

The virtual classroom: a virtual reality environment for the assessment and rehabilitation of attention deficits

Albert A. Rizzo¹, J. Galen Buckwalter², Todd Bowerly³,
Lorie A. Humphrey⁴, Ulrich Neumann¹, Andre van
Rooyen³, Laehyun Kim¹

¹*Integrated Media Systems Center University of Southern California*

²*School of Gerontology University of Southern California*

³*Fuller Graduate School of Psychology Pasadena California*

⁴*Dept of Psychiatry and Biobehavioral Sciences UCLA School of Medicine*

Abstract: Virtual Reality technology offers new options for the study, assessment, and rehabilitation of cognitive/functional processes. This paper describes the initiation of a research program aimed at developing a virtual "classroom" for the assessment of ADHD. The system uses a head mounted display, head, hand, and leg tracking, and is laptop deliverable. The classroom environment contains desks, a virtual teacher, a blackboard, a large window looking out onto a street with background buildings, vehicles, and people, and on each end of the wall opposite the window--a pair of doorways, through which activity occurs. Within this scenario, normal and ADHD-diagnosed children are assessed for performance on visual and audio attention tasks while a series of typical classroom distracters are systematically manipulated within the virtual environment. This technology is seen to offer many advantages for these aims and an introductory section of this paper will discuss the specific rationale for VR applications in the area of clinical neuropsychology. **Key words:** Virtual Reality, ADHD, Assessment, Distraction

Un aula virtual: un ambiente de realidad virtual para la evaluación y rehabilitación de los déficits atencionales

Resumen: La tecnología de la Realidad Virtual ofrece nuevas opciones para el estudio, evaluación, y rehabilitación de los procesos cognitivos/funcionales. Este trabajo describe un programa de investigación en el que se desarrolla un aula virtual para la evaluación de los déficits de atención y trastornos de atención relacionados con hiperactividad. Este método utiliza un casco de inmersión (head mounted display, HMD), dispositivos de entrada (tracking devices) para cabeza, manos y piernas, y se puede usar con un ordenador portátil. El ambiente del aula está formado por varios pupitres, un profesor virtual, una pizarra, una gran ventana que da a una calle con edificios, vehículos,

y personas, y en los puntos opuestos de la pared que está frente a la ventana hay un par de puertas, a través de las cuales se desarrollan los eventos. En este escenario, niños sin alteraciones y otros diagnosticados de trastorno por déficit de atención e hiperactividad (TDAH) son evaluados en la ejecución de diferentes tareas atencionales visuales y auditivas mientras que una serie de distractores propios de las aulas son sistemáticamente manipulados dentro de este ambiente virtual. Esta tecnología ofrece muchas ventajas para este tipo de estudios y la parte introductoria de este trabajo discute las razones específicas para la aplicación de la realidad virtual en el área de la neuropsicología clínica.

Palabras clave: Realidad Virtual, TDAH, evaluación, distracción.

Virtual Reality (VR) technology is increasingly being recognized as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities (Elkind, 1998; Pugnetti, et al., 1995; Rose, Attree, & Brooks, 1997; Rose, Attree, Brooks, & Johnson, 1998; Rizzo, & Buckwalter, 1997). Much like an aircraft simulator serves to test and train piloting ability, virtual environments (VEs) can be developed to present simulations which target human cognition and behavior. The capacity of VR to create dynamic three-dimensional stimulus environments, in which all behavioral responding can be recorded, offers 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 controlled studies reporting encouraging results are now beginning to emerge (Rizzo, Buckwalter, Van der Zaag, 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 and treat impairments in these areas which are typically found in clinical populations. Individuals who may benefit from these applications include persons with cognitive and functional impairments due to traumatic brain injury, neurological disorders, and developmental/learning disabilities. VR applications are now being developed and tested which focus on component cognitive processes including: attention processes (Wann et al.), spatial abilities (Larson et al., 1999; Astur, Ortiz, & Sutherland, 1998; Jacobs, Laurance, & Thomas, 1997; Brown, Kerr, & Bayon, 1998; Rizzo et al., 1998; Stanton, Foreman, & Wilson, 1998; McComas, Pivik, & Laflamme, 1998; Waller, Hunt, & Knapp, 1998), memory (Attree et al., 1996; Rose et al., in press-a, in press-b; Brooks et al., in press; Johnson, Rose, Rushton, Pentland, & Attree, 1998), and executive functions (Pugnetti et al., 1998; Mendozzi, Motta, Barbieri, Alpini, &

Pugnetti, 1998). VR functional training scenarios have also been designed to test and teach basic activities of daily living such as: street-crossing (Strickland, 1996, 1997), common object recognition (Strickland, 1997), meal preparation (Christiansen et al., 1998; Davies et al., 1998), supermarket shopping (Cromby, Standen, Newman, & Tasker, 1996), use of public transportation (Mowafy, & Pollack, 1995), and wheelchair navigation (Inman, Loge, & Leavens, 1997). These initiatives have formed a foundation of work that provides support for the feasibility and potential value of further development of VR/neuropsychological applications. If the associated technology continues to advance in the areas of visual displays, computing speed/memory storage, graphics, 3D audio, wireless tracking, voice recognition, intelligent agents, and VR authoring software, then more powerful and naturalistic VR scenarios will be possible. These advances could result in more readily available desktop-powered VR systems with greater sophistication and responsiveness. Such increases in access would allow for widespread application of VR technology and promote the independent replication of research findings needed for scientific progress in this field.

