Virtual reality applications for the assessment and rehabilitation of attention and visuospatial cognitive processes: an update

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ABSTRACT

Virtual Reality (VR) technology offers potential for sophisticated new tools that could be applied in the areas of neuropsychological assessment and cognitive rehabilitation. If empirical studies demonstrate effectiveness, virtual environments (VEs) could be of considerable benefit to persons with cognitive and functional impairments due to traumatic brain injury, neurological disorders, and learning disabilities. Testing and training scenarios that would be difficult, if not impossible, to deliver using conventional neuropsychological methods are now being developed to take advantage of the attributes of VEs. VR technology allows for the precise presentation and control of dynamic multi-sensory 3D stimulus environments, as well as the recording of all behavioral responses. This paper will focus on the progress of a VR research program at the University of Southern California that has developed and investigated the use of a series of VEs designed to target: 1. Molecular visuospatial skills using a 3D projection-based ImmersaDesk system. and 2. Attention (and soon memory and executive functioning) processes within ecologically valid functional scenarios using a Virtual Research V8 Head Mounted Display (HMD). Results from completed research, rationales and methodology of works in progress, and our plan for future work will be discussed. Our primary vision has been to develop VR systems that target cognitive processes and functional skills that are of relevance to a wide range of patient populations with CNS dysfunction. We have also sought to select cognitive/functional targets that intuitively appear well matched to the specific assets available with the VR equipment that is available for our use.

1. INTRODUCTION

We are experiencing the emergence of an information society, increasingly based on the production and exchange of information. As this vision unfolds, those who are able to thoughtfully develop and apply evolving computer and information technology (CIT), will be in a position to impact fundamental changes for advancing human welfare. In order to maximize the potential benefits of this paradigm shift for those with special needs it is necessary to focus efforts on the development and application of more usable and accessible CIT. This direction fits well with the "Information Society for All" concepts that have recently been addressed in the human-computer interaction literature (Stephanidis & Salvendi, et al, 1999). Efforts in this area support the development of CIT that accommodates the broadest range of human abilities, skills, requirements and preferences. The potential results of such efforts could substantially redefine the

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assessment and rehabilitative strategies that are used with clinical populations. One form of CIT that has shown considerable promise for clinical application is Virtual Reality.

Virtual Reality (VR) is rapidly evolving into a pragmatically usable technology. With continuing advances in the areas of computing power, graphics and image capture, display technology, interfacing tools, immersive audio, haptics, wireless tracking, voice recognition, intelligent agents, and VR authoring software, more powerful, naturalistic and usable Virtual Environments (VEs) will become possible. Concurrent with these technological developments, scientists and clinicians have recognized VR's potential as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities (Brown et al, 1997; Pugnetti et al, 1995; Rizzo & Buckwalter, 1997; Rose, 1996). Much like an aircraft simulator serves to test and train piloting ability, VEs can be developed to present simulations that target human cognition and behavior in normal and impaired populations. Individuals who may benefit from these applications include persons with cognitive and functional impairments due to traumatic brain injury (TBI), neurological disorders, and developmental/learning disabilities. The capacity of VR technology to create dynamic, multi-sensory, three-dimensional (3D) stimulus environments, within which all behavioral responding can be recorded, offers clinical assessment and rehabilitation options that are not available using traditional neuropsychological methods. In this regard, a growing number of laboratories are developing research programs investigating the use of VEs for these purposes and initial exploratory studies reporting encouraging results have begun to emerge (Rizzo et al, in press). This work has the potential to advance the scientific study of normal cognitive and behavioral processes, and to improve our capacity to understand, measure, and treat the impairments typically found in clinical populations with central nervous system (CNS) dysfunction.

