Memory assessment using graphics-based and panoramic video virtual environments

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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, learning disabilities and other forms of Central Nervous System (CNS) dysfunction. 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 behaviour can be assessed and rehabilitated. This paper focuses on the results of two studies that investigated memory performance in two VEs having varying levels of functional realism. Within these VEs, memory tests were designed to assess performance in a manner similar to the challenges that people experience in everyday functional environments. One VE used a graphics based simulation of an office to test object memory in persons with TBI and healthy controls and found that many TBI subjects performed as well as the control group. The other study compared healthy young persons on their memory for a news story delivered across three different display formats, two of which used a 360-Degree Panoramic Video environment. The results of this "in progress" study are discussed in the context of using highly realistic VEs for future functional memory assessment applications with persons having CNS dysfunction.

1. INTRODUCTION

The assessment and rehabilitation of cognition has received considerable attention in the neuropsychological (NP) literature and such research has demonstrated cognitive impairment to be quite common in Traumatic Brain Injury (TBI) (Levin, Gary, Eisenberg, 1990) and other forms of central nervous system (CNS) dysfunction. Such impairments in cognitive functioning include attention (Litvan, Grafman, Vendrell & Martinez 1998), information processing abilities (Diamond, DeLuca, Kim & Kelley, 1997), 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/quality of life, the assessment of functionally relevant memory performance is of vital importance for persons with CNS dysfunction. Advances in functional memory assessment could serve to identify relevant areas of preserved memory strengths, as well as impairments, that could support the creation of interventions that aim to facilitate a return to gainful employment and enhance quality of life.

Traditionally, the mainstay of learning and memory assessment has been NP testing. However, traditional cognitive assessment (and rehabilitation) methods have been criticized as limited in the area of *ecological* validity, that is, the degree of relevance or similarity that a test or training system has relative to the "real" world, and in its value for predicting or improving "everyday" functioning (Neisser, 1978). Adherents of this view challenge the usefulness of traditional psychometric tests for measuring and addressing the complex integrated functioning that is required for successful performance in the real world. A primary strength that Virtual Reality (VR) offers cognitive assessment and rehabilitation is in the creation of simulated functional environments in which performance can be tested and trained in a systematic fashion. By designing virtual environments that not only "look like" the real world, but actually incorporate challenges that require functional behaviours similar to the real world, the ecological validity of assessment and rehabilitation methods could be enhanced. As well, within a VE, the experimental control required for rigorous scientific analysis and replication can still be maintained within simulated contexts that embody the complex challenges found in naturalistic settings. Thus, VR derived results could have greater predictive validity and clinical relevance for quantifying the challenges that patients face in the real world. The unique match between VR technology assets and the needs of various neuropsychological application areas has been recognized by a number of authors (Pugnetti et al., 1995; Rose, 1996; Rizzo, Schultheis, Kerns and Mateer, 2004) and an encouraging body of research has emerged (Rizzo, Buckwalter and van der Zaag, 2002).

This paper will present findings from two HMD VR memory assessment scenarios that possess varying levels of "realism" and place performance demands on participants that are more similar to "real-world" challenges compared to traditional list learning memory tests. The first study used a graphics-based simulation of a virtual office to compare object memory performance in subjects with TBI and healthy controls conducted at the KMRREC via a collaborative agreement with USC. The second study used a 360-degree Panoramic Video (PV) camera system to capture a news reporter presenting a two-minute news story from the streets of Los Angeles. With this system, users can observe pictorially accurate 360-degree video scenes of "real world" environments delivered via a head mounted display (HMD). Healthy young subjects were tested in terms of how much they could remember from the reported story (in similar fashion to the Wechsler Memory Scale III - Logical Memory Subtest), under varying levels of immersion. These results are serving as an initial feasibility test of this media format as a precursor to our future functional memory research using this system with persons having CNS dysfunction.

