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The Virtual Classroom: A Virtual Reality Environment for the Assessment and Rehabilitation of Attention Deficits

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ABSTRACT

The Virtual Environments Laboratory at the University of Southern California (USC) has initiated a research program aimed at developing virtual reality (VR) technology applications for the study, assessment, and rehabilitation of cognitive/functional processes. This technology is seen to offer many advantages for these aims and an introductory section of this article will discuss the specific rationale for VR applications in the area of clinical neuropsychology. A discussion of attention processes will follow and issues for the development of a head-mounted display (HMD) VR system for the study, assessment, and possible rehabilitation of attention disorders will then be presented. 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), Traumatic Brain Injury (TBI), and as a feature of various neurodegenerative disorders (i.e., Alzheimer's Disease, Vascular Dementia, etc.). Virtual Environment (VE) technology appears to provide specific assets for addressing these impairments that are not 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 cognitive 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 tasks 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. A recent project in our lab has involved the development of a virtual "classroom" specifically aimed at the assessment of Attention Deficit Hyperactivity Disorder (ADHD). The system uses a Virtual Research V8 HMD, Ascension Systems head, hand, and leg tracking, and is run on an SGI Onyx platform. The scenario consists of a standard rectangular classroom environment containing student desks, a teacher's desk, a virtual teacher, a blackboard, a large window looking out onto a playground with buildings, vehicles, and people, and a pair of doorways on each end

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of the wall opposite the window through which activity occurs. Within this scenario, normal and ADHD-diagnosed children will be assessed for reaction time performance on immersive visual and 3D audio attention tasks. At the same time, a series of typical classroom distracters are systematically manipulated within the VE (i.e., ambient classroom noise, paper airplane flying around the room, human avatars walking into the room, activity occurring outside the window). Head turning and general motor movement are also recorded to assess hyperactive behavior components that are often seen with this disorder. The article will then present a review of ADHD issues, provide specifics regarding the methodology for our current pilot work targeting ADHD and non-diagnosed groups, and discuss our future plans for this application. It is believed that this project targets a cognitive variable that is well matched to the current strengths and limitations that exist with presently available virtual reality technology.

INTRODUCTION

Virtual reality (VR) technology is increasingly being recognized as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities.[1–5] Much like an aircraft simulator serves to test and train piloting ability, virtual environments (VEs) can be developed to present simulations that target human cognition and behavior. The capacity of VR to create dynamic, immersive 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.[6–23] 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 that 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 that focus on component cognitive processes including: attention processes,[6] spatial abilities,[7–14] memory,[15–19] and executive functions.[20,21] VR functional training scenarios have also been designed to test and teach basic instrumental activities of daily living such as: meal preparation,[22,23] street-crossing,[24,25] common object recognition,[25] supermarket shopping,[26] use of public transportation,[27] and wheelchair navigation.[28] 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.

CLINICAL POPULATIONS WITH CENTRAL NERVOUS SYSTEM DYSFUNCTION

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.[29] The peak age of incidence is in the 15–24-year range (closely followed by the birth to 5 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.[30]

Neurological disorders that 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 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,[31] an estimate that has alarming social, economic, and public health implications.

Approximately three million Americans also suffer with some degree of disability from stroke.[32] Although a stroke can occur at any age, the risk doubles for every decade after the age of 55. 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 function. The total cost of stroke to the United States is estimated to range from $30 to $43 billion per year.[33]

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.[34] 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.

NEUROPSYCHOLOGICAL ASSESSMENT

In the broadest sense, neuropsychology is an applied science that evaluates how specific activities in the brain are expressed in observable behaviors.[35] The increase in our understanding 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. Neuropsychological assessment (NA) uses psychometric evaluation tools to diagnose dysfunction, specify cognitive strengths and weaknesses to help inform the design of rehabilitative strategies, and provide metrics to assess treatment efficacy or plot neurodegenerative decline. VE technology offers the potential to develop human performance testing environments that could supplement existing NA procedures that traditionally rely mainly on pencil and paper tests and behavioral observation. Used in this manner, VEs for NA could lead to improvements in psychometric reliability and validity that would produce better detection, diagnosis, and mapping of the assets and limitations that occur with different forms of CNS dysfunction.