VR applications are now being developed and tested which focus on component cognitive processes including: attention, executive functions, memory, and spatial abilities. Functional VE training scenarios have also been designed to test and teach instrumental activities of daily living such as street-crossing, automobile driving, meal preparation, supermarket shopping, use of public transportation, and wheelchair navigation. More involved discussion of the rationales, issues and application of VR for neuropsychological targets can be found in a number of previous papers (Rizzo & Buckwalter, 1997; Rizzo et al, in press). These initiatives have formed a foundation of work that provides support for the feasibility and potential value of further development of neuropsychological VE applications. The success of these VE scenarios give hope that the 21st century will be ushered in with new and exciting tools to advance a field that has long been mired in the methods of the past. Additionally, the emergence of PC-powered VEs that are less expensive, yet still well rendered and responsive, will result in more readily available systems and support more widespread VR application. Improved access to VR technology would promote both clinical goals and the independent replication of research findings needed for scientific progress in this field. As well, major funding agencies in the USA have realised the potential value of effort in these areas. For example, on a more global level the National Science Foundation stated in a recent VR program announcement that, "…Computer simulation has now joined theory and experimentation as a third path to scientific knowledge. Simulation plays an increasingly critical role in all areas of science and engineering . . . " (p.1) (NSF PA# 98-168). More specific to the application of VR in neuropsychology, the National Institute on Disability and Rehabilitation Research (NIDRR) in a recent position statement highlighted that, "…The benefits of combining virtual reality with rehabilitation interventions are potentially extensive…" and specifically calls for research "….to determine the efficacy of virtual reality techniques in both rehabilitation medicine and in applications that directly affect the lives of persons with disabilities" (NIDRR webpage, August 24, 1999).

In view of the above issues, this article will focus on the progress of a VR research program at the University of Southern California that has developed and investigated the use of a series of VEs designed to target the assessment and rehabilitation of cognitive and functional processes. Results from completed research, rationales and methodology of works in progress, and our plan for future work will be discussed. Our primary vision has been to develop VR systems that target cognitive processes and functional skills that are of relevance to a wide range of patient populations with CNS dysfunction. We have also sought to select cognitive/functional targets that intuitively appear well matched to the specific assets available with the VR equipment that is available for our use. Consequently, we have evolved two parallel programs: 1. The targeting of molecular visuospatial skills using a 3D projection-based ImmersaDesk system. and 2. The targeting of attention (and soon memory and executive functioning) processes within ecologically valid functional scenarios using a Virtual Research V8 Head Mounted Display (HMD). At the time of the initial development of these applications, we used SGI Onyx systems to render and interact with the scenarios. However, we have begun the process of transferring the scenarios to a PC platform in view of the rapid advances that have occurred in this area lately and due to the desire to develop more economical systems that could reach a wider range of potential users.

2. VISUOSPATIAL APPLICATIONS

We have developed a component-based approach for addressing visuospatial ability through the use of a suite of ImmersaDesk-delivered (see Figure 1) three dimensional (3D) applications targeting mental rotation (MR), depth perception, field dependence (3D rod and frame test), static and dynamic manual tracking, and visual field specific reaction time. These scenarios were designed to leverage the 3D interactive assets available with this type of projection-based system in the development of a series of tasks that could assess and possibly rehabilitate these more molecular components of visuospatial functioning. Generally, spatial ability is an important domain to consider in the assessment of neurological disorders, traumatic brain injury, and neuropathological conditions of aging. For example, spatial orientation abilities are an important variable in the differential diagnosis of dementia. Research indicates that victims of Alzheimer's disease have an 84% incidence of spatial orientation impairments compared to only a 4% incidence in frontotemporal dementia (Miller et al, 1997). Impairments in spatial orientation were also shown to be more common in Alzheimer's disease compared to both normal elderly and those with vascular dementia (Gianotti et al, 1992; Signorino et al, 1996). Similar impairments have been observed following the occurrence of traumatic brain injury and stroke (Lezak, 1995). Tests of spatial ability, including the MR variable, are also commonly used for the study of brain/behavior relationships, particularly regarding sex differences in cognition. Mental rotation ability produces the most consistent and sizeable sex differences, in favor of males, in the cognitive literature (Voyer et al, 1995). Consequently, a lively literature has emerged examining MR, as well as with other cognitive variables where female advantages appear (i.e., verbal fluency and fine motor skills among others). Studies have reported differential cognitive performance due to such hormonal factors as onset of menopause, estrogen and testosterone administration, and stage of the menstrual cycle (Gouchie and Kimura, 1991; Kampen and Sherwin, 1994; Silverman and Phillips, 1993). However, these findings remain controversial. Several studies have attempted to explain cognitive sex differences as the product of sociocultural influences, and on non-specific testing performance factors related to the use of timed tests and "reluctance to guess" factors (Richardson, 1994; Qubeck, 1997; Delgado and Prieto, 1996). Also, it has also been suggested that the effect size in gender differences has been decreasing in recent years. However, meta-analytic research has argued against these conclusions (Masters and Sanders, 1993; Voyer et al, 1995). These issues, (which are ongoing research interests at our lab within the USC Alzheimer's Disease Research Center), and our interest in the potential usefulness of VR, motivated our development of the Virtual Reality Mental Rotation/Spatial Skills Project.

