

Virtual Environments for the Assessment of Attention and Memory Processes: The Virtual Classroom and Office

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ABSTRACT

Virtual Reality (VR) technology offers new options for 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 that take advantage of the assets available with VR technology. These assets include the precise presentation and control of dynamic multi-sensory 3D stimulus environments, as well as advanced methods for recording behavioral responses. When combining these assets within the context of functionally relevant, ecologically valid VEs, a fundamental advancement emerges in how human cognition and functional behavior can be assessed and rehabilitated. This paper will focus on the progress of a collaborative VR research program at the University of Southern California and the Kessler Medical Rehabilitation Research and Education Corporation. These groups are developing and evaluating VR neuropsychological applications designed to target: 1. Attention processes in children with ADHD within a HMD virtual classroom and 2. Memory processes in persons with TBI within a HMD virtual office. 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 relevant 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 current state of VR technology.

Keywords: Virtual Reality, Attention, Memory, Neuropsychological Assessment, Cognitive Rehabilitation

1. INTRODUCTION

The Virtual Environments (VE) Laboratory at the Integrated Media Systems Center at the University of Southern California (USC) and the Kessler Medical Rehabilitation Research & Education Corp. (KMRREC) continue to evolve research programs aimed at developing virtual reality (VR) technology applications for the study, assessment, and rehabilitation of cognitive and functional processes. This work primarily focuses on the development of systems that address the needs of clinical populations with some form of central nervous system (CNS) dysfunction. These clinical populations include persons with cognitive and functional impairments due to acquired brain injury, learning disabilities and neurological conditions. The rationale for VR applications designed to serve these populations is fairly straightforward. By analogy, much like an aircraft simulator serves to test and train piloting ability under a variety of systematic and controlled conditions, VEs can be developed that create scenarios that may be similarly used to assess and rehabilitate human cognitive and functional processes. This work has the potential to improve our capacity to understand, measure, and treat the impairments typically found in clinical populations with CNS dysfunction as well as advance the scientific study of normal cognitive and functional/behavioral processes. The unique match between VR technology assets and the needs of various clinical application areas has been recognized by a number of authors (Rizzo et al., 1994; 1997; Pugnetti et al., 1995; Rose, 1996; Schultheis & Rizzo, 2001) and an encouraging body of research has emerged (Rizzo, Buckwalter and van der Zaag, 2002). What makes VR application development in this area so distinctively important is that it represents more than a simple linear extension of existing computer technology for human use. VR offers the potential to deliver systematic human testing and training simulation environments that allow for the precise control of complex, dynamic 3D stimulus presentations, within which sophisticated behavioral recording is possible. When combining these assets within the context of functionally relevant, ecologically valid VEs, a fundamental advancement emerges in how human cognition and functional behavior can be assessed and rehabilitated. This potential was recognized early on in a visionary article (“The Experience Society”) by VR pioneer, Myron Kruegar (1993), in his prescient statement that, “...Virtual Reality arrives at a moment when computer technology in general is moving from automating the paradigms of the past, to creating new ones for the future” (p. 163).

The following report will focus on the development and initial results of our on-going clinical trials using two Head Mounted Display (HMD) delivered VR scenarios: *The Virtual Classroom* and *The Virtual Office*. These scenarios are currently being used to assess attention performance in children with Attention Deficit Hyperactivity Disorder and in the assessment of memory in adults with acquired brain injury, stroke and multiple sclerosis. We will present a rationale for the development and application of each of the systems and a brief description of the methodology that is being applied in the research with these scenarios. Observations will be presented on initial user-centered design evaluation and we will review results from our initial trials with clinical populations. The results presented on the Virtual Classroom ADHD study are from a study conducted at USC and the Virtual Office research is currently being conducted at the KMRREC via a collaborative agreement with USC.

2. THE VIRTUAL CLASSROOM

2.1 Rationale for Application with ADHD

The Virtual Classroom is a HMD VR system for the study, assessment and possible rehabilitation of attention processes. Our efforts to target this cognitive process are supported by the widespread occurrence and relative significance of attention impairments seen in a variety of clinical conditions across the human lifespan. Most notably, attention difficulties are seen in persons with Attention Deficit Hyperactivity Disorders (ADHD), Acquired Brain Injury (ABI), and as a feature of various neurodegenerative disorders (i.e., Alzheimer’s Disease, Vascular Dementia, etc.). VR technology appears to provide specific assets for addressing these impairments that are not readily available using existing methods. VEs delivered via HMDs are well suited for these types of applications as they serve to provide a controlled stimulus environment where attention challenges can be presented along with the precise

delivery and control of “distracting” auditory and visual stimuli. This level of experimental control allows for the development of attention assessment/rehabilitation challenges that are more similar to what is found in the real world and could improve on the ecological validity of measurement and treatment in this area.