VEs may be especially suited to improve *eco-*

logical validity, or the degree of relevance or similarity that a test has relative to the "real" world.[36] This asset would allow for human cognitive/functional performance to be tested in simulated "real-world" VE scenarios. In this way, the complexity of stimulus challenges found in naturalistic settings could be delivered while still maintaining the experimental control required for rigorous scientific analysis. Results would have greater clinical relevance and could have direct implications for the development of more effective functional rehabilitation approaches.

Although formidable problems remain, the potential to augment traditional neuropsychological testing is impressive. The possibility of linking VE assessment with advanced brain imaging and psychophysiological technologies[37,38] may allow neuropsychology to reach its stated purpose, that of determining unequivocal brain–behavior relationships.

COGNITIVE REHABILITATION

Cognitive rehabilitation (CR) can be defined as the application of methods that aim to restore cognitive processes or arrest the resulting decline following injury to the brain.[39] Sohlberg and Mateer[40] suggest that cognitive rehabilitation is "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). Thus, specific cognitive processes and Instrumental Activities of Daily Living (IADLs) are both targeted with CR. In this regard, the conceptual dimensions of CR can be collapsed into two general domains: *Restorative* approaches that focus on the systematic "drill and practice" retraining of component cognitive processes (i.e., attention, memory) and *Functional* approaches that emphasize the stepwise training of observable behaviors, skills, and IADLs. The restorative approach places the attempt to retrain individuals on how to *think* as the primary objective, whereas the primary emphasis of the functional approach is to teach individuals how to *do*. For example, treatment for a 20-year-old with a 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 Alzheimer's dementia may be better suited to a functional approach targeting compensatory, environment-centered goals needed to support independent living.

Specific weaknesses have been identified in both of these approaches. These mainly concern problems with transfer of gains from the training environment to new settings. It is our view that VE technology may uniquely address these concerns and produce a systematic treatment approach that integrates the best features from both methods. In essence, VE applications may serve to provide systematic *restorative* training within the context of *functionally* relevant, ecologically valid simulated environments. This combination would optimize the degree of transfer of training to the person's real world environment, along with cognitive flexibility gains that support skill transfer to an ever-changing world. VEs may also 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 article.[41]

ATTENTION PROCESSES

Over the last 6 years, a growing number of researchers have begun the initial work of exploring the use of VE technology for applications designed to target NA/CR with populations having CNS dysfunction. Although the breadth of this clinical literature pales by comparison to VE research in the testing and training area with normal populations, the initial efforts using VEs designed for impaired clinical groups are encouraging. The remainder of this article will first discuss attention processes generally, and then focus on the details of our development of a VE system that will first target youthful populations with ADHD.

Attention processes are the gateway to information acquisition and serve as a necessary foundation for most higher learning. Impairments in attention can be found in clinical populations across the lifespan and are commonly seen in persons with ADHD, TBI, and as a feature of various forms of age-related dementia (i.e., AD). Little VE work has been done with this "basic" gateway cognitive process thus far, which is surprising in view of the relative significance of attention impairments seen in a variety of clinical conditions. More effective assessment and rehabilitation tools are needed to address attention processes for a variety of reasons.

In children, attention skills are the necessary foundation for future educational activities. Regarding ADHD, improved assessment of attention is vital for diagnostic purposes, special education placement decisions, determination of the use and effectiveness of pharmacological treatments, and for outcome measurement. Persons with TBI often suffer attention deficits that require focus as a precursor to rehabilitative work on higher cognitive processes (i.e., memory, executive functions, and problem solving). Also, even if higher processes are unable to be remediated in cases of severe TBI, some level of attention ability is essential for vocational endeavors, functional independence, and quality of life pursuits. With the elderly, a more fine-grained assessment of basic attention deficits may provide an early indicator of dementia-related symptoms. This assessment could suggest functional areas where an older person might be at risk (i.e., automobile driving, operating machinery) and guide development of compensatory strategies useful to maximize or maintain functional independence.

One form of attention disorder that has been addressed with VE technology concerns the area of visual neglect or inattention to a specific visual field, which is sometimes seen following stroke and TBI. Visual neglect is defined as inattention to objects or events positioned in the visual space opposite to a brain lesion. It is not a vision problem, but a disorder of the integrated functioning of vision and attention. Classic signs of neglect are combing hair on only one side of the head, reading words only on the unaffected half of a printed page, or eating food from one half of a plate and believing it to be empty.