2.1 Brief Review of Initial Mental Rotation Study with Young Adults

Our initial study focused on the development of a VE for the study, assessment, and rehabilitation of a visuospatial ability referred to as Mental Rotation (MR). MR was targeted via a manual spatial rotation task that required subjects to manipulate block configurations within a VE. MR is a well-studied visuospatial variable, which can be described as a dynamic imagery process that involves "turning something over in one's mind" (Shepard and Metzler , 1971). Everyday life situations rely on this ability to use imagery to turn over or manipulate objects mentally. These include automobile driving judgements, organizing items in limited storage space, using a map, sports activities, and many other situations where one needs to visualize the movement and ultimate location of physical objects in 3D space. High-level mathematics performance has also been linked, in large part, to MR ability (Casey et al, 1995). Indeed, in a recent Los Angeles Times interview, it was noted that world renown physicist, Stephen Hawking, "…translates mathematics into geometry, and turns around geometrical shapes in his head." (Cole, 1998). The initial MR investigations began almost 30 years ago with the work of Shepard and Metzler (1971) who tachistoscopically presented pairs of two-dimensional perspective drawings to subjects and required them to make judgements as to whether the 3-D objects they portrayed, were the same or different (see Figure 2). A near perfect linear relationship was found between the amount of angle rotation difference between the pairs of objects, and the reaction time to decide whether or not the objects were the same or different. Since precise mathematical relationships between hypothesized mental representations and behavioral performance are relatively rare, MR has been the focus of much research. Traditional 2D measures for the assessment of mental rotation have produced intriguing findings, yet lack the precision needed to better understand this spatial ability. The most common test uses two-dimensional image stimuli that portray three-dimensional objects and requires mental processing of the stimuli without any motoric involvement (Vandenberg and Kuse, 1978). The use of VR for the assessment of visuospatial abilities supports greater control and description of 3D stimuli along with more precise measurement of responses. This should allow more accurate characterization of cognitive processes involved in visuospatial skills than afforded by standard measures. In addition, by examining changes in spatial performance following VE exposure, useful rehabilitation options may emerge.

In our initial VE feasibility study targeting MR we tested 18-40 year old males and females. Subjects were presented with a specific configuration of 3D blocks within a virtual environment (similar to Figure 2). The stimuli appear as “hologram-like” 3D objects floating above the projection screen and the participant manipulates the control object by grasping and moving a sphere shaped “cyberprop” which contains an Ascension “Flock of Birds” tracking device. The speed (time to complete) and efficiency (ratio of ideal to actual rotations) of their movements to superimpose a replica design upon the target was measured and recorded over 140 trials (20 pre/post test trials and 100 intervening training trials). All manner of angular disparity and rotational axis combinations were programmed into the system allowing for the hierarchical presentation of cognitive challenges. Upon successful superimposition of the control and target objects, a “correct” feedback tone was presented and the next trial began. A control group was also tested that were administered all facets of the experiment, except that they performed crossword puzzles in place of the VR interaction. Details on the relevance of this application and the specific methodological details of this work can be found in Rizzo et al, (1998). A number of encouraging findings emerged including minimal side effect occurrence, reasonable psychometric properties of the VE test, provocative relationships with standard NA tests, a lack of gender differences compared to the pencil and paper performance, training improvement and significant transfer of training with low initial MRT pencil and paper performers.