Indeed, mainstream researchers and clinicians in neuropsychology are “wanting” for these advances in VR technology—whether they realize it or not! For example, in a recent National Institute of Health (NIH) Consensus paper National Institute of Health [NIH], 1998) entitled, “Rehabilitation of Persons with Traumatic Brain Injury (TBI)” two recommendations were made which suggest research directions that VR technology appears well poised to address. The report recommends that, “Innovative rehabilitation interventions for TBI should be developed and studied” and that “Innovative study methodologies that enhance the ability to assess the effectiveness of complex interventions for persons with TBI should be developed and evaluated”. Further indirect support for VR’s potential contribution to neuropsychology can be implied in a 1997 article by the well-respected intelligence theorist, Robert Sternberg (Sternberg, 1997). In this paper he contends that, with the exception of “cosmetic” changes, the field of cognitive ability testing has progressed very little in the last century in contrast to the advancements seen in other technologies over this same time period. He posits that “dynamic” interactive testing provides a new option that could supplement traditional “static” tests. The “dynamic” assessment approach requires the provision of guided performance feedback as a component in tests that measure learning. This method appears well suited to the assets available with VR technology. In fact, VEs might be

the most efficient vehicle for conducting dynamic testing in an “ecologically valid” manner while still maintaining an acceptable level of experimental control. A more specific recommendation for future research into the possibilities of VR technology appeared earlier in a 1995 NIH report of the National Advisory Mental Health Council. In this report the impact of virtual reality environments on cognition was specifically cited with the recommendation that “Research is needed to understand both the positive and negative effects of such participation on children’s and adults’ perceptual and cognitive skills...” (p.51). These observations suggest that the disciplines of neuropsychological assessment and cognitive rehabilitation are fertile ground for studying the innovative applications that are possible with VR technology.

The current status of VR, while provocative, is still limited by the small (but growing) number of controlled studies that apply this technology to clinical populations. This is to be expected considering the technology’s relatively recent development, it’s high initial development costs, and the lack of familiarity with virtual environments (VE) by established researchers who are used to employing the traditional tools and tactics of their fields. In spite of this, a nascent body of work has emerged which can provide knowledge for guiding future research efforts. Although much of the work does not involve the use of fully immersive head mounted displays (HMDs), studies reporting 3D projection screen and PC-based flatscreen approaches are providing useful information necessary for the reasoned development and implementation of VR technology for clinical applications. Relevant to these efforts, the present article will present a brief rationale for the application of VR technology in the area of clinical neuropsychology via an introductory discussion of relevant clinical populations, neuropsychological assessment, and cognitive rehabilitation. We will then present background on our development of a HMD VE for the study, assessment, and possible rehabilitation of attention process impairments. This system, referred to as the “Virtual Classroom” is initially being developed to assess children with Attention Deficit Hyperactivity Disorder (ADHD). However, the overall system is designed to contain options that allow for its flexible application and general use with other clinical populations.

This work is underway at the University of Southern California’s Integrated Media Systems Center (IMSC). The Integrated Media Systems Center at USC consists of a multidisciplinary group of scientists representing engineering, computer science, communications, information technology, education, and psychology. This mix of expertise has served to facilitate the development of this project via an

integrated approach for VR application development. One of the primary aims of the VE laboratory at IMSC is to assess the potential utility and feasibility of VR for neuropsychological assessment and cognitive rehabilitation purposes. The application of VEs targeting cognitive and functional processes, while intuitively appealing, cannot be rationally developed without addressing basic cost/benefit, feasibility, and clinical effectiveness issues (Rizzo, Buckwalter, Neumann, Kesselman, & Thiebaut, 1998; Durlach, & Mavor, 1995). These include factors relating to the selection of appropriate target variables, system costs, clinical population characteristics, optimal levels of presence/immersion, interface and navigational requirements, side effects, learning and generalization, and data analytic/psychometric strategies (Rizzo, Wiederhold, & Buckwalter, 1998). Our research program has been designed so that many of these issues can be addressed economically, concurrent with data collection regarding our cognitive variables of interest.

Clinical Populations

Central Nervous System (CNS) dysfunction, resulting in cognitive and functional impairments, can occur through a variety of circumstances. The most frequent causes include traumatic brain injury (TBI) due to accidents, neurological disorders, developmental and learning disorders, as well as complications from medical conditions and procedures. The resulting impairments commonly involve processes of attention, memory, language, spatial abilities, higher reasoning, and functional abilities. Significant emotional, social, vocational, and self-awareness components that typically co-occur can also further complicate these areas. Because of the pervasive nature of CNS dysfunction, the cost to individuals and society is significant.