Our first project in the attention process domain has involved the development of a virtual “classroom” specifically designed for the assessment of Attention Deficit Hyperactivity Disorder (ADHD) in children. The heterogeneous features of ADHD, a behavioral disorder marked by inattention, impulsivity, and/or hyperactivity, have made consensus regarding its diagnosis difficult. Furthermore, traditional methods for assessing ADHD in children have been questioned regarding issues of reliability and validity. Popular behavioral checklists have been criticized as biased and not a consistent predictor of ADHD, and correlations between concordant measures of ADHD, such as parent and teacher ratings of hyperactivity, have been repeatedly shown to be modest at best and frequently low or absent (Abikoff et al., 1993; Barkley, 1990; Colegrove et al., 1999). Due to the complexity of the disorder and the limitations of traditional assessment techniques, diagnostic information is required from multiple types of ADHD measures and a variety of sources in order for the diagnosis to be given (American Psychological Association, 1994, Barkley, 1990; Greenhill, 1998). Thus, in the area of ADHD assessment where traditional diagnostic techniques have been plagued by subjectivities and inconsistencies, it was believed that an objective and reliable VR approach might add value over existing approaches and methods.

2.2 Structure of the VR Classroom Scenario

The scenario consists of a standard rectangular classroom environment containing desks, a female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a playground and street with moving vehicles, and on each end of the opposite wall, a pair of doorways through which activity occurs (see Figure 1). Within this scenario, children’s attention performance is assessed while a series of typical classroom distracters (i.e., ambient classroom noise, activity occurring outside the window, etc.) are systematically controlled and manipulated within the virtual environment. The child sits at a virtual desk within the virtual classroom and on-task attention is measured in terms of reaction time performance (using a wireless mouse) and error profiles on a variety of attention challenge tasks delivered visually using the virtual blackboard or auditorily via the teacher’s voice.

The system is run on a standard Pentium 3 processor with the nVIDIA G2 graphics card. The HMD used in this study was the V8 model from Virtual Research. Tracking of the head, arm and leg used three 6DF magnetic “Flock of Birds” trackers from Ascension Technology Corp. In addition to driving the graphics display in the HMD, the tracking system also served to provide body movement metrics from the tracked locations. These movement metrics are currently being explored as potential measures that may be of value for assessing the hyperactivity component that is sometimes observed in ADHD.



Figure 1. Scenes from the Virtual Classroom

2.3 Initial User-Centered Design and Development of the VR Scenario

Early application of user-centered design methods is vital for the reasoned development of any VR application (Hix et al, 1999; Brown et al., 2001). User-centered methods generally require the involvement of the targeted user group in the early design and development phase of scenario development. This involves a series of tight, short heuristic and formative evaluation cycles conducted on basic components of the system. Consideration of user characteristics in this fashion is increasingly becoming standard practice in VR development (Hix and Gabbard, 2002). A clear example of the effectiveness of this approach in promoting

usability (and learning) can be seen in the thoughtful work of Brown et al. (1998, 2001) incorporating input from tutors and students with severe learning disabilities in the design of VR life skill training scenarios.

In the user-centered design phase, twenty non-diagnosed children (ages 6-12) tried various evolving forms of the system over the first year of development and their performance was observed while trying out a variety of basic selective and alternating attention tasks. One such task involved having users recite the letters that appeared on the blackboard, while naming the color of the paper airplane that passed by them at random intervals. We also solicited their feedback pertaining to aesthetics and usability of the VE and incorporated some of their comments into the iterative design-evaluate-redesign cycle. Overall results indicated little difficulty in adapting to use of the HMD, no self-reported occurrence of side effects as determined by post-test interviews using the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) and excellent performance on the stimulus tracking challenges.

2.4 Methodology for Initial Clinical Trial

Following the initial user-centered design phase, we conducted a clinical trial that compared eight physician-referred ADHD males (age 6-12) with ten non-diagnosed children. The attention testing involved a vigilance task delivered on the blackboard that required the participants to hit a response button whenever they saw the letter “X” preceded by the letter “A”. Two 10-minute conditions were presented to participants: one without distraction and one with distractions (pure audio, pure visual and combined A/V). The distractions consisted of ambient classroom sound, a paper airplane that periodically circled inside the classroom and changed color with each pass, a car that “rumbled” by the window and an avatar that walked into the classroom through one door and exited through a second door (with appropriate footstep and hall-traffic sounds). VR performance (reaction time and response variability on correct hits, omission and commission errors) was also compared with results from standard neuropsychological testing, behavioral ratings by parents on the SWAN Behavior Checklist (Swanson et al., unpublished manuscript) and on the Connors CPT II (2000) flatscreen continuous performance test. The SSQ (Kennedy et al., 1993) checklist was also administered pre and post VR testing. A detailed description of the full methodology is in preparation for journal submission and is currently available from the first author.