Figure 1. *ImmersaDesk 3D projection Display System.*

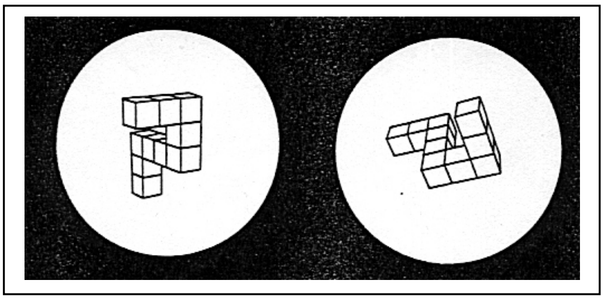

Figure 2. *Mental rotation stimuli.*

2.1.1 Side Effects. A split plot factorial ANOVA indicated that the interaction between group (VR and control) and occasion (pre and post testing) was significant for the amount of side effects reported. While the trend was for the VRSR group to report increased side effects, the trend for the control group to report fewer side effects also contributed to this interaction. Post hoc analyses of the VR group found that the only item where there was a significant increase at post testing was blurred vision.

2.1.2 Reliability. The VR-delivered MRT’s reliability was in the moderate range on calculations of internal consistency and matched parcel reliability. Typically, neuropsychology instruments boast reliability coefficients ranging from 0.80 to 0.95 (Mitrushina et al, 1999). Sattler (1988) asserts that a neuropsychology test’s reliability coefficient must approximate or exceed 0.80 in magnitude, while coefficients of 0.90 or above are considered the most desirable. The VR MRT’s reliability fell below this range with a Coefficient γ equal to 0.71 on its Speed Index and 0.73 for the Efficiency Index. Cronbach’s alpha for these indices were 0.65 and 0.69 respectively. However, our reliability findings do not negate the utility of this tool as a useful neuropsychological instrument. Nunnally and Bernstein (1993) contend that in the early stages of construct validation, it is still useful to investigate measures evidencing only modest reliability (i.e. .70). Furthermore, only after investigating whether corrections for attenuations will increase reliability is it useful to increase the number of items and reduce the measurement error in hopes of enhancing an instrument’s reliability. As a point of comparison, the test-retest reliability was .60 for the paper and pencil MRT. Thus, we interpret our findings to indicate that the VR MRT has potential as a reliable measure and will require further study.

2.1.3 Concurrent Validity. Pearson Product-Moment correlations between the VR time to complete (Speed Index) and all standard measures of neuropsychological functioning yielded a number of statistically significant effects. It was highly correlated with the Efficiency Index ($r = .76$, $p < .001$) and with the paper and pencil Mental Rotation Test (MRT) ($r = .45$, $p = .01$). It also correlated significantly with tests of visual memory under both immediate ($r = .50$, $p = .006$) and delayed ($r = .48$, $= .008$) conditions. There was a significant association with visual attention as measured by Trails A ($r = .38$, $p = .04$). There were also strong correlations with two measures of executive functioning one that includes a strong visuoconstructional component (Trails B; r = .46, p = .01, WAIS Block Design; r = .64, p < .001). Surprisingly, the Speed Index on VR MR testing also was associated with aspects of verbal learning notably the consistency of items recalled over the 5 trials of the California Verbal Learning Test (CVLT) (r = .52, p = .005) and the number of perseverations, or times when subjects repeated the same word. These findings may relate more to the ability to maintain concentration when presented with a large amount of new information (working memory) than to verbal memory per se. (Note that the direction of all correlations is such that slower completion time is associated with worse performance on each test) Correlations between the Efficiency Index and other neuropsychological tests were minimal. As reported above, Efficiency Index did correlate significantly with the Speed Index on the VR MRT. It also correlated significantly with one executive functioning test (WAIS Block Design) which requires manipulation of physical blocks.

A comparison of associations between the paper and pencil MRT with the other neuropsychological tests provides a useful reference point for interpreting the above correlations. The tests that correlated with the MRT are generally very consistent with the tests that correlated with the VR Speed Index with one notable exception. While performance on the Judgement of Line Orientation (JLO) was not associated with the VR MR testing, it was strongly correlated with the MRT. The JLO is a two-dimensional task that evaluates the ability to perceive spatial orientation. That it would be associated with the ability to mentally rotate two dimensional portrayals of 3D objects and not with the ability to physically manipulate 3D virtual objects suggests that one of the major cognitive components underlying ability on the MRT may relate to the person’s ability to construct and manipulate 3D images from two-dimensional perception and future investigations in this area are planned.