2. THE VIRTUAL OFFICE

2.1 Rationale for Development of the Virtual Office Application

Following on our previous work developing a Virtual Classroom for the assessment of attention processes in children with ADHD (Rizzo et al., 2004), we have created 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 (see Figure 1) that evolved from expanding some of the basic design elements of the USC Virtual Classroom. This scenario was generally conceptualized as an "open platform" that could be used to study, test and train a variety of cognitive processes depending on the research question. Within this version of the virtual office, it is possible to place objects in strategic locations in the VE, remove them with a keystroke, and within this format, collect performance data on memory for objects in an environment that resembles a functional setting in everyday life.

2.2 Methods

2.2.1 Participants. The present study recruited 40 participants, 20 individuals with traumatic brain injury (TBI) and 20 healthy controls (HC), matched on age, sex, and education (See Table 1). All participants were between the ages of 18 and 55, were medically stable and had no significant psychiatric, neurological (i.e., other than TBI), or substance abuse history. TBI participants all sustained injuries classified as severe, with Glasgow Coma Scores (GCS) of 8 and/or loss of consciousness (LOC) for no less than 6 hours immediately following injury. Participants with significant visual disturbance (i.e., impeding ability to participate in the VE), aphasia, anomia, and or history of learning disorder were excluded from the study.

2.2.2 VE scenario and Testing Procedure. Three categories of measures were administered. First, general questionnaires were used to solicit past medical and psychiatric histories, as well as, demographic information. Second, a traditional NP battery was administered to assess all major domains of neurocognitive functioning. Finally, all participants were administered the “Virtual Office” memory task. The current “Virtual Office” task is a computer-generated environment designed to simulate a generic office setting. The system equipment included a Dell Inspiron 8100 laptop, a 5th Dimension Technologies (5DT) 800 Series Head Mount Display (HMD), and a Flock of Birds position and orientation tracking system. Participants “entered” the virtual office by placing the HMD display on their head. The HMD could be flipped up and down. When HMD is in the up position, the participant was removed from the VE and could see everything in the “real world”, with no view of the virtual office. In the down position, the participants’ view of the “real world” was occluded and his/her visual field was filled with images of the virtual office environment.

Figure 1. *Scenes from the original Virtual Office and a new version currently under construction.*

Upon entering the virtual office, participants appeared to be seated at a desk and had a head-level view of the entire office space. The office task was programmed to include sixteen target items to be remembered. The sixteen target items consisted of both eight common office items (e.g., notepad) and eight uncommon items (e.g., stop sign). This selection of objects precluded participants from inflating their scores simply by recalling typical office items and allowed us to assess differences in memory based on object novelty effects. The VR task itself was a test of learning and memory. The task began when participants entered the virtual office by wearing the HMD. While “inside” the office, the participants received an audio-guided tour that named the target items to be remembered, each time in a different order. Participants then exited the VE (i.e., by removing HMD) and were asked to recall from memory all target items seen in the VR office. This procedure of entering and exiting the office constituted one learning trial. All participants continuously received learning trials until they could recall all target items across two consecutive trials (i.e., the learning criterion) or until the maximum of twelve trials was reached. After a 30-minute delay and again after a 24-hour delay, participants again were asked to recall as many target items as possible. Following informed consent procedures, participants were administered both the NP battery and the VR task. Order of completion of these tasks was counterbalanced to control for fatigue. All participants were contacted by phone approximately twenty-four hours following test administration to collect long-term recall data. Specifically, they were asked to recall all the items seen in the virtual office on the previous day.

2.2 Results

Among the 20 participants with TBI, 20% (n = 4) were unable to meet the VR Office task learning criterion, whereas 100% of the HC participants met the criterion. Thus, three groups were identified: individuals with TBI who met the criterion (TBI-MET, n = 16), individuals with TBI who did not meet the criterion (TBI-NOT MET, n = 4), and HC participants (n = 20). (See Table 1).

