

Issues for the Assessment of Visuospatial Skills in Older Adults Using Virtual Environment Technology

J.S. MCGEE, M.A.,^{1,4} C. VAN DER ZAAG, Ph.D.,¹ J.G. BUCKWALTER, Ph.D.,¹
M. THIEBAUX, M.S., MFA,³ A. VAN ROOYEN, Ph.D.,⁴ U. NEUMANN, Ph.D.,²
D. SISEMORE, B.A.,¹ and A.A. RIZZO, Ph.D.^{1,2}

ABSTRACT

Virtual Environment (VE) technology offers clinical assessment and rehabilitation options that are currently not available using traditional neuropsychological methods. Advancements in this type of immersive information technology could produce tools that enhance the scientific study of human cognitive/functional processes and improve our capacity to more accurately assess and treat impairments found in persons with central nervous system (CNS) dysfunction. Through the creation of dynamic three-dimensional (3D) stimulus environments, in which all behavioral responding can be recorded, VE technology offers the possibility to more sensitively address a range of age-related CNS disorders including Alzheimer's Disease, Vascular Dementia, Parkinson's Disease, and stroke. Advances in this area could impact quality of life issues for an increasingly aging world population. The VE Laboratory at the University of Southern California has developed a suite of ImmersaDesk-format, 3D projection-based VEs. These scenarios target assessment of visuospatial skills including visual field-specific reaction time, depth perception, 3D field dependency (virtual rod and frame test), static and dynamic manual target tracking in 3D space, and spatial rotation. The current project tested healthy older adults (ages of 65 and 92). Participants were administered a standard neuropsychological battery and a suite of VE-delivered visuospatial tasks. Issues addressed in this project include: the occurrence of VE-related side effects in healthy older adults; the relationship between performance on VE measures and standard neuropsychological tests; the assessment of gender specific performance differences; the relationship between immersive tendencies, presence ratings, and VE performance in older adults; learning and generalization; and VE visuospatial performance differences between younger and older participants. This article will address the motivation, rationale, and relevant issues for use of VEs with older adults. A description of our VE system/methodology in the context of a recent study targeting assessment and possible rehabilitation of visuospatial skills with this population will then be detailed.

¹Andrus Gerontology Center, ²Integrated Media Systems Center, and ³Information Sciences Institute, University of Southern California, Los Angeles, California.

⁴Graduate School of Psychology at Fuller Theological Seminary, Pasadena, California.

INTRODUCTION

APPROXIMATELY 12.6% OF THE POPULATION is over the age of 65 years in the United States today. By the year 2030, this number is expected to increase to 22%, in part due to improvements in medical care resulting in increased life expectancy. Projections indicate that the number of persons aged 85 and over will double by the year 2030.¹ When coupled with observations of age-related cognitive decline, these statistics highlight the importance of increasing our focus on issues of aging and call for the re-evaluation and expansion of current neuropsychological assessment (NA) and cognitive rehabilitation (CR) methods that target the needs of the elderly. It is our position that VE technology could play a part in the advancement of neuropsychological methods and tools.

Neuropsychology is an applied science that evaluates how specific activities in the brain are expressed in observable behaviors.² NA uses psychometric assessment tools to diagnose dysfunction and to specify cognitive strengths and limitations in order to design rehabilitation strategies, assess treatment efficacy, and plot cognitive changes over time. CR aims to restore cognitive/functional abilities following brain damage or dysfunction.³ Also, CR works toward "increasing or improving an individual's capacity to process and use incoming information so as to allow increased functioning in everyday life."⁴ As applications in VE technology become less expensive and more accessible, these tools could become one key that will open the door to enhanced quality of life for older adults in the coming millennium.

VE technology offers the potential to develop immersive, dynamic 3D assessment and training modules that are capable of delivering a broad range of complex stimuli useful for testing and training purposes.⁵⁻⁸ This technology could serve to enhance "ecological validity" or the degree to which a test or training exercise simulates interaction in the "real" world.⁹ Through increased precision in stimulus delivery and enhanced recording of behavioral responding, the rigorous experimental control required for scientific analysis could be improved with VE technology. Further, VEs can provide

flexibility and sophistication for rehabilitation options through an increased capacity to test and train naturalistic behavior within a "real-world" functional module. This could lead to improved development of functional cognitive rehabilitative programs as well as ensuring accurate collection of data, which might have been lost using traditional methods. For example, older adults with impairments in memory and executive functioning could be presented with hierarchical rehabilitative challenges in a VE more efficiently and consistently than with traditional methods.⁵

Although the possibilities are considerable, researchers have only just begun to address the issues surrounding the utilization of VEs with older adults. Currently, applications for use with this population are few and very much in their infancy.^{10,11} In fact, enhancements in human-computer interfaces for older adults have just recently become a focus of researchers.^{12,13} This article will address the motivation, rationale, and relevant issues for use of VEs with older adults. Also, a discussion of our ongoing research project, which targets NA and CR of visuospatial skills in this population, will be included.

GENERAL ISSUES FOR USE OF VE TECHNOLOGY WITH THE ELDERLY

Do the benefits outweigh the costs?

An important step in deciding to develop any VE application is to perform a realistic cost/benefit analysis.¹⁴ One must ask if the targeted assessment objective requires the complexity and cost of a VE approach, or if it can be undertaken using simpler, less expensive, and currently available methods. For example, if one's objective is to assess global cognitive functioning in older adults as an initial screening procedure for dementia, then a very basic, standardized, 30-question mental status measure such as the Mini Mental State Exam¹⁵ may be utilized. However, the same researchers may believe that probable Alzheimer's disease (AD) could be detected at the very earliest stage through a more precise and systematic analysis of cognitive functioning in an ecologically

valid and stimulus-rich functional VE. For this purpose, a VE application may be the most efficient method for systematically controlling the stimulus environment while precisely measuring millisecond-by-millisecond responses. The earlier detection of cognitive decline in AD could signal the start of earlier intervention approaches to slow disease progression and promote increased functional longevity. The potential value of such a VE application could be conjectured to outweigh the initial design and development costs.

Nature of the clinical population

Ethical concerns also require clinical vigilance when using VE applications across different patient groups. Along these lines, researchers and clinicians must be aware of the potential for vast differences within older adult patient groups and take this variability into consideration when developing VE assessment and rehabilitation tools. As pointed out by Neugarten,¹⁶ old age spans many years and might be usefully broken down into categories such as “young-old” (age 65–84) and “old-old” (85+), including both healthy and frail persons. Consequently, categories based on age alone may be arbitrary when it comes to capturing the diverse individual neuropsychological and physical differences present in the elderly. For instance, a 65-year-old person with symptoms of advanced Parkinson’s disease (PD) may function more poorly than an 85-year-old with mild hypertension on a standard NA protocol. Therefore, a focus on differences in functional aging may be more fruitful than chronological aging when it comes to developing and implementing VE applications.