2.1.4 Sex Differences on Rotational Tasks. Men scored significantly better on the MRT given before the VR testing/training (p < .04). By contrast, there were no differences between men and women on either the Speed Index or the Efficiency Index of the VR testing (p’s > .8). Interestingly, the difference between men and women on the MRT after completing the VR training was no longer significant. The existence of gender differences on the MRT is well established but the mechanism for this difference is not identified. That women can manipulate and successful rotate 3D objects as efficiently as men while they cannot visualize the same process as well with 2D stimuli has potentially useful implications for understanding sex differences in brain functioning that influence cognition.

2.1.5 VR and Training/Transfer Issues. Subjects showed significant improvement on the VR testing after completing 100 training trials for both the Speed Index (p < .001) and Efficiency (p = .03). Subjects in the VR group showed a non-significant trend toward improved performance on the MRT (p < .06). When the changes in MRT performance between the VR and control group were compared by utilizing a split plot factorial ANOVA, the interaction between group and change over the two testing occasions was non-significant. This indicates that VR exposure did not have a specific effect on improving performance among *all* subjects. However, upon further inspection, this result may be in part due to a low ceiling for MRT performance with the subjects in this sample. Our sample of subjects was notable for performing much better on the MRT than is reported in studies with broader populations. If rotational skills can be trained, it would seem likely that individuals with high existing levels of rotational ability would be less likely to show improvement than individuals with less ability. In this regard, we examined how individuals who had relatively poor initial MRT scores perform after VR exposure. To directly test this, we divided subjects into groups, based on the MRT scores at the pre-testing. We used a cutpoint of 20 (out of a possible 40) to create a group of subjects with scores closer to those reported in other studies. Again using a split-plot factorial design, we found a significant (p <.02) interaction between group (VR and control), MRT group (≤ 20, > 20) and occasion (pre and post MRT) such that low scorers on the MRT who were in the VR group improved significantly more than other groups (see Figure 3).

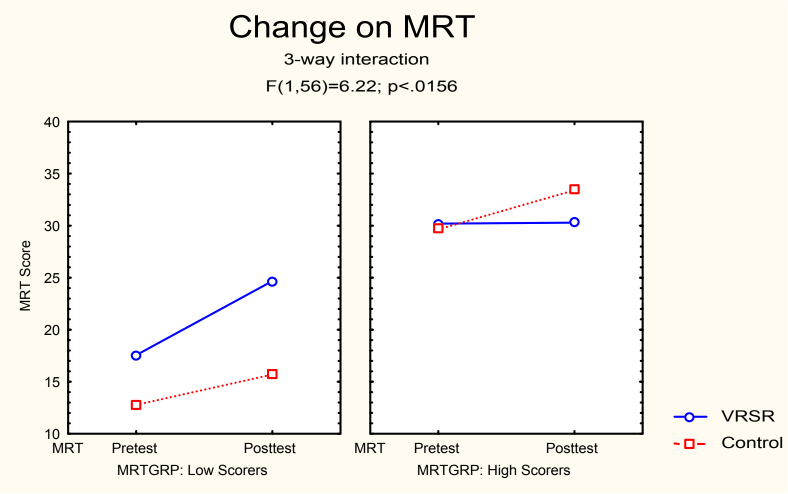

Figure 3. *Pre/Post Performance Changes on MRT with low/high initial performers for VR vs. Control groups.*

This leads to the intriguing suggestion that rotational skills can be trained in VR when they are relatively poor to begin with. This could have implications for cognitive rehabilitation strategies aimed at impaired populations. This experiment indicated that immersive VE-delivered physical rotation training with the MR stimuli may help improve imaginal mental rotation abilities. This assertion is bolstered by a recent study which concluded that rotary object manipulation and mental object rotation share a mutual process that is believed to direct the dynamics of both imagined and actual physical object reorientation (Wohlschlager and Wohlschlager 1998). By conducting additional studies on this VE system with the elderly, and persons with TBI or neurological disorders, the feasibility and effectiveness of this novel technology for assessment and rehabilitation purposes will be better understood.