Initial target acquisition. To examine group differences in initial acquisition of target stimuli, mean number of trials to criterion were compared between the TBI-MET and HC groups. TBI-NOT MET participants were excluded as, by definition, they did not meet the learning criterion. Results indicated that the TBI-MET and HC groups were nearly identical in the number of trials required to learn the 16-items presented, F(1, 34) = 0.00, p = 0.98). Specifically, the TBI-MET group required an average of 3.94 trials (SD = 1.61; range,2-8), whereas the HC group required an average of 3.95 trials (SD = 1.91; range, 2-10) to meet criterion.

Target recall. Virtual office recall performance among the three groups was compared with a 3(Group) X 2(Delay) repeated measures analysis of variance (ANOVA). There was a significant main effect for Group (F(1, 29) = 43.2, p < 0.001), and post hoc Tukey tests revealed that the TBI-NOT MET group recalled significantly fewer items (M = 8.25, SD = 4.57) than both the TBI-MET group (M = 14.31, SD = 1.70) and the HC group (M = 15.35, SD = 1.04). The TBI-MET and HC groups did not differ significantly in overall item recall. There also was a significant main effect for Delay (F(1, 29) = 43.2, p < 0.001), where as expected when data was collapsed across the 3 groups, significantly fewer items were recalled at the 24-hour delay (M = 7.85, SD = 0.72) than at the 30-minute delay (M = 12.67, SD = 0.41). Notably, the interaction of Delay and Group also was statistically significant (F(2, 29) = 4.23, p < 0.05), where performance of the TBI-NOT MET group varied over time. Interestingly, while the TBI-NOT MET group recalled significantly fewer items than the other 2 groups following a 30-minute delay, this difference disappeared following 24-hour delay, as the groups did not differ significantly.

Table 1. *Demographic Characteristics Organized By Group.*

	TBI-MET (*n* = 16)	TBI-NOT MET (*n* = 4)	HC (*n* = 20)
Gender			
Women	7 (44%)	2 (50%)	11 (55%)
Men	9 (56%)	2 (50%)	9 (45%)
Age (in years)			
Mean (*SD*)	37.6 (9.1)	39.5 (11.8)	31.6 (12.4)
Education (in years)			
Mean (*SD*)	13.3 (2.1)	14.0 (2.8)	15.2 (2.4)
Marital Status			
Single	13 (81%)	3 (75%)	13 (65%)
Married	3 (19%)	1 (25%)	7 (35%)
Ethnicity			
Caucasian	15 (94%)	3 (75%)	18 (90%)
African American	0	1 (25%)	1 (5%)
Hispanic	1 (6%)	0	1 (5%)
Employment Status			
Employed	10 (63%)	2 (50%)	13 (65%)
Unemployed	6 (37%)	2 (50%)	7 (35%)
Time LOC* - days	12.7 (15.3)	29.5 (20.5)	--
Time Post-Injury (yr.)	7.5 (5.4)	6.5 (4.2)	--

Note. *LOC = Loss of consciousness.

Traditional Neuropsychological Test Summary. Results of neuropsychological testing revealed significant differences in performance between the HC and TBI groups. Specifically, when compared to the HC group both TBI groups demonstrated significantly lower psychometric intelligence, psychomotor speed, auditory short-term attention, numeric sequencing, executive functioning, visual scanning, confrontation naming, and verbal fluency ($p < 0.05$). Learning and memory was assessed with the California Verbal Learning Test (CVLT) (Delis et al., 1987). Significant group differences also were observed on this verbal list-learning task, as the HC group learned a significantly greater number of words after 5 learning trials and recalled a significantly greater number of words after a 30-minute delay ($p < 0.001$). Overall, TBI groups demonstrated significantly poorer performance than HCs using these traditional measures.

2.4 Conclusions

The present study compared a group of persons with TBI to a group of matched, healthy controls using standard NP tests and on a VR-based memory assessment instrument. Interestingly, a large percent of participants with brain injury were statistically equivalent to healthy controls in their ability to acquire target items during the learning trials of the virtual office task. Furthermore, recall of the target items at both 30 minutes and at 24 hours was not significantly different between some of these participants and the HC group. These findings indicate that many TBI participants failed to demonstrate impaired acquisition and retrieval when using the VR Office as a measure of object memory.