TBI is the most common cause of CNS dysfunction and is broadly defined as brain injury resulting from externally inflicted trauma. Such injury is often the result of automobile accidents, falls, sports accidents, and bullet wounds. In the United States, estimates range from 500,000 to 2 million new cases per year. The peak age of incidence is in the 15 to 24-year range (closely followed by the birth to five years group). In addition to the cost of human suffering, one estimate places the economic costs in terms of medical care, rehabilitation and lost work potential at \$48.3 billion annually.

Neurological disorders which cause CNS dysfunction include Alzheimer's disease, Vascular dementia, Parkinson's disease, Huntington's

disease, cerebral palsy, epilepsy, and multiple sclerosis. In addition, other relatively common causes of CNS dysfunction include strokes, drug reactions, thyroid disease, nutritional deficiencies, tumors, alcoholism, and infections. Alzheimer's Disease (AD) has been estimated to afflict nearly four million Americans, or between 2 to 4% of the population over the age of 65. It is estimated that the prevalence of AD doubles every five years beyond 65 to the point that nearly half of all people 85 and older display symptomatology. Alzheimer's disease is the third most expensive disease in the United States (following heart disease and cancer), with associated costs close to \$100 billion per year. With the increase in life expectancy, it is estimated that the number of Americans aged 85 and over will double by the year 2030, an estimate that has alarming social, economic, and public health implications.

Approximately three million Americans also suffer with some degree of disability from stroke (Gresham, Duncan, Stason, et al., 1995). Although a stroke can occur at any age, for every decade after the age of 55 the risk doubles. Of the nearly 500,000 individuals annually who have a first-time stroke, 55% experience varying degrees of disability, including a range of deficits in language, cognition, and motor functions. The total cost of stroke to the United States is estimated to range from \$30 to \$43 billion per year (National Stroke Association., 1997).

Many others, particularly the young, experience cognitive/functional impairments due to various developmental and learning disabilities. Estimates place the number of children receiving special education services at between 2.5 to 4 million (Barkley, Fisher, Edelbrock, & Smalish, 1990). Rates of other childhood learning disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) and reading disorders, push estimates even higher. Methodological complications preclude precise estimates of the cost of ADHD to society, but according to 1995 statistics, additional national public school costs for these students may have exceeded \$3 billion. Taken together, the above outlined statistics suggest a significant clinical population of persons with CNS dysfunction that may be better served by the types of advanced assessment and rehabilitation tools that are possible via the emerging application of VE technology.

Brief Introduction To Neuropsychological Assessment (NA)

In the broadest sense, neuropsychology is an applied science that evaluates how specific activities in the brain are expressed in observable behaviors (Lezak, 1995). Effective NA is a prerequisite for both the treatment and the scientific analysis of any CNS-based cognitive/functional impairment. The NA of persons with CNS disorders serves a number of functions. These include the determination of a diagnosis, the provision of normative data on the status of impaired cognitive and functional abilities, the production of information for the design of rehabilitative strategies, and the measurement of treatment efficacy. NA also serves to create data for the scientific understanding of brain functioning through the examination of measurable sequelae that occur following brain damage or dysfunction. Our understanding of brain morphology and activity has undergone a revolution in the past three decades that is akin to the revolution seen in microtechnology. However, the increase in our knowledge of the genetics, chemistry, molecular biology, and the “physics” of the brain is mitigated by our understanding of the behavior that is related to specific brain activity. The fact that post-mortem studies of Alzheimer’s Disease (AD) have identified the entorhinal cortex as the area where the pathological changes of AD are first noted (Braak, Braak, & Bohl, 1993) is of little clinical value unless we can identify the cognitive and behavioral processes that are serviced by this region. Once such processes are identified, it becomes possible to diagnose more effectively and intervene at an earlier stage of this neurodegenerative process. VE technology offers the potential to develop human performance testing environments that could supplement traditional NA procedures and conceivably produce new methodologies that support earlier diagnosis by improving on standards for psychometric reliability and validity.

The assessment of cognitive abilities has a long and, at times, explosive history. In 1921, at a contentious symposium on what comprises intelligence, the historian and experimental psychologist Edwin Boring asserted that “intelligence is what the tests test” (Boring, 1923). This notion of making a test and then accepting the results as indicative of an aspect of brain performance may be the classic case of putting the cart before the horse, but to some extent it is a pragmatic reality of our ability, or *inability*, to measure behaviors. Neuropsychology has proceeded by reducing complex behaviors to component cognitive domains. Domains of cognitive functioning identified by neuropsychologists are numerous and many sub-components

have been identified and studied. Some examples of the more global cognitive processes include attention, executive functions, memory, language processing, spatial abilities, problem solving, and higher level abstract reasoning. NA also attempts to define and measure functional processes which are assumed to be comprised of the integration of component cognitive process that are manifested in everyday human behavior. Functional processes might include such Instrumental Activities of Daily Living (IADLs) as meal preparation, using transportation, shopping, housework, vocational activities, and handling finances. These cognitive/functional processes are commonly assessed using such NA methods as psychometric testing, behavioral observation, and an examination of past historical information.