2.5 Summary of Initial Findings

The following results were found on the non-VR measures:

- ? No significant differences were found between groups on age, education, ethnicity, or handedness.
- ? ADHD participants performed significantly worse than normal controls on the SWAN ($t(1,16) = -4.55, p < .001$) and Connors CPT II Commission error score ($t(1,16) = -2.37, p < .03$)
- ? Data from the standardized psychometric tests and correlation matrices related to VR measures are not presented in this paper due to space limitations and are available from the first author.

The following results were found on the Virtual Classroom measures:

- ? No significant side effects were observed in either group based on pre- and post-VR SSQ testing.
- ? ADHD children had slower correct hit reaction time compared with normal controls on the distraction condition (760ms vs. 610ms; $t(1,16) = -2.76, p < .03$).
- ? ADHD children had higher correct hit reaction time *variability* compared with normal controls on both the no-distraction (SD= 220ms vs. 160ms; $t(1,16) = -2.22, p < .05$) and distraction conditions (SD= 250ms vs. 170ms; $t(1,16) = -2.52, p < .03$).
- ? ADHD children made more Omission errors compared with normal controls on both the no-distraction (14 vs. 4.4; $t(1,16) = -4.37, p < .01$) and distraction conditions (21 vs. 7.2; $t(1,16) = -4.15, p < .01$).
- ? ADHD children made more Commission errors compared with normal controls on both the no-distraction (16 vs. 3.7; $t(1,16) = -3.15, p < .01$) and distraction conditions (12.1 vs. 4.2; $t(1,16) = -3.22, p < .01$).
- ? ADHD children made more Omission errors in the distraction condition compared to the non-

- distraction condition (21 vs. 14; $t(1,14) = -3.50, p < .01$). No differences on Omission and Commission errors were found with the non-diagnosed children across no-distraction and distraction conditions.
- ? Exploratory analysis of motor movement in ADHD children (tracked from head, arm and leg) indicated higher activity levels on all metrics compared to non-diagnosed children across both conditions.
 - ? Exploratory analysis of motor movement in ADHD children also indicated higher activity levels on all metrics in the distraction condition compared to the non-distraction condition. This difference was not found with the normal control children.
 - ? An exploratory analysis using a neural net algorithm trained to recognize a stereotypic leg movement on the first five participants in each group was able to accurately discriminate the remaining subjects to groups at 100%.

2.6 Conclusions and Future Directions

The initial results of this study indicate that: (1) ADHD children had slower RTs, higher RT variability, made more omission and commission errors and had higher overall body movement than normal control children in The Virtual Classroom; (2) ADHD children were more negatively impacted by distraction than normal control children; (3) “hyperactive” motor movement metrics were greater in the ADHD group and were more pronounced in this group when in the distraction condition. (4) Virtual Classroom measures showed good reliability; and (5) negative side effects were not self-reported with use of The Virtual Classroom.

At the present time, these data suggest that the Virtual Classroom may have high potential as an efficient, cost-effective and scalable tool for conducting attention performance measurement beyond what exists using traditional methodologies. The system allows for controlled performance assessment within an ecologically valid environment and appears to parse out significant effects due to the presence of distraction stimuli. Additionally, the capacity to integrate measures of movement via the tracking technology further adds value to this form of assessment when compared to traditional analog tests and rating scales. We are continuing to analyze this data in more detail and are currently conducting a follow-up study in the Virtual Classroom on a continuous performance inhibition task. More detailed information on the rationale, equipment, methodology and long-term vision for this project can be found in Rizzo et al., (2000; 2001) and in a detailed paper that is in preparation (Bowerly et al., in prep) that will be available at the time of the ICDVRAT 2002 Conference.

3. THE VIRTUAL OFFICE

3.1 Rationale for Virtual Office Application Development

Following our Virtual Classroom application development approach, we are creating other scenarios (i.e., work situations, home environments, etc..) using the same logic and approach to address cognitive/functional processes that are relevant for a range of other clinical populations. In this regard, we have now constructed a Virtual “Office” environment that evolved from expanding some of the basic design elements of the Classroom VE (see Figure 2). This scenario is generally conceptualized as an “open platform” that could be used to study, test and train a variety of cognitive processes depending on the interests of the researcher.