Changes in physical functioning are important to take into consideration when designing VEs for use with older adults, especially in the visual, auditory, vestibular, and motor systems. In normal aging, there is a decrease in the visual image that reaches the retina and a decreased capacity to focus on objects as they move closer and further away (accommodation).¹⁷ In fact, by the age of 60, the lens is completely incapable of focusing on objects at a close distance.¹⁸ Also, the lens becomes more opaque with age due to an accumulation of yel-

low pigment, making it more difficult to discriminate colors in the green-blue-violet spectrum.¹⁹ This clouding of the lens may result in problems with glare. When tracking moving objects, visual acuity is particularly poor at low levels of illumination.²⁰ Difficulties in depth perception and dark adaptation also occur in advanced age.¹⁷ Over time, visual acuity typically declines so that more than 95% of persons over the age of 65 need glasses and require more light in order to see adequately.²¹ Interestingly, stereopsis, the perception of 3D-space resulting from the varying input that reaches the two eyes, is stable, at least up to age 65 years.²²

Approximately 50% of normal elderly people have significant hearing impairment.¹⁷ Hearing loss, especially for high-frequency tones, increases as people age and is more severe in older men than women.²³ In general, older people are susceptible to masking. That is, they have great difficulty hearing normal speech when there is substantial background noise. As noted by Whitbourne,¹⁷ “higher rate of presentation, deletion of parts of the message, competition from background noise or competing messages, and reverberation” (p. 98) may affect speech perception in the elderly. Further, age-related changes in the vestibular system may result in vertigo and dizziness in older people,²⁴ which may be exacerbated by certain medications and physical illness including cardiac and vascular problems.²⁵

With increasing age, stamina or endurance typically declines due to changes in cardio-pulmonary functioning, circulation, and muscle mass. When assessing cognitive skills, “marathon testing” should be avoided because some older adults may fatigue and perform more poorly if not given appropriate rest and pacing during assessment, especially if they are frail or in poor health.²⁶

Many modes of VE navigation (data-gloves, joysticks, space balls, etc.), while easily mastered by younger participants, could potentially present problems for some older adults. For example, 50% of women and 35% of men in a national sample over the age of 55 reported they had arthritis.²⁷ Arthritis may interfere with grasping, rendering it difficult if not impossible to hold a pencil. Also, paralysis of the

hand may result from stroke. Further, weakness of the muscles, which may be associated with advanced age, may adversely impact range of motion.²⁸

VE-related side effects in older adults

In order for VE technology to become a safe and useful tool for use with older adults, the issue of adverse side effects must be considered. Two general categories of VE-related side effects, cybersickness, and after-effects, have been reported. Cybersickness is a form of motion sickness with symptoms including nausea, vomiting, eyestrain, disorientation, ataxia, and vertigo.²⁹ Cybersickness may result when conflicting perceptual information arises from two or more sensory modalities (auditory, visual, vestibular, proprioceptive) or when one perceives an incongruity between a VE and what one would expect based on "real world" sensory experience.³⁰

After-effects include symptoms such as disturbed locomotion, changes in postural control, perceptual-motor disturbances, past pointing, flashbacks, drowsiness, fatigue, and generally lowered arousal.³¹⁻³⁵ Adaptation to the sensory/motor requirements of VEs that do not represent a perfect replica of the "real" world may be related to the occurrence of after-effects. Upon leaving a VE, after-effects may occur due to a lag in readaptation to the non-VE environment. Persons with unstable binocular vision (which can occur with aging and following strokes and other CNS disorders) may be especially susceptible to post-exposure visual aftereffects.³⁶ Factors that may influence the occurrence of side effects include type of VE program used, technical drivers, length of exposure time, prior experience using VEs, movement (active vs. passive), gender, and method of measurement used to assess occurrences.³⁷⁻⁴⁰

Thus far, only a few studies have addressed the issue of VE-related side effects in older adults. For example, positive results using an HMD driving scenario with older adults have been reported.⁴¹ Also, a favorable experience was reported when assessing a group of stroke patients with a flat screen system for memory following navigation.⁴² Although these initial

reports are encouraging, during our study we took a cautious stance regarding potential VE-related side effects and had funds built into our grant that provided round-trip transportation to and from the assessment site. It was our view that the worst thing for the user, us, and the field would be for an elderly person to have a car accident while driving home after participating in an "experimental virtual reality scenario" where we were exposing subjects to visuospatial manipulations.

VE TECHNOLOGY AND THE STUDY OF 3D

Neuropsychology of 3D space

A thorough understanding of the complexities of human spatial processing is of particular importance when attempting to diagnose underlying brain dysfunction and resulting behavioral manifestations.⁴³ The rehabilitation of spatial abilities serves a vital role in the reacquisition of functional abilities such as driving, navigating environments, and other instrumental activities of daily living (IADLs). According to Previc, "the 3D space surrounding us is ubiquitous, very few human behaviors are completely devoid of spatial aspects or references. For that same reason, our interactions within the 3D spatial environment are arguably the single most important influence on the forging of the structural and functional architecture of the human brain."⁴⁴

The conceptualization of visuospatial ability in 3D space ranges from the general to the highly complex. A general definition of visuospatial processing is presented by Carpenter and Just⁴⁵ who describe it as the ability to generate a mental representation of a 2D or 3D structure, assess its properties, and perform a transformation of that "representation." Often visuospatial ability in 3D space is conceptualized through the understanding of various sub-components, such as spatial perception, orientation, visualization, and mental rotation.⁴⁶ A complex and perhaps more complete way of viewing 3D perceptual-motor operations includes four major behavioral systems; the peripersonal, the focal extrapersonal, the action extrapersonal, and the ambient extrapersonal

systems. The peripersonal system includes reaching, manipulation, and consummatory behavior. The focal extrapersonal system includes visual search and object recognition. The action extrapersonal system includes navigation, orienting to targets, and episodic remembrance in topographical space. Postural orientation during locomotion in gravitationally defined space is included in the ambient extrapersonal system. These systems are linked to both structural (brain anatomy) and functional (neurotransmitters) aspects of the brain.⁴⁴ As technology advances, VEs may provide a unique and accurate way of gaining access to these complex cognitive processes.

3D space and neurodegenerative disorders of aging

A better understanding of visuospatial functioning in 3D space is imperative for accurate assessment and rehabilitation of age-related neurodegenerative disorders. In this section, a brief sampling of 3D spatial deficits associated with CNS disorders of aging will be reviewed. Although this review is not exhaustive, it is designed to provide a glimpse into the importance of 3D spatial assessment for these clinical populations.