2.1.6 Quasi-experimental Follow-up Study. Following this study, we conducted a quasi-experimental design investigation to collect pilot data on what factors may have mediated the performance improvement seen on the pencil and paper MRT following VR training in low initial performers. We videotaped one of the investigators performing well-trained executions of the 140 VR MR trials. The tape was shot in mono-mode (2D) and the resulting video presented crisp moving images of the blocks being successfully superimposed in a very efficient manner. Twenty-four college students (aged 18-36) were administered the MRT and then asked to watch the video tape, followed by administration of the same alternate form MRT as used in the previous study. In this manner, subjects *passively* observed the 2D representations being dynamically superimposed to determine if observation effects might produce equal performance increases as seen with the 3D active interaction study. These subjects had initial MRT scores that were similar those in our "MRT Under-20" sample and following simple video observation of 2D superimposition of block configurations, subject's performance mirrored the control group in the previous study with minimal and non-significant gains (2.3 points compared with an 8-point gain seen with the active VR group in the previous study). While these data are based on a less controlled quasi-experimental design approach, they are suggestive that MR training improvements in low initial performers may require the type of active interaction with 3D stimuli that is characteristic of VR training. A more controlled version of this study separately examining active vs. passive and 2D vs. 3D components is currently in the planning stage.

2.2 *Expanded VR Visuospatial System Experiment with Elderly Subjects*

Following the completion of the above study, we expanded our VR visuospatial system by developing a series of 3D scenarios to investigate depth perception, field dependence (3D rod and frame test), static/dynamic manual tracking, and visual field specific reaction time using the ImmersaDesk system. A battery of standard neuropsychological tests were administered to 30 healthy elderly male and female subjects (age 65-86) along with testing on the following VR scenarios (in addition to the spatial rotation task outlined above):

2.2.1 Visual Field-Specific Reaction Time Task. This series of tasks tested visual-field specific reaction time performance to stimuli that were presented in a consistent Left of Right location (regardless of shifts in the subjects' head position) via input from the tracking system contained in the *Crystal Eyes* stereoglasses. 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 (using the standard ImmersaDesk response wand) with their thumb as soon as they see the dot. They were told that they will respond best by fixating on the center "X" since they were not be able to anticipant when or from which side the stimulus will appear. Twenty blocks of ten trials were administered (200 trials) with participants instructed to switch between their left and right hands for alternate blocks of trials. A "water drop" sound was utilized to alert participants to the beginning of a series of 10 trials. The stimuli appear at six 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. This task provided a baseline of reaction time performance, and data on brain laterality factors that may underlie processing speed for these types of vigilance tasks.

2.2.2 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 standard ImmersaDesk response wand forwards and backwards in relation to the screen and to notice that this action moved one of the cubes towards 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) that subjects were able to interact with similar to the previous task. The final depth perception task involved two vertical lines (*vertical line* depth alignment). The participants were 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.

2.2.3 3D Field Dependency Task. To assess field dependency, a "3D virtual rod and frame test" was developed. A yellow frame seemingly afloat in space appeared on the screen along with a centered white rod, the orientation of which was controlled by the participant's wand movements. On each trial, the yellow frame was positioned slightly different from the one previous and the white bar appeared at a different orientation. Each participant was instructed to respond by pressing the button on the wand when they have positioned the white bar vertically or perpendicular to the floor regardless of the position of the frame. Five trials of this task were presented.

2.2.4 Manual 3D Tracking Task (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 were 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, intersecting 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. The *dynamic* 3D manual tracking task required the subject to keep a moving figure ("Tinkerbell") inside a blue 3D bubble (or orb) that was 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). The second task group consisted of 4 paths of different speeds and lengths. During this portion of the task, the figure's actions increased in speed, became increasingly erratic, and the level of difficulty increased for successful tracking. The entire dynamic 3D manual tracking task took approximately 85 seconds to complete.

The primary purpose of this work was to determine how well elderly individuals could perform these visuospatial tasks in VR, and then apply this healthy group's performance data as a reference sample for future comparisons with elderly persons with various forms of dementia, as well as with a younger sample (that is currently being tested) to determine age-related changes in visuospatial performance. We were also concerned with measuring the occurrence of VR side effects with this age-group and administered pre/post Simulator Sickness Questionnaires (Kennedy et al, 1993) to determine the feasibility of future VR applications with older adults. Gender differences in visuospatial performances and comparisons of results with standard visuospatial testing instruments are also of significant interest in this research. Aside from our motives to devise better visuospatial tools for diagnostic purposes, we are focusing on the added value of testing/training these cognitive processes using the dynamic 3D interactive assets that are available with VR compared to the static 2D tools that currently make up the bulk of traditional approaches in this area.