Figure 2. Various configurations of the Virtual Office

3.2 Structure of the Virtual Office Scenario

As with the Virtual Classroom, the user sits at a real desk, but within the HMD, they see the scenes that make up a standard office setting. The virtual desk contains a phone, computer monitor, and message pad, while throughout the office, a virtual clock ticks in real-time, objects appear (and disappear) and a variety of human avatar representations of co-workers/supervisors can be actively engaged. Various performance challenges can be delivered via a “virtual” computer monitor (visual mode), a 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 would 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 concurrent instructions, 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.), avatar activity, events occurring outside the window (e.g., cars rumbling by), or by producing extraneous stimuli that appear in the immediate desk space (e.g., 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 within a realistic office VE. The same equipment specified for the Virtual Classroom was also used in this scenario.

3.3 Initial User-Centered Design Approach

The Virtual Office scenario has undergone initial user-centered evaluation with normal control, TBI, stroke and Multiple Sclerosis patients similar to that described for the Virtual Classroom. This took the form of having users enter the environment and report on what they observed as they scanned the scenario. Within these trials, participants were asked to explore/scan the office via the HMD for one minute in order to become familiar with the environment. Participants then removed the HMD and were asked to recall the objects that were present in the environment (8 common and 8 uncommon) as an informal assessment of incidental memory performance. Continued memory exposure trials were then conducted with the participants with the experimenter verbally guiding them around the office scenario. Following this guided exploration, the experimenter pressed a key on the system causing the objects to “disappear”. Recall of the objects in the environment was then tested after each trial. User feedback was also solicited to support our ongoing evolution of the scenario components to enhance functional usability, test for side effects, etc. Similar to the Virtual Classroom, we observed good functional HMD use, low incidence of self-reported cybersickness and no difficulty in the visual scanning of the environment by users.

In the course of these initial user trials, it was apparent that clinical and normal control subjects were displaying differing strategies for recalling the objects in the environment. Informal observations suggested that normal control subjects began to use a spatial strategy to assist recall very early the memory trials. This was characterized by subjects initially turning their heads to the direction of the starting point of the guided acquisition trials. Subsequent recall of the objects then appeared to follow the same order that subjects had been directed to observe them in, from the left side of the office to the right side (Schultheis and Rizzo, 2002). Clinical users were observed to take at least four to five trials before the spontaneous emergence of a spatially organized strategy occurred. This observation served as the impetus to formalize a research design to systematically investigate this process in an initial clinical trial. Essentially what began as an informal evaluation of the users’ functional ability to scan and become familiar with the environment, served to produce user behavior that fuelled subsequent hypothesis generation. This led to a more formalized memory study that is currently being conducted as our first effort at investigating cognitive performance in the Virtual Office.

3.4 Rationale for Initial Clinical Trial

Research over the past 20 years has indicated cognitive impairment to be quite common in TBI (Levin, Gary, Eisenberg, 1990), negatively affecting various aspects of cognitive functioning including attention (Litvan, Grafman, Vendrell & Martinez 1998; Beatty, Wilbanks et al., 1996), information processing abilities (Diamond, DeLuca, Kim & Kelley, 1997; Grafman, Rao, Bernardin & Leo, 1991), and memory functioning (Rosenthal &

Ricker, 2000; Brassington & Marsh, 1998). Memory is one of the most consistently impaired functions identified in these populations, with current prevalence rates ranging from 54% to 84% in a TBI population (McKinlay & Watkiss, 1999). In addition, studies have indicated that deficits in memory functioning are a major factor in one's ability to maintain meaningful employment following TBI (McKinlay & Watkiss, 1999). Given the relationship between memory abilities and employment status, accurate and functionally relevant assessment of memory deficits may serve to identify pertinent areas of difficulty, allowing for the creation of interventions that aim to facilitate a return to gainful employment. Traditionally, assessment of learning and memory deficits has been measured through the use of neuropsychological tests. While such assessment techniques are objective, standardized, and very widely applied to neurological disease, neuropsychological assessment procedures have been criticized for providing limited ecological validity. The present study was designed to address this critical limitation via the use of the Virtual Office. Within this virtual environment, the assessment of learning and memory skills in persons with TBI is being conducted within a functionally and vocationally relevant setting.

