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A Virtual Reality Environment for the Assessment of ADHD

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Virtual Reality (VR) technology is increasingly recognized as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities (Rizzo, 1994; Pugnetti et al., 1995; Rizzo & Buckwalter, 1997; Rose, Attree, Brooks & Johnson, 1998). The capacity of VR to create dynamic interactive immersive 3-D stimulus environments, in which all behavioral responding can be recorded, offers assessment and rehabilitation options not available with traditional neuropsychological methods. In this regard, a growing number of laboratories are developing research programs investigating the use of Virtual Environments (VEs) for these purposes; controlled studies reporting encouraging results are now beginning to emerge (Rizzo, Buckwalter, & van der Zaag, 2001). This work has the potential to advance scientific study of normal cognitive and behavioral processes, and to improve our capacity to understand and treat impairments in these areas typically found in clinical populations. Relevant to these efforts, this article will briefly define "virtual reality," and present a rationale for the application of VR technology for the assessment and possible rehabilitation of attention processes. We will then present background on our development of a VE targeting attention processes referred to as the "Virtual Classroom," now evaluated to assess children with ADHD.

WHAT IS VIRTUAL REALITY?

Virtual reality has been generally defined as "a way for humans to visualize, manipulate, and interact with computers and extremely complex data" (Aukstakalnis & Blatner, 1992). While this general definition is useful, more specifically, VR can be viewed as an advanced form of human-computer interface allowing the user to "interact" with and become "immersed" within a computer-generated environment in a naturalistic fashion. By analogy, this means that, much like an aircraft simulator serves to test and train piloting ability, computer-generated virtual environments (VEs) can be created to assess and rehabilitate cognitive and functional abilities. Whereas a flight simulation system provides an interactive sensory illusion of a real flight, VR can provide interactive scenarios designed to target client needs via exposure to simulated "real world" and/or analog tasks.

Interaction in three dimensions (3D) is a key characteristic distinguishing a VR experience from watching a movie. The believability of the virtual experience (or "sense of presence") occurs by employing such specialized technology as head-mounted displays (HMDs), tracking systems, earphones, gesture-sensing gloves, and sometimes haptic-feedback devices. For example, a HMD is an image display system designed to be worn on the head (like a diving mask) that remains optically coupled to the user's eyes as he/she turns and moves. A tracking system senses the position and orientation of the user's head (and HMD), and reports that information to a computer updating (in real time) images for display in the HMD. In most cases, full-color stereo image pairs are produced and earphones may also deliver relevant 3D sound. The combination of a HMD and tracking system allows the computer to generate images and sounds in any computer-modeled (virtual) scene corresponding to what the user would see and hear from their current position if the scene were real. The user may walk and turn around to survey a virtual landscape, or inspect a virtual object by moving toward it and peering around its sides or back. While HMDs are most commonly associated with VR, other methods incorporating 3D projection walls and rooms (known as CAVES), as well as basic flat screen computer systems, have been used to create interactive scenarios of value for clinical purposes.

THE "VIRTUAL CLASSROOM" ATTENTION-PROCESS ASSESSMENT AND TRAINING PROJECT

We are currently developing a series of HMD-delivered VR systems 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 addressing these impairments—unavailable using existing methods. Virtual reality HMDs are well suited for these types of applications. They provide a controlled stimulus environment in which cognitive challenges can be presented, along with the precise delivery and control of "distracting" auditory and visual stimuli. This level of experimental control potentially could allow for the development of attention assessment tasks more similar to those found in the real world. Hence, the ecological validity of measurement in this area could be improved.

Our first project in the attention process domain involved developing a virtual "classroom" specifically aimed at the assessment of ADHD. The scenario consists of a standard rectangular classroom environment containing student desks, a teacher's desk, a virtual teacher, a blackboard, a large window overlooking a playground with moving vehicles, and—on each end of the wall opposite the window—a pair of doorways through which activity occurs. Within this scenario, children can be assessed in terms of attention performance while a series of typical classroom distracters (i.e. ambient classroom and hall noise, movement of a virtual "person," activity occurring outside the window, virtual paper airplane flying, 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 regard to seating position, number of students, teacher gender, etc. On-task attention in terms of performance can be measured on a variety of attention challenges—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 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 test itself. 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*")—only when the word "dog" is written (or its picture appears) on the blackboard.

In addition to these attention performance measures, behavioral activity correlated with distractibility and/or hyperactivity components (i.e., head turning, gross motor movement), and impulsive nontask behaviors (playing with "distracter" items on the desk) could be measured. Other scenarios (i.e., work situations, home environments, etc.) using the same logic and approach are being developed to address attention process impairments in other clinical populations. Our first clinical trial is comparing ADHD diagnosed children (aged 8 to 12) with a nondiagnosed control group using more basic attention challenges as outlined in the next section.

Methods for Initial ADHD Clinical Trial with the Virtual Classroom Currently in Progress

Subjects. Subjects consist of 15 ADHD-diagnosed children and 15 children in a nondiagnosed control group. The subjects were recruited from local agencies in the greater Los Angeles area with which our lab established collaborative agreements—including USC Children's Hospital. Males, aged 8 to 12 are being tested in the VR scenario. A full-standard diagnostic assessment, using currently available tools, is available on all subjects. This includes a full neuropsychological battery of tests, classroom behavioral ratings, and flat screen, computer-delivered, continuous performance test results. Nondiagnosed subjects are administered the same diagnostic workup. ADHD subjects are tested prior to taking any medications; the VR exposure lasts for approximately 30 min.