Current estimates of the prevalence of AD range from 3% of persons between the ages of 65 and 74 years to 47% in those over 85 years old.⁴⁷ Indeed an estimated four million Americans over the age of 65 are afflicted with AD, making it the third most costly (financial and emotional) disease to families in the United States.⁴⁸ Although AD is usually associated with devastating memory and language difficulties, 3D spatial deficits are also present. Most prominently, it has been suggested that these deficits may contribute to a person's difficulty navigating in the spatial environment and becoming lost or disoriented.⁴⁹

Studies of neuropsychological test performance in persons with AD suggest that there are a number of extrapersonal visuoconstructive deficits present.⁴⁴ For instance, there is a tendency to omit or inaccurately portray the local details in drawings as opposed to distorting the picture's global configuration.⁵⁰ Persons with AD may also exhibit upper visual neglect, as seen in missing details located to vi-

suospatial stimuli and identify targets in visual array, has also been reported to be impaired in some cases.⁵³

In contrast, visuospatial skills are relatively spared in persons with frontotemporal dementia (FTD). In 96.6% of FTD patients, spatial orientation was preserved as opposed to AD patients. This finding persists even into the later stages of FTD, while only 16% of AD patients displayed unimpaired performance (drawing interlocking pentagons) in the early stages of the disease.⁵⁶

PD damage to the nigrostriatal dopaminergic system of the brain is present, resulting in an extrapersonal motoric deficit.⁴⁴ For PD patients, verbal comprehension abilities are generally spared, whereas perceptual organizational ability, speed of processing, and, to some degree, working memory are relatively impaired.² Notably, there can be a restriction of upward gaze in the context of a general dearth of saccadic scanning^{54,55} as well as a downward pointing bias to remembered targets in PD.⁵⁶

Nearly 500,000 individuals have a first-time stroke each year. Overall, approximately three million Americans experience some degree of disability from stroke and it is the third leading cause of death after heart disease and cancer.⁵⁷ The incidence of stroke increases with age, occurring more in men than women. The effects of stroke on cognitive functioning depend upon the location of the infarction or hemorrhage, what kind of damage is caused, and the size of the lesion.²

As a final example, patients with cerebellar damage (CD) have been assessed on tasks of selective and spatial attention, mental imagery, and verbal-linguistic-temporal-order memory. CD patients were slower than normal controls on spatial attention tasks across all conditions (asked to focus on the center of the computer monitor and to press a key whenever a target appeared in the right or left visual field). On a spatial rotation task, only the degree of stimulus rotation affected accuracy, but there was not a significant difference between groups (subjects were required to press a key as soon as they decided whether two 2D geometric figures were either the same or mirror images). One figure was systematically rotated with respect to the other by 0, 60, 120, or 180 degrees.

It was concluded that the spatial attention task was the only task in which CD patients' response times were significantly slowed compared to normal controls, but they were equally accurate.⁵⁸

VEs and the study of visuospatial skills

A number of VE scenarios have been developed to target spatial abilities, and a sampling of these applications will be provided below. For a more detailed review of this area with clinical populations, see Rizzo *et al.*⁵⁹

Flatscreen scenarios. A VE version of the Morris water task⁶⁰ has been developed to study place learning.⁶¹ On this VE task, persons must navigate an environment in search of a hidden platform utilizing local environment cues on the walls of the VE. Significant differences in performance were found when comparing age, CNS dysfunction, drug effects, and gender differences in this VE. Also, the use of flatscreen VE scenarios have shown promising results for training spatial orientation and navigation skills with children having motor disabilities.⁶² Transfer of spatial learning was shown to generalize to the "real" school environment after the children interacted in the VE school scenario, and learning improved with practice. Flexibility in the cognitive representation or "mapping" of the environment was inferred, as the children were able to accurately identify the direction of objects not in their line of sight from a position not modeled in the VE. Similar findings have been reported by another group of researchers who have developed a visuospatial VE scenario designed for use with children who have motor impairments.⁶³ In this study, spatial performance was equated with "real world" training, and successful generalization to the real environment was reported. Also, improvement using a flat screen VE training system, targeting functional spatial knowledge, has been reported for teenagers with developmental disabilities in a supermarket search and navigation scenario.⁶⁴

Projection-based scenarios. An early study from the USC VE Lab targeted Mental Rotation (MR) via a manual spatial rotation task that

required subjects to manipulate block configurations within an ImmersaDesk-delivered VE.^{65,66} MR is a well-studied visuospatial variable that can be described as a dynamic imagery process that involves "turning something over in one's mind."⁶⁷ Participants were presented with a target block configuration and the speed and efficiency of their movements to superimpose a replica design upon the target was measured and recorded. All manner of angle disparity and axis combinations were programmed into the system allowing for the hierarchical presentation of cognitive challenges required for NA/CR purposes. The initial feasibility study, targeting MR in a VE, assessed young adults (ages 18–40) on a number of variables including side effects, learning on the VE MR task, and transfer of training from the VE to performance on a 2D paper and pencil MR task.⁶⁸ The relationship between VE performance and other "standard" neuropsychological tests of cognitive performance were investigated along with gender differences on these variables. A number of encouraging findings emerged including minimal side effects, good psychometric properties of the VE test, provocative relationships with standard NA tests, a lack of gender differences compared to the paper and pencil measures, training improvement, and significant transfer of training with low initial paper and pencil performers.^{65,66}

HMD scenario. HMD-delivered VEs have been utilized for studying spatial processes in normal subjects on mental rotation ability,⁶⁹ facial scanning in autistic children (with an eye-tracking system built into the head mount),⁷⁰ and spatial exploratory behavior with clinical populations having vestibular dysfunction.⁷¹ HMD VEs, targeting driving ability, have also been utilized with TBI patients and older adults.¹⁰ Another intriguing VE system, designed to train elderly persons to step over obstacles is being developed.¹¹ This HMD VE application allows at-risk elderly persons to practice stepping over moving obstacles on a treadmill while wearing an overhead safety harness. This type of VE is especially important given the fact that preventable falls, often resulting in hip damage, are a leading factor in

loss of functional independence for older adults.

Age, gender, and spatial ability in normal aging

Gender and age differences in cognitive performance have been reported throughout the psychological literature. Consequently, these variables should be considered and controlled for when cognitive research is conducted in VEs. In general, older adults demonstrate slower performance on spatial tasks than younger adults,^{72,73} and gender differences in spatial skills may be larger in older adults.⁷⁴ Interestingly, some studies have reported a verbal advantage for elderly women^{75,76} and spatial advantage for elderly men.⁷⁷ However, other studies have not yielded similar findings.^{78,79}

One of the more interesting gender-influenced cognitive skills within the spatial domain involves mental rotation. The Mental Rotation Test (MRT), a paper and pencil measure designed to assess mental rotation, involves the presentation of representations of 3D objects in which subjects are required to make judgments as to whether objects are the same or different in various angles of rotation.⁶⁷ The MRT has consistently produced robust gender differences in favor of males.⁸⁰ In a recent study assessing older adults on the MRT, males demonstrated decreased performance on the MRT with age but still performed at a significantly higher level than older females. These findings were independent of global cognitive functioning between gender groups, and may represent cognitive changes due to hormonal factors.⁸¹ By contrast, results from the Virtual Reality Spatial Rotation (VRSR) test with a young sample did not demonstrate gender differences when male and female participants were able to manually manipulate the stimuli in a VE.^{65,66} This was in sharp contrast to a large male advantage on the 2D pencil and paper MRT.