Attention abilities are now being addressed using VEs,[6,42,43] and the assessment and rehabilitation needs for this cognitive process are well matched to a comprehensive VR approach. Within an HMD-delivered virtual environment, it is possible to systematically present cognitive tasks targeting attention performance beyond what are currently available using traditional methods. Current methods for assessing attention performance 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 additionally, some approaches such as behavioral observation, are time consuming and costly. Rehabilitation approaches for this cognitive process also suffer similar obstacles. Further, 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.[36,44,45] 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 clear when one looks at the various components that comprise successful attention ability.

Sohlberg and Mateer[40] 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 that 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 VE within which attention components could be assessed and potentially rehabilitated. While immersed in the VE, 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.[46]

ATTENTION DEFICIT/HYPERACTIVITY DISORDER

Attention Deficit-Hyperactivity Disorder (ADHD) is a behavioral condition identified by the DSM-IV.[47] For a diagnosis of ADHD to be made, symptoms must be present before the age of 7, persist for at least 6 months, and be of sufficient intensity to impact functioning across several settings (e.g., home and school). Epidemiological studies have indicated that 3–5% of the general population in the United States suffers from the disorder. Males are disproportionately represented in this diagnostic category, but research has not found significant differences in the presentation of the disorder between males and females. Biological theories implicate dopamine D4 receptors, a right hemisphere deficit, disregulation in the frontal cortical basal ganglia connection, polymorphisms in dopamine chains, and catecholamine balance.

Three subtypes of ADHD have been identified by the DSM-IV. The first is the hyperactive type where overactivity and impulsivity are dominant features. Patients within this subtype demonstrate excessive motor fidgetiness, excessive talking, a tendency to interrupt people, and general increased activity. The inattentive type is marked by difficulties with attention such as failure to give close attention to details, difficulty organizing tasks and activities but without hyperactivity. The combined type that some argue may be a later developmental manifestation of the hyperactive type[48] evidences both types of symptoms.

There is considerable debate in the literature as to whether the subtypes of ADHD listed in the DSM-IV represent different presentations of the same disorder or are three separate disorders. Some researchers postulate that all three subtypes are part of the same diagnostic category, and that the differences between them are more a matter of degree. It is argued that behavioral disinhibition is central to only two of the subtypes,[48,49] a feature that helps to explain why these children are able to pay attention but are impaired in their ability to sustain attention.[50] These children, like other children, tend to pay attention to the most salient or stimulating event in the room. Their difficulty becomes apparent when they are required to inhibit the tendency to attend to a new stimulus. For example, when a teacher begins a lecture, the presentation itself is new and therefore stimulating for the first few minutes. As the lecture progresses, however, other events such as the squirrels on the tree outside the window or the movement of the child sitting next to the student become more stimulating than the teacher. People with normally functioning attention systems are able to inhibit the impulse to divert their attention and, therefore, remain tuned into the lecture. Children with either the hyperactive-impulsive or combined types of ADHD appear to lack the ability to disregard the competing stimulus and consequently are thrown "off track" by it. Their difficulty with continued attention creates the impression of distractibility, a hallmark of the ADHD syndrome. By contrast, the inattentive type is viewed by many researchers as being a deficit in focused or selective attention and speed of information processing, and may consist of more internalizing rather than externalizing symptoms.[51,52] In addition to these qualitative differences in attention deficits among subtypes, researchers have noted that co-existing diagnoses differ between the two categories. For example, children with the hyperactive or combined type exhibit more conduct disorder and oppositional defiant disorder while children with the inattentive type have increased incidences of learning disabilities.[53] Other researchers propose additional subtypes for the DSM-V. These include aggressive, antisocial, and anxious subtypes.[54,55]

Cognitive symptoms beyond inattention and hyperactivity have also been implicated in the ADHD syndrome. Most notably executive functioning, which is defined as self-directed actions of the individual that are being used to self-regulate,[48] is often decreased with this disorder. Individuals with ADHD often exhibit difficulty organizing their behavior and problem solving, as well as impaired cognitive flexibility. Based on this conceptualization, four components of executive functioning have been isolated and include:

1. Nonverbal working memory.
2. Verbal working memory/internalization of speech.
3. Self-regulation of affect, motivation, and arousal.
4. Reconstitution (analysis/synthesis of mentally represented information).