The measurement of cognitive/functional processes is based on two criteria: reliability and validity. Reliability is the capacity of an instrument to consistently obtain the same results. Validity is concerned with how well an instrument actually measures what it purports to measure. Traditional assessment methodology, primarily based on the use of pencil and paper tests, presents the neuropsychologist with both reliability and validity problems. The reliability of these instruments is adversely affected by the variability of administration procedures due to differences in examiners, the testing environment (i.e., lighting, room size, background noise), the quality of the stimuli presented to the subject, and by inevitable scoring errors. The validity of traditional methods is attenuated by the fact that some tests require multiple cognitive domains for successful completion, and thus it remains unclear what specific cognitive domain is being evaluated. It is likely that both reliability and validity can be improved upon with the use of VE technology. Reliability can be enhanced by better control of the perceptual environment, more consistent stimulus presentation, and by more precise and accurate scoring. VEs may also improve on the validity of measurement via the quantification of more discrete behavioral responses, allowing for the identification of more specific cognitive domains.

Traditional NA testing has also been criticized as limited in the area of *ecological* validity, which is concerned with the degree of relevance or similarity that a test has relative to the “real” world (Neisser, 1978). While existing neuropsychological tests obviously measure some behavior mediated by the brain, it is difficult to say with any certainty how performance on a contrived assessment task relates to complex performance in an “everyday” functional environment. Cognitive/functional performances could be tested in simulated “real-

world” VE scenarios and improve on the ecological validity of measurement. In this way, the complexity of stimuli found in naturalistic settings could be presented while still maintaining the experimental control required for rigorous scientific analysis (see Table 1). Thus, results would have greater clinical relevance and could have direct implications for the development of functional cognitive rehabilitation approaches. However, it is also important to recognize that in all cases it may not be desirable for VEs to fully “mimic” reality. Another strength of VEs for assessment purposes may include the capacity to present scenarios that include features not available in the “real-world”. This would be the case when “cueing” stimuli are presented to examine at what level “augmentive” information can be used by patients to assist in compensatory strategies aimed at improving day-to-day functional behavior.

It is possible that the use of VE technology could revolutionize our approach to NA. While formidable problems remain, the potential is impressive. The possibility of linking VE assessment with advanced brain imaging and psychophysiological techniques (Pugnetti, Mendozzi, Barberi, Rose, & Attree, 1996; Aguirre, & D’Esposito, 1997; Decety et al., 1994) may allow neuropsychology to reach its stated purpose, that of determining unequivocal brain-behavior relationships. While pragmatic concerns need to be addressed in order for this technology to come close to meeting this lofty goal, the benefits that could be accrued appear to justify the effort.

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1. The presentation of ecologically valid testing and training scenarios and/or cognitive challenges which are difficult to present using other means (i.e., dynamic, interactive 3D stimuli).
 2. Total control and consistency of stimulus delivery.
 3. The presentation of hierarchical and repetitive stimulus challenges which can be varied from simple to complex, contingent upon success.
 4. The provision of “cueing” stimuli or visualization tactics (i.e., selective emphasis) designed to help guide successful performance within a “dynamic” testing or errorless learning paradigm.
 5. The delivery of immediate performance feedback in a variety of forms.
 6. The capacity to pause assessment and training for discussion or other means of instruction.
 7. The option for self-guided exploration and independent testing and training when deemed appropriate.
 8. The modification of sensory presentation and response requirements based on the user’s impairments (i.e., movement, hearing, and visual disorders).

9. The capacity for complete performance recording.
10. The availability of a more naturalistic/intuitive performance record for review and analysis by the user.
11. The design of safe learning environments which minimize the risks due to errors.
12. The introduction of “gaming” factors into the learning situation to enhance motivation.
13. The ability to create low cost functional training environments.

Table 1. *VE Advantages for Neuropsychological Assessment and Cognitive Rehabilitation Applications*

Brief Introduction To Cognitive Rehabilitation (CR)

Many definitions of what cognitive rehabilitation (CR) involves have been put forth, with Parente and Herrmann (Parente, & Herrmann, 1996) describing it in general terms as “the art and science of restoring . . . mental processes after injury to the brain”(p.1). Sohlberg and Mateer, (1989) define CR as “. . .the therapeutic process of increasing or improving an individual’s capacity to process and use incoming information so as to allow increased functioning in everyday life”(p.3). As with NA, both component cognitive processes and functional activities of daily living are typically targeted with CR. Cognitive processes are often further broken down into sub-components and addressed. For example, attention can be partitioned into focused, sustained, selective, alternating, and divided components that are targeted with different tactics (Sohlberg, & Mateer, 1989). Likewise, memory is often broken down into traditional cognitive psychology categories such as iconic, working, procedural, declarative, prospective, and episodic memory domains. IADLs are also targeted with functional CR strategies. Between the complexity of the subject matter and the nascent status of work in this area, considerable controversy exists as to the relative effectiveness of various CR approaches (Wilson, 1998). Rather than debating the merits of any specific CR approach, our discussion will focus primarily on how VE technology may be a useful tool for administering a wide range of CR strategies.