Our primary effort in this project has been to study performance on the VRSR test and on seven other newly developed visuospatial scenarios with a normal aged population and use these results for comparison purposes with a young sample. As well, we plan to use this

sample as a baseline for future research comparing performance with older persons have various forms of dementia. Although we having limited analyses to report on the current project in time for this publication deadline, results of our ongoing analyses will be available by June 1, 2000 and can be obtained via E-mail at arrizo@usc.edu in advance of our formal presentation of results in a future paper. Also, mpg video images of all the visuospatial scenarios are available from this E-mail address.

METHODS

Participants

Thirty community-dwelling older adults (15 men and 15 women) between the ages of 65 and 92 participated in the present study. Participants consisted mainly of volunteers from the Andrus Gerontology Center at the University of Southern California and resided in the greater Los Angeles area. Participants were paid \$50.00 for their participation in the study. There were no significant differences between men and women on age (men, mean = 74.8, $SD = 6.18$; women, mean = 73.4, $SD = 7.46$) or education (men, mean = 16.4, $SD = 3.1$; women, mean = 14.8, $SD = 2.53$). Prior to selection for the study, participants were screened with the "Telephone Interview for Cognitive Status" (TICS) to rule out cognitive impairment.⁸² A cut-off score of 30 was used. Other exclusion criteria included history of neurological illness, physical, or psychiatric disorder that might impair performance in the VE.

Virtual reality system

The display system used to deliver the visuospatial VE scenarios was a Pyramid Systems ImmersaDesk™ drafting-table format rear-projection display. The large-screen semi-immersive display system provides a wide-angle view that allows participants to interact with 3D "hologram-like" stimuli. This is accomplished through the use of a 5' × 7' rear-projected screen positioned at a 45-degree angle. Stereo glasses and magnetic head and hand tracking are employed in this system. For more

information on the ImmersaDesk™ display tool, please visit: <http://www.fakespace.com/>. An SGI Onyx system is used for this application.

Procedures

Experimental sessions took place in three phases and lasted for an average of 3 hours total for completion. During the first phase, prescreening was completed and informed consent was obtained. Also, participants completed a number of surveys sent to their homes including the following: (a) a basic demographics questionnaire; (b) a handedness inventory⁸³; (c) the Immersive Tendencies Questionnaire⁸⁴; (d) the Telegen Absorption Scale,⁸⁵ which also measures potential for "immersive" experiences; and (e) a computer experience questionnaire.

During the second phase, a neuropsychological battery was administered to participants along with The Motion History Questionnaire.⁸⁶ Tests of auditory and visual acuity were conducted at that time. The neuropsychological battery included a diverse set of assessment tools, widely utilized and standardized for use with older adults. Within the verbal domain, pre-morbid verbal ability was estimated with the *National Adult Reading Test-American Version (AMNART)*.⁸⁷ Fluency was assessed through the *Animal Fluency Test*.⁸⁸ The *California Verbal Learning Test (CVLT)* was employed to assess verbal learning and memory.⁸⁹ Primary attentional capacity and mental tracking, within the verbal domain, was assessed with the *WAIS-III Digit Span Forwards* and *Digit Span Backwards* subtests.⁹⁰ Working memory was assessed through the *Arithmetic* and *Letter-Number Sequencing* subtests of the *WAIS-III*.⁹⁰ In the visual domain, visuospatial skills were assessed with *Judgment of Line Orientation (JLO)*.⁹¹ Visuoconstructional ability was assessed with the *Block Design* subtest of the *WAIS-III*.⁹⁰ *Visual Reproduction I and II (WMS-III Subtests)* was utilized to assess visual learning and memory.⁹² Primary attentional capacity and mental tracking, within the visual domain, was assessed with *Trailmaking A and B*.⁹³ Non-verbal reasoning was assessed through *Matrix Reasoning (WAIS-III*

Subtests).⁹⁰ *Line Bisection* was utilized to assess for right and left visual field neglect.⁹⁴ Due to the potential influence of emotional status on psychological and neuropsychological test performance, emotional status was assessed through use of the *Symptom Checklist-90 (SCL-90)*.⁹⁵ This test is composed of 90 items that assess for a number of major symptoms of psychological disturbance.

In the third phase, participants were given a pre-VE exposure administration of the Simulator Sickness Questionnaire.⁹⁶ Baseline mental rotation ability was assessed using the *Mental Rotation Test (MRT)*,⁶⁸ which uses line drawings of block stimuli. The MRT consists of two 10-item sections in which participants match two of four choices to a target figure. Incorrect choices are mirror images of the target or alternative block configurations. Standard administration provides a time limit of 5 minutes per 10-item section. The alternate form of the MRT uses the same drawings but reorders their presentation and switches position of the target stimuli.⁹⁷ Participants were then administered a series of VE visuospatial scenarios that will be described in the next session. After the VE tasks, subjects were given an equivalent form of the MRT and a post-VE exposure administration of the Simulator Sickness Questionnaire. Participants were monitored for any observable signs of discomfort throughout the testing and were encouraged to discontinue participation at any time if ill effects were experienced. Transportation to and from the experimental setting was provided to participants as a precaution against impaired driving ability due to possible perceptual aftereffects.

Visuospatial virtual environment tasks

The VE components of this study were conducted in a darkened room with each participant seated in front of the ImmersaDesk at a standardized position relative to the screen. The distance from the participant to the midpoint of the screen was 4.0 feet. An adjustable chair was positioned for consistent height of viewing using a standard length of cord going from the ceiling to the top of the participant's head. Each participant was instructed to put on a set of Crystal Eyes stereo glasses, which can

be worn over corrective lenses. The procedure began with an on-screen test to make certain that the glasses were working in stereo. Participants were instructed on how to utilize the standard ImmersaDesk response wand and then were requested to look at the screen and were asked, "Do you see a block hovering over the wand?" If the glasses were not functioning properly, the participant would see double images of the stimuli. The glasses could be reset at that time or at any time during the examination. Participants were then administered the visuospatial tasks in the VE as described below.

A suite of eight VE-delivered visuospatial tasks was administered to each participant. These tasks included the following: (a) a bimanual visual field-specific reaction time task, (b) a series of interactive depth perception tasks (with three levels of diminishing cues), (c) a 3D field dependency task (virtual rod and frame test), (d) static and dynamic manual 3D target tracking tasks, and (e) a spatial rotation task.