This finding is at variance with the earlier work of DeLuca, Schultheis, Madigan, Christodoulou, and Averill (2000), who conducted an analogous study and observed TBI participants to have significantly worse initial acquisition and retrieval of target items than a group of matched, healthy controls using a commonly employed verbal list learning task, The Selective Reminding Task (SRT) (Buschke, 1973). One important way in which these two tasks differ is that the VR Office provides a rich context in which visual target stimuli are presented. This context is not available in the SRT or in other traditional verbal list-learning tasks and therefore a different memory process is being assessed. Similar results were found in the current study using the CVLT whereby participants appeared able to benefit from the presence of contextual visuospatial cues, which might have enhanced initial encoding of target items. Specifically, participants were afforded the opportunity to visually associate target items with elements of the environment, as well as with other target items in the virtual office. In addition, during testing with VR numerous elements of memory (e.g., verbal, visual, spatial) are assessed in combination, thereby potentially improving scores beyond traditional measures that are typically used to assess components of memory in isolation. Indeed, this may have improved the quality with which target items were encoded and reduced the quantity of learning trials required to meet the learning criterion. Perhaps the availability of such contextual cues during testing with VR more closely mimics the affordances in the real-world compared to traditional verbal measures of memory. In this regard, we could speculate that either the VR task has limited utility for isolating certain memory component impairments, or that the context provided in this type of VR assessment revealed preserved integrated functional memory ability that would be underestimated if memory assessment was limited to the types of verbal learning tests that are commonly employed in traditional NP assessment. The initial results from this research are highly suggestive of a future research direction that could have value for broadening our understanding of everyday memory and for perhaps guiding rehabilitative strategies with better input on preserved functioning.

3. PANORAMIC VIDEO VR MEMORY TEST

3.1 Rationale for Panoramic Video VR Memory Test

Recent advances in Panoramic Video (PV) camera systems have produced new methods for the creation of virtual environments (James, 2001). With these systems, users can capture, playback and observe pictorially accurate 360-degree video scenes of "real world" environments. When delivered via an immersive head mounted display (HMD), an experience of presence within these captured scenarios can be supported in human users. This is in sharp contrast to the constrained delivery and passive viewing of television and video images that have been the primary mode for providing humans with a "virtual eye" into distant times and locations over the last fifty years. Along with traditional computer graphics (CG) based virtual environments, PV overcomes the passive and structured limitations of how imagery is presented and perceived. The recent convergence of camera, processing and display technologies make it possible for a user to have control and choice in their viewing direction. As opposed to mouse and keyboard methods for interacting with flat screen panoramic content, users can more intuitively observe PV content via natural head movement within an HMD. Users of PV become virtual participants immersed in the observed scene, creating a new dimension in the way people perceive imagery within these types of VEs. However, when compared with CG-based VEs, PV has some limitations regarding functional interactivity. Whereas users operating within a CG-based VE scenario are usually capable of both 6DF navigation, and interaction with rendered objects, PV immersion allows mainly for observation of the scene from the fixed location of the camera with varying degrees of orientation control (i.e. pitch, roll and yaw). In spite of this limitation, the goals of certain application areas may be well matched to the assets available with this type of PV image capture and delivery system. One potential clinical application area in the use of PV content for creating standardized tests or training tools for addressing cognitive function within an ecologically enhanced real-world VE.

3.2 Brief system overview and technical description

Panoramic image acquisition is based on mosaic approaches developed in the context of still imagery. Mosaics are created from multiple overlapping sub-images pieced together to form a high resolution, panoramic, wide field-of-view image. Viewers often dynamically select subsets of the complete panorama for viewing. Several panoramic video systems use single camera images (Nayar, 1997), however, the resolution limits of a single image sensor reduce the quality of the imagery presented to a user. While still image mosaics and panoramas are common, we produce high-resolution panoramic video by employing an array of five video cameras viewing the scene over a combined 360-degrees of horizontal arc. The cameras are arrayed to look at a five-facet pyramid mirror. The images from neighbouring cameras overlap slightly to facilitate their merger. The camera controllers are each accessible through a serial port so that a host computer can save and restore camera settings as needed. The complete camera system (see Figure 2) is available from FullView, Inc. (FullView, 2001).