Thus far, preliminary analyses of this data have indicated a low occurrence of self-reported negative VR side effects. Additionally, sex differences (in favor of males) were found on standard visuospatial psychometric assessment tools. These include, pre-VR testing MRT (t(28) = 3.33, p = .002), post-VR MRT (t(28) = 2.75, p = .010), Judgement of Line Orientation (t(28) = 5.05, p = .000), WAIS-R Block Design (t(28) = 3.01, p = .006), Matrix Reasoning (t(28) = 2.04, p = .051) and WAIS-R Arithmetic (t(28) = 7.70, p = .001). Comparisons between the standard neuropsychological test results and VR performance testing is currently being analyzed and will be presented at the conference. At the time of this writing we have analyzed the "identical object" VR depth perception task and no male/female difference were found. One of our primary interests involves examining VR visuospatial performance to determine if females' performance *doesn't* differ from males, as found in our younger sample. This finding would be of value for later use of these VR tools for detecting visuospatial declines in women due to early-onset dementing conditions that may be masked on standard tests due to the generally lowered test performance seen in women.

We plan to follow up our current work with studies involving populations with CNS dysfunction (Alzheimer's, Stroke, TBI, etc.) and then develop a 3D desktop system using *Crystal Eyes* shutter glasses to run comparative tests to determine if these scenarios can be successfully delivered on a less expensive and more accessible platform. Our longer-term plan is to produce a suite of standardized VE-delivered 3D visuospatial assessment and rehabilitation tools and are currently designing new tasks to target 3D line bisection, figure/ground judgements and other perceptual reasoning targets for use by researchers and clinicians. Videotapes of the scenarios described above will be shown during the ICDVRAT 2000 conference presentation along with more evolved data analyses that are still in progress at the time of this writing. More detailed information on the rationale, equipment, and methodology for this work can be found in McGee et al, (2000).

Figure 4. *Scenes from the "Virtual Classroom" for Assessment of Attention Deficit Hyperactivity Disorder.*

3. ATTENTION PROCESS APPLICATIONS USING HMD'S

A second line of research that is being addressed in our lab concerns the development of a series of ecologically valid functional VEs that will serve as platforms for addressing a range of cognitive and functional processes. Our first effort in this direction is in the development of a HMD-delivered classroom scenario for the assessment and rehabilitation of attention processes (see figure 4). While this platform is ultimately envisioned to be capable of delivering cognitive testing and training protocols that could address other cognitive processes including memory and executive functions, we are initially targeting attention. Attention processes are the gateway to information acquisition and serve as a necessary foundation for most higher learning. Impairments in attention can be found in clinical populations across the lifespan and are commonly seen in persons with Attention Deficit Hyperactivity Disorder (ADHD), TBI, and as a feature of various forms of age-related Dementia (e.g., Alzheimer's Disease). Little VE work has been done with this "basic" gateway cognitive process thus far, which is surprising in view of the relative significance of attention impairments seen in a variety of clinical conditions. More effective assessment and rehabilitation tools are needed to address attention processes for a variety of reasons. In children, attention skills are the necessary foundation for future educational activities. Specific to ADHD, improved assessment of attention is vital for diagnostic purposes, special education placement decisions, determination of the use and effectiveness of pharmacological treatments, and for outcome measurement following interventions. Regarding TBI, even with mild trauma, these patients often suffer attention deficits that require focus as a precursor to rehabilitative work on higher cognitive processes (i.e., memory, executive functions, and problem solving). Also, even if higher processes are unable to be remediated in cases of severe TBI, some level of attention ability is essential for vocational endeavors, functional independence, and quality of life pursuits. With the elderly, a more fine-grained assessment of basic attention deficits may provide an early indicator of dementia-related symptoms, could suggest functional areas where an older person might be at risk (i.e., automobile driving, operating machinery, etc.), and guide development of compensatory strategies useful to maximize or maintain functional independence. HMDs are well suited for these types of applications as they present a controlled stimulus environment where cognitive/attention challenges can be administered along with the precise control of “distracting” auditory and visual stimuli. This level of experimental control may also allow for the development of attention assessment and rehabilitation tasks more similar to what is found in the real world.