Visual field-specific reaction time task. The series of tasks begins with a visual-field specific reaction time task. Participants were asked to focus their gaze on an "X" presented at the center of the screen and instructed to anticipate a dot to flash either to the left or right of the X and to press the response button with their thumb as soon as they see the dot. They were told that they will respond best by fixating on the center X because they would not be able to anticipate when or from which side the stimulus will appear. Also, they were instructed to keep their feet and hands uncrossed, to put their responding hand on their laps, and to respond as quickly as possible. Twenty blocks of 10 trials were administered (200 trials) with participants instructed to switch between their left and right hands for alternate blocks of trials. At the beginning of each block of trials, participants were reminded to focus on the X in the center of the screen. A "water drop" sound was utilized to alert participants to the beginning of a series of 10 trials. The stimuli appear at 6 degrees to the left or right of the midpoint at a width of 0.5 degrees. Random intervals are timed from 0.5 to 2.0 seconds, and intervals

were counterbalanced. The flash duration was at least 0.05 seconds, and if a person missed the flash, the timeout period was 2 seconds after the flash occurs.

Depth perception tasks. The next series of visuospatial tasks consisted of three depth perception scenarios. The first scenario required subjects to match two cubes (identical object depth alignment). Participants were instructed to familiarize themselves to the task by moving the wand forwards and backwards in relation to the screen and to notice that this action moves one of the cubes toward or away from them. A static target cube was positioned at varying distances from the subject. The following instructions were given: "The task is to move the cube that you are controlling until it matches the position of the static target cube. When you are satisfied that the cubes are the same distance from you, click the response button of the wand. Respond as accurately as you can. At the tone, the task will begin and, when you respond, a chime will sound and you will continue with the next trial of the matching task with the static target cube moving to a new position. Are you ready?"

The second depth perception task involved a static cube and a larger-sized movable ball (dissimilar object depth alignment). Participants were instructed as follows: "When you are satisfied that the cube and the ball are the same distance from you, click the response button of the wand. At the tone, the task will begin and when you respond, a chime will sound and you will continue with the next trial of the matching task with the static target cube moving to a new target position. Are you ready?"

The final depth perception task involved two vertical lines (vertical line depth alignment). The participant was instructed to move the line on the right side of the screen by moving the wand back and forth. When the participant judged the two lines to be at the same distance (matched), he/she pushed the response button. After each response, a chime sounded and a new line appeared. Five trials of each depth perception task were administered.

3D field dependency task. To assess field dependency, a "3D virtual rod and frame test"

was developed. A yellow frame seemingly afloat in space appears on the screen along with a white rod that can be controlled by the participant. On each trial, the yellow frame was positioned in a slightly different spot from the one previous, and the white bar appeared at a different location. Each participant was oriented to the task and instructed to respond by pressing the button on the wand when he/she believed that the white bar was perpendicular or vertical to the floor. Five trials were presented with this task.

Manual 3D tracking tasks (static & dynamic). During the static 3D manual tracking task, two balls (a blue one on the left and a red one on the right) appeared on the projection screen with a white line running horizontally between them. Participants were instructed to position the "wand-controlled" cross hairs in the center of the blue ball on the left. They are then instructed to move the ball along the white line using the cross hairs to "push" it, and were told that in order to make the ball move, the cross hairs must be in the center of the ball with the intersection of the cross hairs closest to the white line. The task involves moving the blue ball to the end of the line where the red ball was, and then back to the original position. If the participant was unsuccessful, the system was programmed to "time out" or reset the task after 60 seconds, and another trial began.

The *dynamic* 3D manual tracking task required the subject to keep a moving figure ("Tinkerbell") inside a blue 3D bubble (or orb) that they controlled with the wand. During the first task group, the figure's movement was relatively fluid and stereotypic, consisting of one trial each of x , y , and z rotations (circular paths), including three 1-second pauses between trials. The second task group consisted of 4 paths of different speeds and lengths, with variable pauses, only if the participant was off target. During this portion of the task, the figure's actions became increasingly erratic, increased in speed, and the level of difficulty increased for successful tracking. The entire dynamic 3D manual tracking task took approximately 85 seconds to complete.

Spatial Rotation Task. The final VE visuospatial assessment tool was the spatial rotation task (referred to previously as the "VRSR"). This portion of the assessment and training system was designed to present a stimulus that consisted of 3D block configurations similar to the standard Shepard stimuli.⁶⁷ The stimuli appeared as "hologram-like," three-dimensional objects floating above the projection screen. After presentation of the target stimuli, the participant was presented with the same configuration of blocks (control object) to be rotated to the orientation of the target and then superimposed within it. Participants manipulated the control object by grasping and moving a racquetball, within which a tracking device was embedded. Upon successful superimposition of the control and target objects, a "correct" feedback tone was presented and the next trial began. After 5 non-rotational practice trials, each participant's VE spatial rotation baseline performance was assessed over 20 trials using a virtual version of the items from the pencil and paper MRT. Next, 50 training trials of increasing stimulus complexity were administered. Finally, the original 20 VE spatial rotation trials were readministered to measure "within-VE task" performance changes in spatial rotation ability. For the practice trials, subjects were oriented and instructed as follows: "This task involves manipulating objects. Notice when you rotate the ball, the object rotates. When you move it, the object also moves on the screen. A target object will appear on the screen. Your goal is to superimpose the control object onto the target object. When that is complete, a new target object will appear and you should do the same as in the previous trial." More details on the rationale and procedure for the spatial rotation task can be found in a previous paper.⁶⁵

Research Questions

1. As previously discussed, the possibility of side effects is an important ethical issue to consider when utilizing any new technology with potentially "at risk" populations. One of our initial concerns was the extent to which VE-related side effects would occur when older adults utilized the VE system

and to what extent an age-specific profile of side effects would emerge. Our other primary concern was to determine whether the occurrence of side effects was low enough to justify future VE trials aimed at testing persons with dementia, traumatic brain injury, and individuals with other neurological impairments.

2. Establishing the statistical reliability and validity of any new assessment tool is vital to its usability. We sought to determine the relationship between various tasks on the VE system and performance on standard neuropsychological tests in the domains of attention, executive functioning, memory, language, and visuospatial processes.
3. Presence, or an individual's sense of being somewhere other than where they are physically, may be related to task performance in VE systems. We are aiming to further study this issue in the current project with healthy older adults in our visuospatial system.
4. The value of most assessment and/or rehabilitation tools exists to the degree in which measurable performance status or changes are transferable, or generalizable, to real world activities. We plan to investigate generalizability in older adults on the VE spatial rotation task by examining pre and post measures of the pencil and paper MRT. It is hypothesized that performance will improve after practice using the virtual spatial rotation task.
5. Age and gender differences in cognitive performance have been reported throughout the literature. We plan to examine the impact of these variables on performance results on the suite of visuospatial tasks presented in the VE system.

DISCUSSION

This study represents an initial attempt to address the feasibility of utilizing VE technology to assess normal older adult participants (age 65+). Although we are in the data analysis phase of this project, one initial observation can be made: older adult participants experienced minimal side effects and reported favorable responses to the current system. There

were no increases in self-reported negative symptoms pre- to post-exposure for subjects in the VE that was based on SSQ data. These encouraging results provide an incentive for future trials with older persons who have neurological disorders such as Alzheimer's disease, Parkinson's disease, stroke-related illness, and TBI.