Figure 2. *FullView Panoramic Camera*

The five camera video streams feed into a digital recording and playback system that we designed and constructed for maintaining precise frame synchronization. All recording and playback is performed at full video (30Hz) frame rates. The five live or recorded video streams are digitized and processed in real time by the computer system. The camera lens distortions and colorimetric variations are corrected by our software application and a complete panoramic image is constructed in memory. With five cameras, this image has over 3000x480 pixels. From the complete image, one or more scaled sub-images are extracted for real-time display in one or more frame buffers and display channels. Figure 3 shows an example of the screen output with a full 360° still image extracted from the video.

The camera system was designed for viewing the images on a desktop monitor. With a software modification provided by FullView Inc. (FullView, 2001), we were able to create an immersive viewing interface using a head-mounted display (HMD). A single window with a resolution of 800x600 is output to the HMD worn by a user. A real-time inertial orientation tracker (Intersense, 2001) is fixed to the HMD to sense the user's head orientation. The orientation is reported to the viewing application through an IP socket, and the output display window is positioned (to mimic pan and tilt) within the full panoramic image in response to the user's head orientation. View control by head motion is a major contributor to the sense of immersion experienced by the user. It provides the natural viewing control we are accustomed to without any intervening devices or translations.

3.3 Panoramic Video Memory Test Scenario Design and Method

This project was conducted in collaboration with the USC Annenberg School of Journalism as part of a research effort aiming to investigate the use of Panoramic Video for viewing newsworthy content, as well as its impact on memory for the verbal content of a news story compared to traditional viewing methods. The news "stimuli" consisted of a female reporter presenting a story from a fixed position on a street in downtown Los Angeles. The news story involved a two-minute report on issues regarding the "homeless" in Los Angeles. The camera was positioned in the middle of a street in the midst of an array of tents and makeshift living quarters on the sidewalk. In addition to seeing the reporter, the 360-degree PV content contained the imagery and sounds of the surroundings with many homeless individuals going about their day-to-day activities in this area (See Figure 4). With this captured content we compared memory performance with a between groups design across three different viewing format conditions. The three conditions were:

Single Frame Condition (C1) subjects viewed the 2-minute news story in a "traditional" single-frame viewing format on a computer monitor. This group of participants had access only to the single frame field of view containing the news reporter's standing delivery of the story, as is commonly seen in a standard on-the-scene reporting approach presented on a television news broadcast.

Flat screen Panoramic Condition (C2) participants had access to view the complete 360-degree arc of the environment from where the C1 news story was reported. They had access to and viewed the 360-degree arc on a computer monitor using an inertial orientation tracker mounted on a disc to freely navigate around the panoramic arc. C2 subjects also heard the *exact same verbal delivery and had access to the same audiovisual presentation of the reporter* as presented in C1, since the C1 story was actually a flat panel extracted from the full panoramic 360-degree arc used in C2.

HMD Panoramic Condition (C3) participants viewed the exact same 360-degree arc of the news story environment that was available to the C2 group, but from within an orientation tracked HMD. This system updated the video image in the display in real time as the subject turned their head. This allowed the participant to view the scene as they would if they were at the site of the news story and to have free choice to observe the panoramic scene from any perspective within the 360-degree arc using head turning movements as they would under normal real world viewing conditions.