The features of ADHD have made a consensus regarding assessment and diagnosis being somewhat difficult. Given that the symptoms of ADHD are more obvious in situations that are boring, marked by a lack of structure, or have redundant features, a traditional testing environment does not always elicit them. In a traditional testing environment there is a one-to-one relationship with the examiner, and the activities change every few minutes, thereby creating interest and excitement on the part of the examinee. This makes inattention more difficult to identify. As a response to this predicament, the assessment of ADHD has generally followed several paths.

The most popular at present is the use of behavioral questionnaires completed by respondents who are with the examinee throughout the day, typically parents and teachers. Questionnaires are completed in order to track a child's behavior across a 24-hour period. This allows for the same control of situational variables, although problems exist with such questionnaires. One study indicated that behavioral checklists were not a consistent predictor of ADHD.[56] Many of the children in this study were found to have difficulty paying attention due to a variety of reasons including inappropriate placement, learning problems, and emotional problems due to trauma. In addition, many checklists do not include validity scales and therefore allow personal bias to occlude reality. Another problem is that disorders that mimic ADHD, such as poor receptive language processing or mood disorders, may not be identified.

Other researchers have proposed to assess certain *symptoms* of ADHD, most notably, decreased executive functioning. Although research has demonstrated variable results in the use of such tests to assess ADHD, some measures appear to be more sensitive than others. For example, the Wisconsin Card Sorting Test,[57] a measure of cognitive flexibility and problem solving associated with the pre-frontal cortex has been shown to discriminate between subjects diagnosed with ADHD and normals in several experiments.[58–60] Other measures of executive functioning shown to discriminate between the two groups have been the Stroop Test,[58] Controlled Oral Word Association Test,[61] and Picture Arrangement (from the Wechsler Intelligence Scale for Children-III).[62]

Another approach has been to assess attention directly. This has been attempted with more success through the development of various continuous performance tests (CPTs). Originally thought to assess "sustained vigilance," the CPTs are thought to encompass many dimensions such as arousal, activation, and effort.[63,64] Forbes[65] suggests the CPT is a laboratory measure of attention and impulsivity. The CPT measures, often administered via a computer screen, ask the examinees to respond differently to the target than to other non-target stimuli. One of the earliest forms is the Gordon CPT,[66] which lasts 9 minutes and shows the examinee a succession of letters and asks him/her to respond whenever the letter X appears just after the letter A is presented. These continuous performance tests are designed to be boring and repetitive, thereby demanding attention from the examinee, something that is more difficult for a person with ADHD.

Research on various forms of the CPT has indicated that one of the most valid variables in the instrument is the variability of the response time between the presentation of the stimulus and the response. Alternating the speed of presentation of stimuli heightens the sensitivity of this measure.[63] A problem with the CPT is that although it assumes that distracters within the examination room are affecting the child, there has been little control over what the distracters might be. Although test instructions suggest ways of controlling the distracters (e.g., placing the subject in a non-stimulating room, leaving the subject alone with the task) other distracters such as the noise outside the window are not controlled. Rather than controlling the distracters, the CPT assumes that children who do not have ADHD will be able to ignore whatever distracters are present better than those with ADHD, and therefore will have less response time variability and more correct responding. Better control of distracters within the environment as well as measurement of the time the child is looking away from the target task might increase the sensitivity of the CPT in discriminating between normal subjects and those affected by ADHD.

Another approach to ADHD assessment has been direct observation of the examinee in a controlled environment where the child has monitors attached to his/her arms and legs in order to measure hyperkinesis. Barkley and colleagues,[67] describe this approach as follows: The child is given a worksheet of math problems to complete in a very stimulating environment. Raters watch the child through a one-way mirror and note off-task behavior at the same time that the leg monitor measures fidgetiness. Results of this experiment showed that the ADHD children were off-task significantly more than normals, but increased leg movement was not found. Problems with this approach include the expense of using reviewers as well as the issue that the novelty of the leg monitor in an understimulating environment may have helped the child manage his/her motor restlessness to a greater degree.

Many researchers agree that a multi-modal approach is crucial and propose a more conservative approach to diagnosis that includes diagnosing ADHD in only those children who rate consistently across various assessment measures.[63,68] The diagnosis will be deferred for those children who rate with inconsistent results. Only after a monitoring period during which interventions are made on various levels, will a child be reassessed and a diagnosis will be reconsidered.[56]

Overall, these traditional ADHD assessment methods all have limitations regarding the capability to systematically record and measure attention performance within a controllable, yet ecologically valid environment, in a cost-effective manner. To address this concern, we are developing a VE that provides systematic multi-sensory delivery of attention test challenges within a realistic classroom scenario containing "typical" distractions. In addition to the control of stimulus parameters, VE tracking technology will also allow for a more integrated assessment of real time motor activity components.

