation in an individual's home or frequently encountered environment, may provide a better gauge of difficulties experienced in everyday life.

Second, executive functioning has been conceptualized to be comprised of several different abilities (components) and is frequently tested using a variety of tests. For this study, we tested only two measures that fall into the working memory and switching subcomponents. Therefore, the two measures used in this study may not be representative of all aspects of the executive functioning construct. Future studies focusing on more subcomponents of executive functioning, and with more tests may provide additional information to the relative contribution of executive functioning abilities to real world spatial navigation. In keeping, mental rotation ability was only measured by one test in this project, and may therefore not be an accurate indicator of the relative contribution to real world navigation performance.

Because this study focused on two healthy groups of participants, it was not focused on demonstrating links between behavioral performance and the underlying neural substrate for spatial cognition. Future studies focused on clinical populations may include anatomic measures of MTMS pathology using structural MRI; demonstrating sensitivity and specificity to anatomic losses would improve the task's clinical and experimental utility. In addition, inclusion of individuals with dementia could assist in examining the relationship of these neurobiological measures to performance.

While our current sample is nearly matched on IQ and education, the study was conducted on a sample of healthy, predominately Caucasian adults, with high levels of education. Therefore, caution must be exercised when generalizing to other populations. Future direction would aim to recruit a more diverse sample that is more representative of the population.

Due to ceiling effects in the young group, accompanying issues with restricted range of scores, and small sample sizes overall, relationships between all cognitive abilities and HNT performance could not be fully assessed. In future studies, it would be useful to include either a large sample of either healthy older or young adults in this type of study. If normal healthy younger adults were examined, then test demands should be increased to reduce ceiling effects. Contributions of other cognitive factors could then be further assessed. HNT and CG Arena performance should then be included in a factor-analytic study of cognitive ability that includes neuropsychological measures from many domains.

Present findings have shed some light on changes in real world spatial navigation that occur with aging and how these abilities may actually be mediated by other factors. Our findings show that real world navigation as measured by HNT is strongly influenced by executive functioning (working memory and switching). The influence of aging on executive functioning should be taken in consideration in future studies of spatial cognition. The use of real world environments in future research with normal aging individuals as well as young individuals with frontal lobe insult may help further our understanding of spatial ability age differences and brain mechanisms involving spatial navigation with greater clarity. We believe that a systematic analysis of the causal link between executive functioning and real world navigation ability is an appropriate next step in this line of research.

In conclusion, the present report provides additional evidence that older adults demonstrate poorer performance on virtual and real world tasks of spatial learning and memory than do their younger counterparts. These data confirm the feasibility of the HNT task in an older population and speak to the possible utility of using more ecologically valid measures in a clinical setting. Given the importance of environmental demands when assessing cognitive functioning, both laboratory and real world tasks need to be utilized for accurate assessment.

APPENDIX A
COGNITIVE TEST BATTERY

Overall Construct	Measure	Description of Test Measure	Source
General Mental Status	Mini Mental State Exam (MMSE)	Estimation of dementia severity	Folstein et al., (1975)
Observer/ Interview Ratings	Clinical Dementia Rating Scale (CDR)	Disease severity rating: informant & patient subjective, objective elements	Morris, (1993)
Functional Assessment	Memory Assessment Centers-Questionnaire (MAC-Q)	Subjective memory complaints	Crook and Larrabee, (1992)
Intellectual Functioning	Wechsler Abbreviated Scales of Intelligence (WASI - 2 subtest) - Vocabulary, Matrix Reasoning	Predicts general intelligence, verbal and performance abilities	Wechsler, (1999)
	Wechsler Test of Adult Reading (WTAR)	Estimation of premorbid levels of intelligence	Wechsler, (2001)
Overall Functioning/ Screening Battery	Repeatable Battery for the Assessment of Neuropsychological Status (RBANS)	Brief core battery for detection of brain insult - dementia, head injury, or stroke.	Randolph (1998)
Language Functioning	Boston Naming Test-2nd Edition (BNT)	Confrontation naming using large ink drawings	Goodglass & Kaplan, (2001)
	Controlled Oral Word Association (COWA)	Verbal fluency to alphabet letter (FAS).	Spreen & Benton, (1977)

Overall Construct	Measure	Description of Test Measure	Source
Frontal/Executive Skills- Attention, Processing Speed, Problem Solving, Abstract thinking	WAIS-III - Digit Span	Attention span	Wechsler, (1997)
	D-KEFS Trail Making Test Condition	Visuomotor speed, visual scanning, sequencing, cognitive flexibility	Delis, Kaplan, & Kramer, (2001)
Motor	Finger Oscillation Test	motor speed	Reitan (1969)
	Grooved Pegboard test	speeded fine motor dexterity	Klove (1963); Reitan (1969)
Spatial Skills/Cognition			
	Wechsler Memory Scale-III -Spatial Span	visuospatial short-term and working memory	Wechsler, (1997)
	Mental Rotation Test	Mental Rotation	Vandenberg & Kuse (1978)
	Space Thinking-Flags		Thurstone & Jeffrey (1959)
	Neuropsychological Assessment Battery – Spatial Module: Map Test (NAB)	Local Navigation Strategy/Map Reading	Stern and White, (2003)
Mood	Geriatric Depression Scale (GDS)	Self evaluation assessing elements of depression	Yesavage, Brink, Rose, Lum, Huang, Adey, and Leirer, (1983)
	Beck Depression Inventory -2nd Edition (BDI-II)	Self evaluation assessing elements of depression	Beck, Steer & Brown, (1996)

APPENDIX B
HOUSE NAVIGATION TASK ITEM LIST

Packing for a trip out of town and need to locate the following items…. Colors represent items that were located in the same room or close to one another.

Six of the proposed items were based on the MIR task (not used-glass, scissor, matchbox, comb)

1. pencil
2. keys
3. ring
4. watch
5. pill bottle
6. sunglasses
7. toothbrush
8. crackers
9. wallet
10. sunscreen
11. socks
12. water bottle
13. camera
14. peppermint
15. granola bar
16. gauze pads

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BIOGRAPHICAL SKETCH

Emily King graduated from the University of Florida with a bachelor's degree in health science. She then spent a year working as a psychometrist at Mayo Clinic in Jacksonville, Florida and three years as a research project coordinator for various studies with investigators from Harvard Medical School in Boston, Massachusetts. She earned a master's degree in clinical and health psychology at the University of Florida in 2006 and then began her doctoral studies in the same program, with a concentration in clinical neuropsychology. Ms. King concluded her doctoral training with an internship at the James A. Haley Veterans' Medical Center in Tampa, Florida.