Cognitive rehabilitation approaches can differ based on a variety of conceptual criteria (Kirsch, Levine, Lajiness-O’neill, & Schnyder, 1992). For the purposes of describing the application of VE

technology to CR, these conceptual dimensions can be “collapsed” into two general domains: *Restorative* approaches which focus on the systematic retraining of component cognitive processes (i.e., attention, memory, etc.) and *Functional* approaches which emphasize the stepwise training of observable behaviors, skills, and IADLs. These domains can be viewed as opposite ends of a continuum of methods with many specific CR approaches falling somewhere between these poles. The restorative and functional approaches to CR have different methods and goals. The primary objective of the restorative approach is to retrain individuals how to *think*, whereas the emphasis of the functional approach is to teach individuals how to *do*. For example, the treatment direction for a 20-year old with mild head injury may primarily have a restorative focus and target component thinking processes with a goal of improving cognitive flexibility. By contrast, an elderly patient with dementia may be better suited to a functional approach targeting compensatory, environment-centered goals needed to maintain independent living. An example of the differential emphases contained within these approaches can be seen in the area of memory rehabilitation. The restorative approach emphasizes a "drill and practice" method in which the person is challenged to attend to, remember, and/or manipulate increasingly more difficult pieces of information contingent on success (Lynch, 1983) and hence, cognitive ability is expected to improve, much like a muscle gets stronger with increased exercise. Stimuli that are easily quantifiable and can be gradually increased in difficulty level are often used with this approach (i.e., lists of letters, numbers, words, sentences, directions, geometric designs, etc.). Functional approaches generally focus on training IADLs, such as practicing a sequence of events to prepare for work in the morning or a set of structured steps for completing day-to-day functional activities. These strategies attempt to rehabilitate the person by training the actual IADL skills using well-practiced routines within the target environment, sometimes incorporating compensatory mental “prosthetic” devices, such as alarms and reminder notes, located in strategic positions around the environment.

Specific weaknesses have been identified in both of these approaches. One often cited criticism of restorative methods is the reliance on test materials or tasks that are essentially artificial and have little relevance to real-world functional cognitive challenges. This criticism holds that "memorizing" increasingly difficult lists of words or activities within a therapy or school environment does not support the *transfer* or *generalization* of memory ability to the person's real-world situation

(O’Conner, & Cermack, 1987; Chase, & Ericsson, 1981). The fundamental criticism of functional methods is that the learning of standard stereotyped behaviors to accomplish IADLs assumes that the person lives in a static world where life demands do not change, and that the person’s underlying cognitive processes are not addressed. This is believed to limit the flexible and creative problem-solving required to adjust to and think through changing circumstances in the real world (Kirsch et al., 1992).

The application of VE technology for the rehabilitation of cognitive/functional deficits could serve to limit the major weaknesses of both the restorative and functional approaches, and actually produce a systematic treatment method that would integrate the best features from both methods. In essence, it may be possible for a VE application to provide systematic restorative training within the context of functionally relevant, ecologically valid simulated environments that optimize the degree of transfer of training or generalization of learning to the person’s real world environment. VEs could also serve to provide a more controlled and systematic means for *separately* administering restorative or functional techniques when this direction is deemed appropriate. An analysis of the suitability of VE technology in meeting the minimum criteria for both restorative and functional approaches can be found in a previous paper (Rizzo, 1994). Also see Table 1.

It should also be noted that underlying the goals of both of these conveniently termed treatment directions (thinking vs. doing) is the concept of *neural plasticity*. Neural plasticity refers to the capacity of the brain to reorganize or repair itself following injury, through various mechanisms (i.e., axonal sprouting, glial cell activation, denervation supersensitivity, and metabolic changes) in response to environmental stimulation. Recognition of neural plasticity in response to both environmental enrichment or impoverishment has its roots in the animal literature (Renner, & Rosenzweig, 1987) and detailed reviews of this increasingly favored view of the brain can be found elsewhere (Rose, & Johnson, 1992). Consequently, it can be appreciated that the stimulation or “enrichment” provided by both restorative and functional approaches may each have some effect on the physical brain structure, and hence, training with both methods would be assumed to affect brain plasticity. If this view is accepted, stimulating virtual training environments would seem well suited to support this process and new approaches to CR would be warranted.