THE "VIRTUAL CLASSROOM" ATTENTION PROCESS ASSESSMENT AND TRAINING PROJECT

We are currently developing an 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. VR 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.

Our first project in this area has involved the development of a virtual "classroom" specifically aimed at the assessment of 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.[69] 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 student desks, a teacher's desk, a virtual teacher, a blackboard, a large window looking out onto a playground with buildings, vehicles, and people, and a pair of doorways on each end of the wall opposite the window, through which activity occurs (Fig. 1). Within this scenario, children can 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) are systematically controlled and manipulated within the VE. The child sits at a virtual desk within the virtual classroom and the environment can be programmed to vary with regard to such factors as seating position, number of students, and gender of the teacher.

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 remote

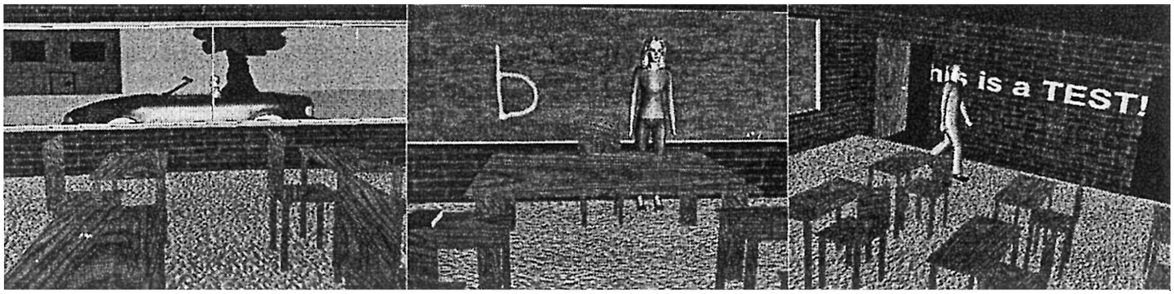

FIG. 1. Scenes from the "virtual classroom" for assessment of Attention Deficit/Hyperactivity Disorder.

mouse controller 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 response button 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) could be measured. Other scenarios (i.e., work stations, home environments) 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 as outlined in the next section.

METHODS FOR INITIAL ADHD CLINICAL TRIAL WITH THE VIRTUAL CLASSROOM

Subjects

Subjects will consist of 15 ADHD-diagnosed children and 15 children in a non-diagnosed control group. The subjects will be recruited from local agencies in the greater Los Angeles area with which our lab has established collaborative agreements, including USC Children's Hospital and UCLA Neuropsychiatric Institute. Males, aged 8–12, will be tested in the VR scenario. A full standard diagnostic assessment using currently available tools will be available on all subjects. This will include a full neuropsychological battery of tests, classroom behavioral ratings, and flatscreen computer–delivered continuous performance test results. This testing will be conducted at the referring facility and the results will be made available for data analysis comparisons with findings from the VR scenario. Normal subjects will also be administered the same diagnostic work-up. ADHD subjects will be tested prior to taking any medications and the VR exposure will last for approximately 30 minutes.

Procedures

Warm-up and familiarization with the scenario. Following completion of the USC Human Subjects Research Review Committee procedures and the signing of informed consent, subjects will be escorted into the testing room. The subject will sit at a standard "school desk" and a lab technician will assist in adjusting the fit of the Virtual Research V8 HMD to the child's head. An ascension tracking device will then be fitted to the subjects' non-dominant hand and opposite knee. At this point, the system presenting the virtual classroom will be activated and the subject will see the interior of the classroom in the HMD. The scenario consists of a standard rectangular classroom environment containing three rows of desks, a teacher's desk at the front, a blackboard across the front wall, a female virtual teacher between the desk and blackboard, a large window looking out onto a playground with buildings, vehicles, and people on the left side wall, and a pair of doorways on each end of the wall opposite the window through which activity occurs. The virtual teacher (VT) will then instruct the subject to spend a minute looking around the room and point and name the various objects that they observe. This will serve to assist the subject in becoming familiar with the components of the classroom environment. Following this 1-minute period, the VT will tell the subject that they are now going to "play a game." The VT will instruct the subject to hold the remote mouse in his dominant hand and press the button when the teacher says "go." This will serve to familiarize the subject with the operation of the remote mouse and provide functional practice for its use during the testing proper. Reaction time to hit the mouse button following the VT's command will be recorded from a series of 20 hit commands that will be presented at random intervals during a 1-minute period. The VT will then instruct the subject that a new game will now begin and the testing proper phase will commence.