Our first effort in this area has involved the development of a virtual “classroom” specifically aimed at the assessment of ADHD. VE technology appears to provide specific assets for addressing impairments seen in ADHD that are not available using existing methods. The scenario consists of a standard rectangular classroom environment containing desks, a male or female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a playground and street with vehicles and people, and on each end of the opposite wall, a pair of doorways through which activity occurs. Within this scenario, children’s attention performance is assessed while a series of typical classroom distracters (i.e., immersive audio supported ambient classroom noise, movement of other pupils, activity occurring outside the window, etc.) are systematically controlled and manipulated within the virtual environment. The child sits at a real desk while seeing a virtual desk in the HMD within the virtual classroom. On-task attention can be measured in terms of performance (reaction time) on a variety of attention challenges that can be adjusted based on the child’s expected age/grade level of performance. For example, on the simpler end of the continuum, the child can be required to press a response button upon the direct instruction of the virtual teacher or whenever the child hears the name of a specific target color mentioned by the teacher (*focused* or *selective* attention task). *Sustained* attention can be assessed by manipulating the time demands of the testing. More complex demands requiring *alternating* or *divided* attention can be developed whereby the student needs to respond only when the teacher states the target color in relation to an animal (i.e., the brown *dog,* as opposed to the statement, “ I like the color *brown*”) and only when the word “dog” is written, or a picture of a dog appears on the blackboard. In addition to attention-driven reaction time performance, behavioral measures that are correlated with distractibility and/or hyperactivity components (i.e., head turning, gross motor movement), and impulsive non-task behaviors (time playing with “distracter” items on the desk) can be measured via strategically located trackers. Our first study is presently comparing ADHD diagnosed children (aged 8-12) with a non-diagnosed control group using more basic attention challenges that are commonly seen on currently available continuous performance tasks and in common classroom tasks (listen-look-respond).

Figure 5. *The Virtual Office Scenario.*

This work is currently in progress and is in the user-centered design phase. In this phase we are testing children on basic selective and alternating attention tasks, soliciting their feedback pertaining to aesthetics and usability of the VE, and incorporating some of their comments into the actual iterative design-evaluate-redesign cycle. Thus far we have tested 10 non-diagnosed children (ages 6-12) and initial results indicate little difficulty in adapting to use of the HMD, no self-reported occurrence of side effects determined by post-interviews using the Simulator Sickness Questionnaire (Kennedy et al, 1993) and excellent performance on the stimulus tracking challenges. Our initial clinical trial is schedule to commence in August 2000. More detailed information on the rationale, equipment, and methodology for this project can be found in Rizzo et al, (2000).

Other scenarios (i.e., work situations, home environments, etc.,) using the same logic and approach are being conceptualized and developed to address cognitive/functional processes that are relevant for a range of other clinical populations. For example, we have now constructed a virtual “Office” environment that evolved from expanding some of the basic design elements of the Classroom VE (see Figure 5). As with the Classroom VE, the user will sit at a real desk, but within the HMD, they will see the scenes that make up the virtual "office". The virtual desk contains a phone, computer screen, and message pad, while throughout the office, a virtual clock ticks in real-time, and a variety of human avatar representations of co-workers/supervisors can be actively engaged. Various performance challenges can be delivered via the computer screen (visual mode), the phone (auditory mode), and from the avatar "supervisors" verbal directions. These commands can direct the user to perform certain functions within the environment that can be designed to assess and rehabilitate attention, memory, and executive functions. For example, to produce "prospective" memory challenges, the user might receive a command from the virtual supervisor to "turn-on" the computer at a specific time to retrieve a message that will direct a response. This will require the user to hold this information in mind, monitor the time via the wall clock and then initiate a response at the appropriate time. By adding multiple contingent commands, both attention and executive functioning can be addressed. As well, the influence of distraction can be tested or trained for via the presentation of ambient office sounds (i.e., radio announcements, conversations, etc.), activity occurring outside the window (cars rumbling by), or by producing extraneous stimuli on the desktop (i.e., irrelevant, yet "attention-grabbing" email messages appearing on computer screen). Essentially, functional work performance challenges typical of what occurs in the real world can be systematically presented in an ecologically valid VE. The variety of scenario complexity and potential usefulness of such a tool is only limited by the developer's imagination and a thoughtful informed assessment of the needs of the user! Such virtual environments underscore the challenges and opportunities that VR offers for the advancement of neuropsychological assessment and cognitive rehabilitation!

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