The “Virtual Classroom” Attention Process Assessment and Training Project

We are currently developing a HMD-delivered VR system for the assessment and possible rehabilitation of attention processes. Our rationale for choosing this cognitive process relates to the widespread occurrence of attention impairments seen in a variety of clinical conditions and our belief that VR provides specific assets to address these impairments that are not available using existing methods. Virtual reality HMDs are well suited for these types of applications as they serve to provide a controlled stimulus environment where cognitive challenges can be presented along with the precise delivery and control of “distracting” auditory and visual stimuli. This level of experimental control could potentially allow for the development of attention assessment tasks that are more similar to what is found in the real world, and hence, the ecological validity of measurement in this area could be improved.

Problems with attention are seen in a wide range of diagnoses across the human lifespan. Most notably, attention difficulties are seen in persons with Attention Deficit Hyperactivity Disorders (ADHD), Traumatic Brain Injury (TBI), and as a feature of various forms of Dementia (i.e., Alzheimer’s Disease, Vascular Dementia, etc.). For example, the prevalence of ADHD is estimated at 3%-5% in school age children, with data on its occurrence in adolescence and adulthood being somewhat limited (DSM-IV, 1994). Traumatic Brain Injury due to various forms of head trauma is also a significant mental health concern. Conservative estimates of prevalence range from 2.5 million to 6.5 million individuals living with the consequences of TBI (NIH Consensus Statement, 1998), with attention problems frequently cited as the chief disability in this clinical population (Wilson, 1998). Attention difficulties also commonly occur in the elderly, with some form of dementia affecting between 5 and 10 percent of those older than 65 years, and 47 percent of those older than 85 years of age (Max, 1993). Similar attention problems may also result from lack of oxygen to the brain secondary to cardiovascular conditions including strokes and myocardial infarctions.

More effective assessment and rehabilitation tools are needed to address attention abilities for a variety of reasons. In children, attention skills are the necessary foundation for future educational activities. Accurate cognitive assessment is also vital for decision making regarding special educational placement concerns, the possible use of

pharmacological treatments, and for treatment efficacy and outcome measurement. Persons with acquired brain injury also require focus on attention abilities as a precursor to rehabilitative work on higher cognitive processes such as memory, perceptual processing, executive functions, and problem-solving. 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. A more fine-grained assessment of attention deficits may also provide an early indicator of dementia-related symptoms and could suggest functional areas where an older person might be at risk (i.e., automobile driving, operating machinery, etc.), or where compensatory strategies may be needed in order to maximize or maintain functional independence.

The cognitive process of attention is well suited for a comprehensive VR assessment and rehabilitation approach. Within an HMD-delivered virtual environment, it is possible to systematically present cognitive tasks targeting attention performance beyond what is available using traditional methods. Current methods for assessing attention difficulties include traditional paper and pencil tests, motor reaction time tasks in response to various signaling stimuli, flatscreen computer delivered approaches, and behavioral observation techniques. These methods have limitations regarding issues of reliability and validity, and behavioral observation methods are additionally time consuming and costly. Rehabilitation approaches for this cognitive process also suffer similar obstacles.

Traditional neuropsychological testing and rehabilitation approaches have also been criticized as limited in the area of ecological validity, which refers to the activity's degree of relevance to the "real" world (Neisser, 1978; Wilson, 1998; Posner, & Rafal, 1987). VR could allow for attention to be tested in situations that are more ecologically valid. Subjects can be evaluated in an environment that simulates the real world, not a *contrived* testing environment. This last point is particularly important in view of the complexity of attention demands that people face in even the most simple of everyday activities. This becomes clearer when one looks at the various components that compose successful attention ability.

Sohlberg and Mateer (Sohlberg, & Mateer, 1989) have presented an intuitively appealing "Clinical" model of attention processes that is useful for conceptualizing and targeting deficits seen in various clinical conditions. Within this model, they outline levels of attention that are hierarchically organized:

1. *Focused* attention – This is the basic ability to respond to specific external stimuli which is often disrupted during the early stages of emergence of coma, but is usually well recovered over time.
2. *Sustained* attention – While commonly termed "concentration", this refers to the maintenance of a consistent behavioral response during continuous and repetitive activity. This component is often measured using "radar detection" type tasks, where the person is required to attend to ongoing stimuli consistently over long periods of time. Impairments in this area may limit a person's ability to become involved in, or benefit from educational (classroom lectures) and recreational (watching a movie) activities.
3. *Selective* attention – This refers to the ability to maintain behavioral or cognitive attention set in the face of distracting or competing stimuli. Again, deficits in this area would impede a person from benefiting from any activity where internal and/or external stimuli compete with what needs to be focused upon. This might be seen in children who are unable to focus on the conversation of a teacher or peer in the presence of additional activity going on around them. This is also often referred to as "freedom from distractibility."
4. *Alternating* attention – This refers to the capacity for mental flexibility that allows one to shift the focus of attention and move between tasks having different requirements. Functional living problems in this area could be seen in the relatively simple task of preparing a meal. In this situation, the person is required to alternately attend to multiple task sequences in order to prepare two or more "recipes" for a meal. Even mild impairments in this area might also limit a person's vocational options, as in the case where they would be required to use a computer in conjunction with taking telephone orders.
5. *Divided* attention – This would describe the type of attention skill needed when two or more behavioral responses may be required, or two or more kinds of stimuli may need to be monitored. Although a case could be made that this may really be rapidly alternating attention, or that one of the tasks is highly overlearned, the ability to attend and respond to multiple tasks simultaneously is a common experience in everyday life. Thus, divided attention suggests an important attention target to assess