3.5 Methodology for Initial Clinical Trial

The initial clinical trial with the Virtual Office is currently in progress at KMRREC and aims to recruit 40 participants in total: 20 individuals with moderate to severe TBI and 20 healthy control participants, matched on age, gender, and education. Three major categories of outcome measures will be administered: general questionnaires, neuropsychological measures and the Virtual Office tasks. The Virtual Office is set-up to contain 16 items to be remembered (i.e., target items), which have been placed throughout the scenario. The target items include 8 common items, or those things typically found in an office (e.g., notepad) and 8 uncommon items, or things not typically found in an office (e.g., fire hydrant). Both common and uncommon items were selected so that participants 1) could not inflate their score simply by naming common office items, and 2) to examine differences in learning between more salient or unconventional target items and more common or conventional items. From the perspective of the participant seated at the virtual desk, each side of the room will appear to contain 8 items. In order to balance the distribution of common and uncommon items, placement of target items was determined using three rules. First, items near the participant are all common items typically found on an office desk and items farther from the participant are all uncommon items. Second, the number of common and uncommon items on each side of the room has been counter-balanced. Third, common and uncommon items have been grouped together throughout the office, as would be seen in a typical office (e.g., the telephone is located near the notepad). Common items include: telephone, flower vase, calendar pad, pencil holder, clipboard, stack of books, coffee cup and a framed family photo. Uncommon items include: dog, fire hydrant, stop sign, hammer, blender, guitar, basketball and blender.

The Learning and Recall task examined in this study was designed based on the structure and design of traditional neuropsychological measures. This approach was taken to allow for a more direct comparison between memory performance measures in both the Virtual Office and on standard analog neuropsychological tests. The following are the steps in the procedure for this study.

Incidental Memory Measure

- Subject "enters" the Virtual Office by putting on HMD.
- Subjects given an audio-guided tour of the Virtual Office. This tour is tape-recorded to control for consistency of descriptions and time in the Virtual Office for the tour.
- Subject then "exits" the Virtual Office. This is achieved by flipping up the "eyeglass" section of the HMD, thereby eliminating the need to remove the entire HMD.
- After "exiting" the Virtual Office, subject is asked: *"Tell me everything you remember from the office"*
- All responses are recorded. The total number of target items recalled serves as a dependent measure of incidental memory.

Learning Trials

- Subjects “re-enter” the Virtual Office and are guided through the office with the target items being pointed out (verbally) by the examiner. This constitutes a learning trial.
- At the end of the guided tour (learning trial), the subject “exits” the office and is asked to name as many of the target items within the office that they can recall.
- Subject is administered learning trials until they reach the defined learning criterion (successful recall of all items for 2 consecutive trials) or a total of 12 learning trials. This criterion and cut-off is based on previous studies examining learning and memory among individuals with TBI and MS (Deluca et al., 2000).

Recall and Recognition (30’, 90’ minute and 24 hour delay)

- Subject is asked to spontaneously recall all 16 target items (outside of the Virtual Office)
- Subject “re-enters” a version of the virtual office (that does NOT include the target items)
- Subjects are asked to verbally recall the 16 target items and point using a 6DF Flock of Birds tracker that actuates a virtual hand, to where the items had been located.
- Cued Recall: Examiner points to location of target items within the Virtual Office using the same hand tracking method that the subject used previously (a 6DF Flock of Birds tracker that actuates a virtual hand), and asks the subject: *1. Was there an object here? 2. What was the object?*
- The principal investigator contacts all participants approximately 24 hours after completing the study protocol in an effort to assess long term recall of the target items

Dependent variables for the Virtual Office task include total number of learning trials required to meet criterion and total number of items recalled and recognized at the designated time delays and a series of “ordering” metrics that will serve to quantify the use of spatial strategies to assist in memory performance. Detailed specification of the methodology of this study is currently available from the first author and results from this clinical trial are expected in early-2003.

4. CONCLUSION

The projects briefly summarized in this paper reflect our view that VR technology offers assets that could potentially improve the reliability and validity of methods used in the areas of neuropsychological assessment and rehabilitation. The key elements for this exist in VR’s capacity for consistent delivery of complex dynamic test and distraction stimuli along with more precise measurement of participant responses within the context of functionally relevant simulated settings. In this manner, VR allows for systematic assessment and rehabilitation within simulated “real-world” functional testing and training environments with an aim towards enhancing ecological validity. Such a merger between traditional analog methods with more functional/contextual approaches, if successful, could remedy some of the limitations found individually in these approaches and result in more effective neuropsychological tools. As VR technology becomes more accessible, these applications could have a significant impact on the level of standard care available to clinical populations that are often “bypassed” by advanced information technology developments and this view reflects the current thrust of our work.

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ACKNOWLEDGMENT: Preparation of this manuscript and research presented was supported in part by National Institute of Health Grant No. 1 F32 HD08589-01 and by the Integrated Media Systems Center, National Science Foundation Engineering Research Center, Cooperative Agreement No. EEC-9529152.