Experimental conditions

Three conditions will follow, each lasting 10 minutes. The first two conditions will use basic visual stimulus challenges found in commonly used continuous performance tasks (CPTs) that are delivered by a flatscreen computer. In these conditions, the subject will be instructed to view a series of letters presented on the blackboard and to hit the response button only after he views the letter "X" preceded by an "A" (successive discrimination task). The AX version of the CPT will consist of the letters A, B, C, D, E, F, G, H, J, L, and X. The letters will be white on a gray background (the virtual blackboard) presented in a fixed position directly in front of the subject. The stimuli will remain on the screen for 150 msec, with a fixed interstimulus interval of 1350 msec. Four hundred stimuli will be presented in the 10-minute condition. The target letter X (correct hit stimuli) and the letter X without the A (incorrect hit stimuli) will each appear with equal probability of 10%. The letters A and H will both appear with a frequency of 20%. The remaining eight letters will occur with 5% probability. Subjects will be instructed to press the mouse button as quickly and accurately as possible (with their dominant hand) upon detection of an X after an A (correct hit stimuli) and withhold their response to any other sequence of letters. A 1-minute practice trial consisting of a very basic sample series will be presented to the subject with the experimenter providing prompts in order to assist the subject in learning the task. Upon completion of this phase, Condition 1 or 2 will begin.

Condition 1 will be administered without distractions, while *Condition 2* will consist of the same tasks *but* with distractions included. The order of presentation of all conditions will be counterbalanced across all subjects. The order of presentation of the hit stimuli will be administered based on the following rules: letters will appear on the board at a constant rate of one letter per 1.5 seconds (40× per minute); four correct hit stimuli per minute will presented (X preceded by an A) in a fixed order that will occur every 200 seconds. This means that three blocks of 200-second "orders" will be created; four incorrect hit stimuli per minute will be presented (X NOT preceded by an A) in the same format as outlined in step 2; 32 non-hit stimuli will be presented during each minute.

Condition 2 will present identical stimulus challenges as those presented in Condition 1; however, these will occur in the presence of pure 3D immersive audio distracters, pure visual distracters, or mixed 3D audio/visual distracters. Distracters will consist of the following: (1) *pure auditory*—ambient classroom sounds (i.e., whispering, pencils dropping, chairs moving) "behind" the student; (2) *pure visual*—3D paper airplane flying directly across the subject's field of view; (3) *mixed audio/visual*—car "rumbling" by outside window on the left; and man coming in and out of doors with sounds of the door "creaking open," footsteps, and hallway activity on the right side of the classroom.

Distracters will be presented in a consistent manner in 3-minute blocked segments that will correspond to the 3-minute "blocked" stimulus presentations. In this manner, performances in each subsequent, identical 200-second block will allow for comparison over time. Distracters will each be displayed for 5 seconds, and present in randomly assigned, equally appearing intervals of 10 seconds, 15 seconds, or 25 seconds. Thirty-six distraction intervals (12 of each) and 36 distracters (9 of each) will be included in the 10-minute condition.

Condition 3 will consist of a more realistic "ecologically valid" attention task requiring the integration of audio and visual attention processes. In this condition, line drawings of common objects will appear on the "blackboard." These drawings will be taken from the Boston Naming Test[70] and the VT will call out the item's name, either correctly or incorrectly. The subject will be asked to listen to the VT, observe the "blackboard," and to hit the response pad every time the VT incorrectly names the object. Stimulus drawings will be presented at a rate of one every 5 seconds. After 4.5 minutes, the criterion for response will shift to requiring the subject to hit the response pad after correct matches between the visual stimulus and the auditory name emanating from the VT. This condition will always be presented with both no distraction and with distractions occurring within the 10-minute block in a systematic fashion (15 seconds on/15 seconds off). The same type of distractions that occurred in Conditions 1 and 2 will be used in Condition 3. While the types of stimulus challenges used in Conditions 1 and 2 are not typical of what is found in a real classroom environment, the cognitive challenge that characterizes Condition 3 will more closely mimic real-world attention challenges. This task 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.