and rehabilitate. In educational settings this might be seen when a person is required to take notes while listening to a lecture. This component might also describe the common everyday experience of listening to verbal instructions and taking direction for a task to perform at a later time, while another activity is ongoing. This might be seen in the case of paying attention to directions on the phone during a meal preparation.

These attention components are being used as a framework for a series of VR assessment and rehabilitation applications that are being developed in our lab. Our plan is to develop a variety of functional scenarios that will be delivered in a virtual environment within which, attention components could be assessed and potentially rehabilitated. While immersed in the virtual environment, a person could be tested and trained on attention tasks that more systematically target specific levels of attention. These tasks include stimulus demands and response requirements that simulate real-world cognitive challenges (ecological validity), beyond what currently exists using traditional methodologies. We are currently developing a virtual “classroom” scenario and future projects will model other clinically relevant scenarios including factory, office, home, and other day-to-day functional environments. Further, with the addition of voice recognition technology, verbal responding could supplement motor performance in an effort to further replicate the ecological demands of real-world functional environments. This approach would allow for naturalistic assessment and rehabilitation strategies without the loss of experimental control typically cited as problematic with behavioral observation methodologies (Rose, 1996).

A recent effort by our lab in this area has involved the development of a virtual “classroom” specifically aimed at the assessment of Attention Deficit Hyperactivity Disorder (ADHD). A recent Consensus Report by the National Institute of Health on ADHD suggests a variety of areas where better assessment tools would be of value. The report specifically cites the need for better definition of the nature of this disorder and an emphasis on measuring the effectiveness of intervention strategies (NIH Consensus Statement, 1998). These recommendations supported our interest in addressing this clinical group in our first VR/attention application. The scenario consists of a standard rectangular classroom environment containing three rows of desks, a teacher’s desk at the front, a male or female teacher, a blackboard across the front wall, a side wall with large window looking out onto a street with background

buildings, vehicles, and people, and on each end of the wall opposite the window-- a pair of doorways (see Figure 1).

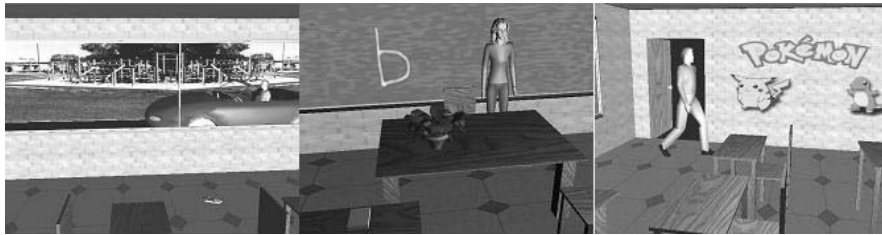


Figure 1. Scenes from the “Virtual Classroom” for assessment of Attention Deficit Hyperactivity Disorder

Within this scenario, children will be assessed in terms of attention performance while a series of typical classroom distracters (i.e. 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 virtual desk within the virtual classroom and the environment can be programmed to vary with regards to such factors as seating position, number of students, gender of the teacher, etc. On-task attention can be measured in terms of performance on a variety of attention challenges that can be adjusted based on the child’s expected age or grade level of performance. For example, on the simpler end of the continuum, the child could be required to press a “colored” section of the virtual desk upon the direct instruction of the teacher or whenever the child hears the name of the 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 by pressing the “colored” section only when the teacher states the 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 on the blackboard. In addition to these attention performance indicators, behavioral measures that are correlated with distractibility and/or hyperactivity components (i.e., head turning, gross motor movement), and impulsive non-task behaviors (playing with “distracter” items on the desk) will be measured. Other scenarios (i.e., work situations, home

environments, etc.) using the same logic and approach are being conceptualized to address these and other clinical groups.