Our long-range goal is to develop a comprehensive VE visuospatial assessment and rehabilitation system delivered on a large-screen desktop system, using Crystal Eyes shutter glasses. A comparative test may be run to determine if these scenarios can be successfully delivered on a less expensive and more accessible platform. The aim of this being toward the packaging of a suite of VE-delivered 3D testing and training tools that could target the NA/CR of visuospatial processes for use by researchers and clinicians. Correspondence and questions regarding the ongoing status of our work and updates on current statistical analyses are welcome at arizzo@usc.edu.

REFERENCES

1. Adams, P.F., & Benson, V. (1992). Current estimates from the National Health Interview Survey, 1991 (*Vital and Health Statistics, Series 10, No. 184*). Hyattsville, MD: National Center for Health Statistics.
2. Lezak, M.D. (1995). *Neuropsychological assessment*. New York: Oxford University Press.
3. Parente, R., & Hermann, D. (1996). *Retraining cognition: Techniques and applications*. Gaithersburg, MD: Aspen Publishing, Inc.
4. Sohlberg, M.M., & Mateer, C.A. (1989). *Introduction to cognitive rehabilitation: Theory and practice*. New York: The Guilford Press.
5. Rizzo, A., Buckwalter, J., Neumann, U., Kesselman, C., & Thiebaut, M. (1998). Basic issues in the application of virtual reality for the assessment and rehabilitation of cognitive impairments and functional disabilities. *Cyberpsychology and Behavior* 1:59-78.
6. Rizzo, A., Wiederhold, M., & Buckwalter, J. (1998). Basic issues in the use of virtual environments for mental health applications. In Riva, G., Wiederhold, B.K., & Molinari, E. (eds.) *Virtual environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-therapist interaction*. Amsterdam: IOS Press, pp. 21-42.
7. Riva, G. (1998). Virtual reality in neuroscience: A survey. In Riva, G., Wiederhold, B.K., & Molinari, E. (eds.), *Virtual environments in clinical psychology and neuroscience: Methods and techniques in advanced patient-*

- therapist interaction. Amsterdam: IOS Press, pp. 191–199.
8. Rose, F. (1996). Virtual reality in rehabilitation following traumatic brain injury. In Sharkey, P. (ed.) *Proceedings on the First European Conference on Disability, Virtual Reality and Associated Technology*. Maidenhead, UK: University of Reading, pp. 5–12.
 9. Neisser, U. (1978). What are the important questions? In Gruneberg, M., Morris, P., & Sykes, R. (eds.) *Practical aspects of memory*. London: Academic Press, pp. 3–24.
 10. Liu, L., Watson, B., & Miyazaki, M. (1999). VR for the elderly: Quantitative and qualitative differences in performance with a driving simulator. *Cyberpsychology and Behavior* 2(6):567–576.
 11. Jaffe, D.L. (1998). *Use of virtual reality techniques to train elderly people to step over obstacles*. Paper presented at the Technology and Persons with Disabilities Conference, Los Angeles, CA.
 12. Mead, S.E., Spaulding, V.A., Sit, R.A., Meyer, B., & Walker, N. (1997). Effects of age and training on world wide web navigation strategies. *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, pp. 152–157.
 13. Czaja, S.J. (1996). Aging and the acquisition of computer skills. In Rogers, W.A., Fisk, A.D., Walker, N. (eds.) *Aging and skilled performance*. Mahwah, NJ: Lawrence Erlbaum Associates, pp. 201–220.
 14. Rizzo, A.A., Buckwalter, J.G., van der Zaag, C., Neumann, U., Thiebaut, M., Chua, C., van Rooyen, A., & Larson, P. (in press). Virtual Environment applications in neuropsychology. *Proceedings of the IEEE Virtual Reality 2000 Conference*. IEEE Press: Los Alamitos, CA.
 15. Folstein, M.F., Folstein, S.E., & McHugh, P.R. (1975). "Mini mental state": A practical method for grading the cognitive status of outpatients for the clinician. *Journal of Psychiatric Research* 12:198–198.
 16. Neugarten, B.L. (1977). Personality and aging. In Birren, J.E., & Schaie, K.W. (eds.) *Handbook of psychology of aging*. New York: Van Nostrand Reinhold.
 17. Whitbourne, S. (1998). Physical changes in the aging individual. In Nordhus, I.H., Vandenbos, G.R., Berg, S., Fromholt, P. (eds.) *Clinical geropsychology*. Washington, DC: American Psychological Association.
 18. Moses, R.A. (1981). Accommodation. In Moses, R.A. (ed.) *Adler's physiology of the eye*. St. Louis, MO: Mosby.
 19. Mancil, G.L., & Owsley, C. (1988). "Vision through my aging eyes" revisited. *Journal of the American Optometric Association* 59:288–294.
 20. Kline, D.W. (1994). Optimizing the visibility of displays for older observers. *Experimental Aging Research* 20:11–23.
 21. Cavanaugh, J.C. (1997). *Adult development and aging* (3rd ed). Pacific Grove, CA: Brooks/Cole.
 22. Yetka, A.A., Pickwell, L.D., & Jenkins, T.C. (1998). Binocular vision: Age and symptoms. *Ophthalmic Physiological Optics* 9:115–120.
 23. Lebo, C.P., & Reddell, R.C. (1972). The presbycusis component in occupational hearing loss. *Laryngoscope* 82:1399–1409.
 24. Toglia, J.U. (1975). Dizziness in the elderly. In Fields, W. (ed.) *Neurological and sensory disorders in the elderly*. New York: Grune & Stratton.
 25. Anderson, D.C., Yolton, R.L., Reinke, A.R., & Kohl, P. (1995). The dizzy patient: A review of etiology, differential diagnosis, and management. *Journal of the American Optometric Association*.
 26. Segal, D., Coolidge, F.L., & Hersen, M. (1998). Psychological testing of older people. In: Nordhus, I.H., Vandenbos, G.R., Berg, S., & Fromholt, P. (eds.) *Clinical geropsychology*. Washington, DC: APA.
 27. Verbrugge, L.M., Kepkowski, J.M., & Konkol, L.L. (1991). Levels of disability among U.S. adults with arthritis. *Journal of Gerontology: Social Sciences* 46:S71–S83.
 28. Vandervoort, A.A., Chesworth, B.M., Cunningham, D.A., Peterson, D.H., Rechnitzer, P.A., & Koval, J.J. (1992). Age and sex effects on mobility of the human ankle. *Journal of Gerontology: Medical Sciences* 47:M17–M21.
 29. Kennedy, R.S., Berbaum, K.S., & Drexler, J. (1994). Methodological and measurement issues for the identification of engineering features contributing to virtual reality sickness. *Paper presented at: Image 7 Conference*. Tucson, AZ.
 30. Reason, J.T. (1970). Motion sickness: A special case of sensory rearrangement. *Advancement in Science* 26:386–393.
 31. Kennedy, R.S., Stanney, K.M., Ordy, J.M., & Dunlap, W.P. (1997). Virtual reality effects produced by heads-mounted display (HMD) on human eye-hand coordination, postural equilibrium, and symptoms of cybersickness. *Society for Neuroscience Abstracts* 23:772.
 32. Lawson, B.D., Rupert, A.H., Guedry, F.E., Grissett, J.D., & Mead, A.M. (1997). The human-machine interface challenges of using virtual environment (VE) displays aboard centrifuge devices. In Smith, M., Salvendy, G., & Koubek, R. (eds.) *Design of computing systems: Social and ergonomic considerations*. Amsterdam: Elsevier Science Publishers, pp. 945–948.
 33. Rolland, J.P., Biocca, F.A., Barlow, T., & Kancherla, A. (1995). Quantification of adaptation to virtual-eye location in see-thru head-mounted displays. *Proceedings of the IEEE Computer Society Press: Los Alamitos, CA*.
 34. DiZio, P., & Lackner, J.R. (1992). Spatial orientation, adaptation, and motion sickness in real and virtual environments. *Presence: Teleoperators and Virtual Environments* 1:323.
 35. Kennedy, R.S., & Stanney, K.M. (1996). Postural instability induced by virtual reality exposure: Development of certification protocol. *International Journal of Human-Computer Interaction* 8:2547.
 36. Wann, J.P., Rushton, S.K., & Mon-Williams, M. (1995). Natural problems for stereoscopic depth perception in virtual environments. *Vision Research* 19:2731–2736.
 37. Hettlinger, L.J. (1992). Visually induced motion sick-