Figure 3. *360-degree PV image extracted from video footage taken at the Los Angeles Coliseum*

Figure 4. *Traditional Viewing Range (L) vs. Panoramic Viewing Range (R)*

Currently, 16 unimpaired research participants have been tested in each condition (avg. age=20y/o). Due to research participant acquisition challenges, the total sample reported on in this paper consists of 40 females and 8 males. The study is ongoing with a total sample of 96 anticipated, with equal gender representation expected. Participants were tested on free recall, cued recall and multiple choice recognition for the auditory content immediately following presentation of the news story, and in a delay condition (1 week later). This design allowed for comparison of memory across groups on immediate acquisition/recall/recognition of the story content and on long-term incidental recall/recognition retrieval. Initial analysis of the memory data with the existing sample is presented in this paper. Results to be presented at the conference will include head tracking analyses as a measure of exploratory scanning behaviour and its influence on memory, and results from the Presence Questionnaire (Witmer and Singer, 1998) to determine the relevance of this intervening variable as a factor in memory performance.

3.4 Panoramic Video Study Results and Conclusions

As seen in Table 2, single frame viewing produced significantly better memory than *both* PV conditions only for Immediate Recall. Single frame viewing was also shown to promote better immediate recognition memory than the flat screen panoramic condition. Memory performance was found to be equivalent for all conditions for immediate cued recall and for all delayed memory variables.

Table 2. *Memory Results.*

	Single Frame	Flat screen Panoramic	HMD Panoramic	Sig.
Recall Means (*SD*)				
Immediate	11.81 (4.7)	8.81 (4.6)	8.44 (2.8)	(F(2, 45) = 3.2, p < 0.05)£
1-Week Delayed	9.94 (4.2)	7.75 (2.9)	7.44 (2.5)	NS
Cued Recall Means (*SD*)				
Immediate	5.44 (2.0)	4.38 (2.2)	3.94 (1.7)	NS
1-Week Delayed	6.19 (2.2)	4.69 (1.9)	5.0 (2.0)	NS
Recognition Means (*SD*)				
Immediate	8.25 (1.5)	6.56 (2.2)	7.31 (2.0)	(F(2, 45) = 3.1 p < 0.05)*
1-Week Delayed	7.63 (1.8)	6.56 (1.9)	6.94 (1.4)	NS

£Post Hoc difference significant between Single Frame and both Panoramic Conditions combined.
*Post Hoc difference only significant between Single Frame and Flat screen Panoramic Condition.

One of our initial working hypotheses was that the sense of "being there" or "presence" would be enhanced in the HMD Panoramic Condition via the use of an immersive HMD and that this added engagement would increase *long term* recall by providing better contextual retrieval cues that leverage episodic memory processes. However, both Panoramic Conditions also provide the participant with additional information beyond the auditory content of the reported news story in the single frame condition. This occurs in the form of the real world activity that transpired in the full 360-Degree field of view that the user has available to explore. Whether this added cognitive load serves as a distraction that limits memory for the audio content or provides contextual cues that support memory retrieval is one of the open questions that this research will address via more refined analyses relating memory to presence and head movement. Data from those analyses from this preliminary sample will be available at the conference. One of the aims of this study was to determine if panoramic video VR would have added-value as a tool for testing everyday functional memory in clinical populations. These preliminary results suggest that in an unimpaired young sample, the added information available in the panoramic conditions did not impair long-term memory retrieval although initial recall was impacted. Future research with participants having CNS dysfunction will be conducted to determine if (unlike the unimpaired groups tested thus far) the added cognitive load that may exist in such Panoramic VR scenarios will serve to impair long-term memory performance. This could serve as the basis for a measurement tool that could provide a more relevant assessment of clinical impairments in everyday functional memory.

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 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 with these approaches and result in more effective prediction of real world performance. The studies presented in this paper illustrate two approaches toward testing cognitive processes in environments that possess attributes similar to challenges commonly found in everyday memory. However, the value of this form of assessment in relation to traditional component testing will only be determined via rigorous experimentation with an eye towards enhanced explanation and prediction of memory impairments in a patients' day-to-day functional environment. It may be found that such testing will both reveal preserved functioning that could be leveraged in rehabilitation programming as well as exposing impairments in more integrated functioning that would not be uncovered with basic component tests.