Response measurement

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/knee tracking system. Conditions 1 and 2 were selected for the initial study in order to compare what added value this system may have relative to standard flatscreen–delivered approaches using similar stimuli (of which we will have full protocols with these subjects). Condition 3 was chosen to assess differential performance that may occur when using somewhat more "ecologically-valid" stimuli along with a basic archetypic classroom task consisting of *listen-look-respond* components. Also, while the stimuli in Condition 3 are still rather simple, there is considerable standardization data on the Boston Naming Test that will allow us to examine performance in a meaningful way, armed with a rich history of objective results on the psychometric properties of these particular stimuli.

Thus far (at the time of this writing), initial user-centered design evaluation on the present scenario with seven non-diagnosed children (aged 6–12) has provided encouraging usability results. None of the children were observed to have any hesitancy for using the HMD and none reported symptoms of cybersickness following 10–20 minute exposures within the scenario. Also, all of the users were able to read the letter stimuli on the board and track and report occurrences of the distraction stimuli. We are currently integrating the immersive audio component into the scenario and will continue iterative upgrades based on user-evaluations until the system is fully functional and ready for our first clinical trial planned to begin in June 2000.

DISCUSSION AND FUTURE PLANS

It is our view that an immersive VR approach possesses the capacity to systematically provide attention challenges and *distraction* within an ecologically valid scenario (classroom) and would offer better predictive information regarding performance in the real environment. For example, in future studies, 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 manner 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 for attention measurement as opposed to picking up general influences due to impairments in other cognitive domains. 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 for an attention-specific scenario. By contrast, questioning as to whether or not a sentence contains the means 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 future planned program of research.

Another 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.[68] While this observation may suggest possible directions for computer and VR-delivered approaches to education and cognitive rehabilitation strategies, it could minimize the *assessment* value if VR scenarios are "too interesting" to children. Our strategy to address this concern 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 subtypes reported to occur with ADHD.[47] The occurrence of pure attention versus pure hyperactive versus 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 because 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 in part due 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 NIH ADHD Consensus report[69] suggests that more effort is needed in assessing the inattentive subtype, particularly because 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 and limit access to appropriate clinical services. A VE approach in this area would be well suited to address this question.

Our future work with this scenario will also involve using the classroom "platform" as a tool to assess cognitive performance targeting attention, memory and executive functions with persons having other clinical diagnoses (i.e., pediatric TBI). Further development of other forms of distraction will also be explored. For example, the influence of distracting intrusive thoughts could be modeled in this scenario. This might be addressed by having subjects read a list of commonly reported "daydream" type thoughts (i.e., "Gee, I wish this class was over") before the test session. Then during the testing trials, these statements would be played back in a modulated "dreamlike" sound format to assess their impact on performance. Populating the classroom environment with virtual avatars of other students as a form of realistic distraction will also be undertaken. Behavioral inhibition might also be studied by providing options for "gaming" tasks presented initially upon introduction to the classroom and then instructing the subject that while testing is going on, they are to no longer "play" with the game. For example, the subject can be shown that pressing a "button" in close proximity to the regular "response" button will cause the "distracting" paper airplane to "crash." The number of impulsive "off-task" button presses during testing trials could serve as a behavioral inhibition metric. Finally, once the parameters of the environment are better understood, it may be possible to incorporate systematic attention training trials that more specifically target the stimulus conditions under which an individual's performance was shown to be impaired. This option could be used in a systematic drill and practice fashion within the context of this functionally relevant environment with the hope of maximizing transfer of attention improvements to real educational settings.

While we are currently using high-end equipment, we anticipate that following clinical trials and empirical development of a reliable and valid set of VR tasks that the technology will have advanced concurrently to the point where our scenario could be delivered on less expensive and readily available equipment. The next step would be to develop an accessible PC-based system that could be used in clinics, schools, and research settings that would be programmable by a "non-tech" professional as easily as one would interface with *PowerPoint* presentation tools for more flexible user-tailored application development.

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 stimulated "real-world" functional testing and training environments with an aim toward improving ecological validity. A more precise form of measuring attention performance using VEs modeled after real life settings should, in theory,[71] provide better predictions (and training) of performance in the real world. This view reflects the current thrust of our work.

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