- ness in virtual environments. *Presence: Teleoperators and Virtual Environments* 1:306–307.
38. Kennedy, R.S., Lane, N.E., Lilienthal, M.G., Berbaum, K.S., & Hettinger, L.J. (1992). Profile analysis of simulator sickness symptoms: Application to virtual environment systems. *Presence: Teleoperators and Virtual Environments* 1:295–301.
 39. Regan, E., & Price, K.R. (1994). The frequency of occurrence and severity of side-effects of immersion virtual reality. *Aviation, Space, & Environmental Medicine* 65:527–530.
 40. Kolasinski, G. (1995). *Simulator sickness in virtual environments (Tech Report 1027)*. Orlando: United States Army Research Institute for the Behavioral and Social Sciences.
 41. Liu, L., Miyazaki, M., & Watson, B. (1999). Norms and validity of the DrIVR: A virtual reality driving assessment for persons with head injuries. *Cyberpsychology and Behavior* 2:53–68.
 42. Rose, F.D., Brooks, B.M., Attree, L.A., Parslow, D.M., Leadbetter, A.G., McNeil, J.E., Jayawardena, S., Greenwood, R.J., Potter, J. (in press). A preliminary investigation into the use of virtual environments in memory retraining of stroke patients: Indications for future strategy? *Disability and Rehabilitation*.
 43. De Renzi, E. (1985). Disorders of spatial orientation. In Frederiks, J. (ed.) *Handbook of Clinical Neurology*, Vol. 1 Amsterdam: Elsevier, pp. 405–422.
 44. Previc, F. (1998). The neuropsychology of 3-D space. *Psychological Bulletin*, 124(2):123–164.
 45. Carpenter, P., & Just, M. (1986). Spatial ability: An information processing approach to psychometrics, In Sternberg R.J. (ed.) *Advances in the Psychology of Human Intelligence (third edition)*. Hillsdale, NJ: Erlbaum, pp. 221–253.
 46. Kolb, B., & Wishaw, I.Q. (1990). *Fundamentals of human neuropsychology (third edition)*. New York: W.H. Freeman and Company.
 47. Evans, D.A. (1989). Prevalence of Alzheimer's disease in a community of older persons. *Journal of the American Medical Association* 226:2551–2556.
 48. Storandt, M., & VandenBos, G. (1997). Neuropsychological assessment of dementia and depression in older adults: A clinician's guide. Washington, DC: American Psychological Association.
 49. Henderson, V.W., Mack, W., & Williams, B.W. (1989). Spatial disorientation in Alzheimer's disease. *Archives of Neurology* 46:391–394.
 50. Moore, V., & Wyke, M. (1984). Drawing disability in patients with senile dementia. *Psychological Medicine* 14:97–105.
 51. Rouleau, I., Salmon, D.P., Butters, N., Kennedy, C., & McGuire, K. (1992). Quantitative and qualitative analysis of clock drawings in Alzheimer's and Huntington's disease. *Brain and Cognition* 18:70–87.
 52. Flicker, C., Ferris, S.H., Crook, T., Reisberg, B., & Bartus, R. (1988). Equivalent spatial rotation deficits in normal aging and Alzheimer's disease. *Journal of Clinical and Experimental Neuropsychology* 10(4):387–399.
 53. Miller, B.L., Ikonte, C., Ponton, M., Levy, M., Boone, K., Darby, A., Berman, N., Mena, I., Cummings, J.L. (1997). A study of the Lund-Manchester research criteria for frontotemporal dementia: Clinical and single-photon emission CT correlations. *Neurology* 48:937–942.
 54. Corin, M.S., Elizan, T.S., & Bender, M.B. (1972). Oculomotor function in patients with Parkinson's disease. *Journal of Neurological Sciences* 15:251–265.
 55. Hotson, J.R., Langston, E.B., & Langston, J.W. (1986). Saccade responses to dopamine in human MPTP-induced Parkinsonism. *Annals of Neurology* 20:456–463.
 56. Berkinblit, M.B., Fookson, O.I., Smetanin, B., Adamovich, S.V., & Poizner, H. (1995). The interaction of visual and proprioceptive inputs in pointing to actual and remembered targets. *Experimental Brain Research* 107:326–330.
 57. Gresham, G., Duncan, P., Stason, W. (1995). *Post-Stroke Rehabilitation. Clinical Practice Guideline No. 16*. (AHCPR Publication No. 95-0662) Rockville, MD: US Department of Health and Human Services.
 58. Dimitrov, M., Grafman, J., Kosseff, P., Wachs, J., Alway, D., Higgins, J., Litvan, I., & Lou, J-S., Hallett, M. (1996). Preserved cognitive processes in cerebellar degeneration. *Behavioral Brain Research* 79:131–135.
 59. Rizzo, A., Buckwalter, J.G., & van der Zaag, C. (in press). *Virtual environment applications in clinical neuropsychology. The Handbook of Virtual Environments*. New York: L.A. Erlbaum.
 60. Morris, R.G.M. (1981). Spatial localization does not require the presence of local cues. *Learning and Motivation* 12:239–260.
 61. Thomas, G.F., Laurance, H.E., Luczak, S.E., & Jacobs, W.J. (1999). Age related changes in a human cognitive mapping system: Data from a computer-generated environment. *CyberPsychology and Behavior* 2(6):545–566.
 62. Stanton, D., Foreman, N., & Wilson, P.N. (1998). Uses of virtual reality in clinical training: Developing the spatial skills of children with mobility impairments. In Riva, G., Wiederhold, B., & Molinari, E. (eds.) *Virtual reality in clinical psychology and neuroscience*. Amsterdam: IOS Press, pp. 219–232.
 63. McComas, J., Pivik, J., & Laflamme, M. (1998). Children's transfer of spatial learning from virtual reality to real environments. *CyberPsychology and Behavior* 1(2):121–128.
 64. Cromby, J.J., Standen, P.J., & Brown, D.J. (1996). The potential of virtual environments in the education and training of people with learning disabilities. *Journal of Intellectual Disabilities Research* 40(6):489–501.
 65. Larson, P.A., Rizzo, A.A., Buckwalter, J.G., van Rooyen, A., Kratz, K., Neumann, U., Kesselman, C., Thiebaut, M., & van der Zaag, C. (1999). Gender issues in the application of a virtual environment spatial rotation project. *Cyberpsychology and Behavior* 2:2.
 66. Rizzo, A.A., Buckwalter, J.G., Larson, P., Van Rooyen, A., Kratz, K., Neumann, U., Kesselman, C., & Thiebaut, M. (1998). Preliminary findings on a virtual