5. REFERENCES

J C Brassington, N V & Marsh (1998). Neuropsychological aspects of multiple sclerosis. *Neuropsychology Review,* **8**, pp. 43-77.

H Buschke (1973). Selective reminding analysis of memory and learning. *Journal of Verbal Learning and Verbal Behaviour,* 12, pp. 543-550.

D C Delis, J H Kramer, E Kaplan & B A Ober (1987). *California Verbal Learning Test, Adult Research Edition.* New York: The Psychological Corporation.

J DeLuca, M T Schultheis, N Madigan, C Christodoulou & A Averill (2000). Acquisition versus retrieval deficits in traumatic brain injury: Implications for memory rehabilitation. *Archives of Physical Medicine and Rehabilitation*, **81**, pp. 1327-1333.

B J Diamond, J DeLuca, H Kim & S M Kelley (1997). The question of disproportionate impairments in visual and auditory information processing in multiple sclerosis. *Journal of Clinical & Experimental Neuropsychology.* **19**, pp. 34-42.

FullView.com Inc. (2003). Retrieved February 15, 2003, from www.fullview.com

Intersense Inc. (2003). Retrieved February 15, 2003, from www.isense.com

M S James (2001). 360-Degree Photography and Video Moving a Step Closer to Consumers. Retrieved March 23, 2001, from http://abcnews.go.com/sections/scitech/CuttingEdge/cuttingedge010323.html

H S Levin, H E Gary & H M Eisenberg (1990). Neurobehavioral outcome 1 year after severe head injury. *Journal of Neurosurgery.* **73**, pp. 669-709.

I Litvan, J Grafman, P Vendrell & J M Martinez (1988). Slowed information processing in multiple sclerosis. *Archives of Neurology.* **45**, pp. 281-285.

W McKinlay & A J Watkiss (1999). *Cognitive and Behavioral Effect of Brain Injury*. 3rd ed. F.A. Davis: Philadelphia, pp. 74-86.

S K Nayar (1997). Catadioptric Omnidirectional Camera, Proc. of IEEE Computer Vision and Pattern Recognition, (CVPR).

U Neisser (1978). Memory: what are the important questions? In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical Aspects of Memory*. London: Academic Press. 3-24.

L Pugnetti, L Mendozzi, A Motta, A Cattaneo, E Barbieri and S Brancotti (1995). Evaluation and retraining of adults' cognitive impairments: Which role for virtual reality technology? *Computers in Bio. and Medicine,* **25**, *2*, pp.213-227.

A Rizzo, M Schultheis, K Kerns & C Mateer (2004). Analysis of Assets for Virtual Reality Applications in Neuropsychology. *Neuropsychological Rehabilitation.***14**(1/2) 207-239.

A Rizzo, D Klimchuk, R Mitura, T Bowerly, C Shahabi & J G Buckwalter (2004). Diagnosing Attention Disorders in a Virtual Classroom. *IEEE Computer*. **37** (5), 87-89.

A Rizzo, J G Buckwalter, and C van der Zaag (2002), Virtual environment applications in clinical neuropsychology. In *The Handbook of Virtual Environments,* (K Stanney, Ed.), Erlbaum Publishing, New York. pp. 1027-1064.

F D Rose (1996). *Virtual reality in rehabilitation following traumatic brain injury,* In Proceedings of the European Conference on Disability, Virtual Reality and Associated Technology (P Sharkey, Ed.), Reading UK: The University of Reading, pp. 5-12.

M Rosenthal & J H Ricker (2000). Traumatic brain injury. In *Handbook of Rehabilitation Psychology.* (R Frank & T Eliot, Eds.), American Psychological Association: Washington, D.C.

D Wechsler (1997). Manual: Wechsler Memory Scale - III (WMS-III). San Antonio: Psychological Corporation.

B G Witmer and M J Singer (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*. 7, 225-240.