Our first study will compare ADHD diagnosed children (aged 8-12) with a non-diagnosed control group using more basic attention challenges. A full standard diagnostic assessment using currently available tools will be available on all subjects. ADHD subjects will be tested prior to taking any medications and the VR exposure will last for 30 minutes. Three conditions will be presented for nine minutes each. The first two conditions will use basic visual stimulus challenges found in commonly used flatscreen computer assessment tools. The subject will be instructed to view a series of letters presented on the blackboard and to hit the response button only after he/she views the letter "X" preceded by an "A". Condition 1 will be administered without distractions, while Condition 2 will be the same task with distractions included. Reaction time and response variability will be used as performance measures, while "head turning" and gross motor movement will be recorded by the tracking devices on the HMD and on the hand tracking system to assess activity levels. These conditions were selected for our first study in order to compare what added value this system may have relative to standard

It is our view that an immersive VR approach possesses the capacity to systematically provide *distraction* within an ecologically valid scenario (classroom) and would offer better predictive information regarding performance in the real environment. However, the types of stimulus challenges used in Conditions 1 & 2 are not typical of what is found in a classroom environment. To further address these issues, in Condition 3 we will use cognitive challenges that more closely mimic the types of attention tasks that are typically found in a classroom environment. These tasks will create challenges that combine both visual and auditory sensory stimuli and possibly allow for a more ecologically valid assessment of higher levels of attention. In this condition, the subject will need to follow verbal instructions from the virtual teacher that directs attention to the blackboard, which in turn will provide visual stimuli requiring a response. For example, the virtual teacher may request a hit response if an image of a cat appears on the blackboard. The next level may request a response if the cat is wearing a collar, and a successive series of questions would follow in like manner. In essence, attention targeting in this condition could utilize a wide variety of "real-life" classroom stimuli and tasks that can be created using auditory (teacher's speech) and visual (on the blackboard) presentation of colors, geometric forms, numbers, letters, single words, full sentences, and illustrations of objects, all of which require some response. The key to designing these

types of challenges is to create test items that measure attention in a complex manner without requiring complex reading, language, and reasoning skills. This is necessary in order to have an adequate level of specificity of measurement as opposed to picking up general influences due to limitations in ability in other areas. In this regard, the focus of testing should be to be directed towards primarily measuring attention rather than involving other skills. For example, a slower response time to a task involving complex math may reflect poorer math ability rather than attention. Similarly, the use of complex language challenges such as requesting the student to respond when the sentence presented on the board contains two adverbs may not be advised. By contrast, questioning as to whether or not a sentence contains the names of two common house pets may be more appropriate. These issues tap a range of human information processing questions that are beyond the scope of this article and will be empirically addressed in our pilot study set to commence in early 1999.

One other consideration for working with this population concerns the observation that children diagnosed with ADHD often have a fascination for the type of stimulus environments that occur with computer/video games. Parents are often puzzled when they observe their children focusing on video games intently while teacher reports indicate inattention in the classroom (Greenhill, 1998). While this observation may suggest possible directions for computer and VR-delivered approaches to education and cognitive rehabilitation strategies, it could minimize the value of *assessment* if VR scenarios are “too interesting” to children. Our strategy to address this involves limiting the stimulus “variety” in the design of testing trials in the virtual classroom environment and by emphasizing longer testing periods characterized by repetitive tasks coupled with distraction. Again, empirical analysis will be the primary method to sort out these issues.

We anticipate that this work may also serve to help differentiate the various sub-types reported to occur with ADHD. The occurrence of pure attention vs. pure hyperactive vs. mixed subtypes may be better assessed in a VE where, in addition to cognitive performance, motor activity levels can be recorded via the position tracking system. This might also be of particular value for assessing the effects of medications on performance. While pharmacological treatment may produce a measurable decline in motor “fidgetiness”, it may be found through measurement within a VE, that concurrent attention does not improve. This may also be of value for examining gender differences in the diagnosis of this disorder since the male predominance reported in

incidence statistics have ranged from between 4:1 and 9:1 depending on the setting where the data was collected. Perhaps boys are more commonly diagnosed due partly to differences in occurrence of the more “observable” hyperactive component. By contrast, girls who do not manifest the hyperactive component may be less “noticed” yet may still have attention deficits that go undiagnosed. In fact, the recent NIH ADHD Consensus report suggests that more effort is needed in assessing the inattentive subtype, particularly since it may comprise a higher proportion of girls than the other subtypes. This underscores an area where social expectations for classroom behavior may result in biased behavioral observations that affect diagnostic accuracy. A VE approach in this area would be well matched to address this question.

Summary and Future Plans

VR technology could potentially improve the reliability of neuropsychological assessment by allowing for more consistent presentation and manipulation of complex test stimuli along with more precise measurement of participant responses. The reliability and validity of measurement of the component cognitive domains of attention could potentially be enhanced by the capacity of VR technology to present both test and distraction stimuli along with better quantification of discrete responding. In this manner, VR could offer the potential for cognitive assessment and rehabilitation within simulated “real-world” functional testing and training environments with an aim towards improving ecological validity. Following empirical testing of the parameters outlined above, our plan is to develop an inexpensive system that would be used in clinics, schools, and research settings. While we are currently using high-end equipment, we hope that by the time we have empirically developed a reliable and valid set of VR tasks, and basic clinical trials are conducted to develop normative data, that the technology will have advanced concurrently to the point where our scenario could be delivered on less expensive and readily available equipment. A more precise form of measuring attention performance using VEs modeled after real life settings should, in theory (Decety et al, 1994), provide better predictions of performance in the real world. This view reflects the current thrust of our work.

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