- environment targeting human mental rotation/spatial abilities. *Proceedings of The 2nd European Conference on Disability, Virtual Reality and Associated Technologies*. Sweden: University of Reading, pp. 213–219.
67. Shepard, R.N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science* 171:701–703.
 68. Vandenberg, S.G., & Kuse, A.R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills* 47:599–604.
 69. Wraga, M., Creem, S.H., & Proffitt, D.R. (1997). Imagined Viewer vs. Object Rotations: Is Mental Rotation a General Ability? Online document: <http://www.Virginia.EDU/~perlab/presenta.html>.
 70. Trepagnier, C. (1999). Virtual environments for the investigation and rehabilitation of cognitive and perceptual impairments. *NeuroRehabilitation* 12:63–72.
 71. Alpini, D., Pugnetti, L., Mendozzi, L., Barbieri, E., Monti, B., & Cesarani, A. (1998). Virtual Reality in vestibular diagnosis and rehabilitation. In Sharkey, P., Rose, D., & Lindstrom, J. (eds.) *Proceedings of the European Conference on Disability, Virtual Reality and Associated Techniques* (pp. 221–228). Sweden.
 72. Jacewicz, M.M., & Hartley, A.A. (1987). Rotation of mental images by young and old college students: The effects of familiarity. *Journal of Gerontology* 24:396–403.
 73. Dollinger, S.M.C. (1995). Mental rotation performance: Age, sex, and visual field differences. *Developmental Neuropsychology* 11:215–222.
 74. Dobson, S.H., Kirasic, K.C., & Allen, G.L. (1995). Age-related differences in adults' spatial task performance: Influences of task complexity and perceptual speed. *Aging and Cognition* 2:19–38.
 75. Wiederholt, W.C., Cahn, D., Butters, N.M., Salmon, D.P., Krtiz-Silverstein, D., & Barret-Conner, E. (1993). Effects of age, gender, and education on selected neuropsychological tests in an elderly community cohort. *Journal of the American Geriatric Society* 41:639–647.
 76. Trahan, D.E., & Quintana, J.W. (1990). Analysis of gender effects upon verbal and visual memory performance in adults. *Archives of Clinical Neuropsychology* 5:325–334.
 77. Rosselli, M., & Ardila, A. (1991). Effects of age, education and gender on the Rey-Osterrieth Complex Figure. *Clinical Neuropsychology* 5:370–376.
 78. Mitrushina, M., & Satz, P. (1990). Cardiovascular status and other factors in speed of mental processes. *Brain Dysfunction* 3:151–155.
 79. Armstrong, L., & Walker, K. (1994). Preliminary evidence on the question of gender differences in language testing of older people. *European Journal of Disorders in Communication* 29:371–378.
 80. Voyer, D., Voyer, S., & Bryden, M.P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin* 117:250–270.
 81. Rizzo, A., Buckwalter, J.G., Henderson, V., Murdock, G., McCleary, C. (Unpublished Manuscript). Gender and spatial ability in non-demented elderly.
 82. Welsh, K.A., Breitner, J.C.S., & Magruder-Habib, K.M. (1993). Detection of dementia in the elderly using telephone screening of cognitive status. *Neuropsychiatry, Neuropsychology, and Behavioral Neurology* 6:103–110.
 83. Briggs, G.G., & Nebes, R.D. (1975). Patterns of hand preference in a student population. *Cortex* 11:230–238.
 84. Witmer, B.G., & Singer, M.J. (1998). Measuring presence in virtual environments. A presence questionnaire. *Presence: Teleoperators and Virtual Environments* 7(3):225–240.
 85. Tellegen, A., & Atkinson, G. (1974). Openness to absorbing and self-altering experiences ("absorption"), a trait related to hypnotic susceptibility. *Journal of Abnormal Psychology* 83:268–277.
 86. Kennedy, R.S., & McCauley, M.E. (1984). *The motion history questionnaire*. Orlando, FL: Essex Corporation.
 87. Blair, J.R., & Spreen, O. (1989). Predicting premorbid IQ: A revision of the National Adult Reading Test. *The Clinical Neuropsychologist* 3:129–136.
 88. Morris, J.C., Heyman, A., Mohs, R.C., et al. (1989). The consortium to establish a registry for Alzheimer's Disease (CERAD). Part I. Clinical and neuropsychological assessment of Alzheimer's disease. *Neurology* 39:1159–1165.
 89. Delis, D.C., Kramer, J.H., Kaplan, E., & Ober, B. (1983). *California Verbal Learning Test*. New York: Psychological Corporation.
 90. Wechsler, D. (1997). *Wechsler Adult Intelligence Scale—III*. New York: The Psychological Corporation.
 91. Benton, A.L., Varney, N.R., & Hamsher, K.S. (1978). Visuospatial judgment: A clinical test. *Archives of Neurology* 35:364–367.
 92. Wechsler, D. (1997). *Wechsler Memory Scale-III*. New York: The Psychological Corporation.
 93. Army Individual Test Battery. (1944). *Manual of directions and scoring*. Washington, DC: War Department, Adjutant Generals Office.
 94. Schenkenberg, T., Bradford, D.C., & Ajax, E.T. (1980). Line bisection and unilateral visual neglect in patients with neurologic impairment. *Neurology* 30:509–517.
 95. Derogatis, L. (1983). *The Symptom Checklist-90-R*. Towson, MD: Clinical Psychometric Research.
 96. Kennedy, R.S., Lande, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology* 3: 203–220.
 97. Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance. *Brain and Cognition* 28:39–58.

Address reprint requests to:
 Albert A. Rizzo, Ph.D.
 Integrated Media Systems Center
 University of Southern California
 3715 McClintock Avenue
 Los Angeles, CA 90089-0191

E-mail: arizzo@usc.edu