Warm-up and familiarization with the scenario. Following completion of the USC Human Subjects Research Review Committee, procedures and informed consent are obtained, then subjects are escorted into the testing room. The subject sits at a standard "school desk" and a lab technician helps adjust the fit of the Virtual Research V8 head-mounted display (HMD) to the child's head. An Ascension Tracking Device is then fitted to the subject's nondominant hand and opposite knee.

At this point, the system presenting the virtual classroom is activated and the subject sees 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, and a female virtual teacher between the desk and blackboard. On the left wall, a large window overlooks a playground and a street with moving vehicles. On each end of the wall opposite the window, there is a pair of doorways through which activity occurs.

The virtual teacher (VT) then instructs the subject to spend 1 min looking around the room, pointing at and naming various objects observed. This assists the subject in becoming familiar with components of the classroom environment. Following this 1 min period, the VT tells the subject they are now going to "play a game." The VT instructs the subject to hold the remote mouse in his or her dominant hand and press the button when the teacher says "go." This familiarizes the subject with the operation of the remote mouse and provides functional practice for its use during the testing proper. Reaction time to hit the mouse button following the VTs command is recorded from a series of 20 hit commands that are presented at random intervals during a 1 min period. The virtual teacher then instructs the subject that a new game will now begin and the testing proper phase commences.

Experimental Conditions. Three conditions follow, each lasting 10 min. The first two conditions use basic visual stimulus challenges found in commonly used flat screen computer-delivered continuous performance tasks (CPTs). In these conditions, the subject is 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 consists of the letters A, B, C, D, E, F, G, H, J, L, and X. The letters are white on a gray background (the virtual blackboard), presented in a fixed position directly in front of the subject. The stimuli remain on the screen for 150 msec, with a fixed interstimulus interval of 1350 msec. Four hundred stimuli are presented in the 10-min condition. The target letter "X" (correct hit stimuli) and the letter "X" without the "A" (incorrect hit stimuli) each appear with equal probability of 10%. The letters "A" and "H" both appear with a frequency of 20%. The remaining eight letters occur with 5% probability. Subjects are 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-min practice trial, consisting of a very basic sample series, is 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 begins.

- Condition 1 is administered without distractions, while Condition 2 consists of the same tasks—with distractions included. Presentation order of every condition is counterbalanced across all subjects. The order of presentation of the hit stimuli is administered based on the following rules: Letters appear on the board at a constant rate of one letter per 1.5 sec (40x per min); four correct hit stimuli per min are presented ("X" preceded by an "A"), in a fixed order occurring every 200 sec. This means that three blocks of 200 sec "orders" are created; four incorrect hit stimuli per minute are presented ("X" preceded by an "A"), in the same format as outlined in Step #2; 32 nonhit stimuli are presented during each min.
- Condition 2 presents identical stimulus challenges, as presented in Condition 1. However these occur in the presence of pure 3D immersive audio distracters, pure visual distracters, or mixed 3D audio/visual distracters. Distracters consist of the following:
  Pure auditory—ambient classroom sounds (i.e., whispering, pencils dropping, chairs moving, etc.) "behind" the student
  Pure visual—3D paper airplane flying directly across the subject's field of view
  Mixed audio/visual—Car "rumbling" by outside window on the left, and a virtual person coming in and out of doors on the right side of the classroom with sounds of the door "creaking open," footsteps, and hallway activity.
  Distracters are presented in a consistent manner in 3 min blocked segments corresponding to the 3 min "blocked" stimulus presentations. In this manner, performances in each subsequent identical 200 sec block will allow for comparison over time. Distracters are displayed for 5 sec, and presented in randomly assigned, equally appearing intervals, of 10 sec, 15 sec, or 25 sec. Thirty-six distraction intervals (12 of each) and 36 distracters (9 of each) are included in the 10-min condition.
- Condition 3 consists of a more realistic "ecologically valid" attention task, requiring integration of audio and visual attention processes. In this condition, line drawings of common objects appear on the "blackboard." These drawings were taken from the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1978, 1983), and the VT calls out the item's name—either correctly or incorrectly. The subject is asked to listen to the VT, observe the "blackboard," and hit the response pad every time the VT incorrectly names the object. Stimulus drawings are presented at a rate of one every 5 sec. After 4.5 min the criterion for response shifts—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 is presented with distractions occurring within the 10-min block in the same fashion as Condition 2. The same types of distractions occurring in Conditions 1 and 2 are used

in Condition 3. While types of stimulus challenges used in Conditions 1 and 2 are not typical of what exists in a real classroom environment, the cognitive challenge characterizing Condition 3 more closely mimics "real-world" attention challenges. This task creates challenges combining both visual and auditory sensory stimuli—possibly allowing for a more ecologically valid assessment of higher levels of attention.

Response Measurement. Reaction time and response variability are used as performance measures, while "head turning" and gross motor movement is recorded by the tracking devices on the HMD and on the hand/ankle 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 flat screen-delivered approaches using similar stimuli (of which we will have full protocols for these subjects). Condition 3 was chosen to assess differential performance that may occur when using somewhat more evolved and ecologically valid conditions envisioned as similar to the basic archetypic classroom task of listening/looking/responding. Also, while stimuli in Condition 3 are still rather simple, considerable standardization data on the Boston Naming Test allows us to examine performance in a meaningful way—armed with a rich history of objective results on the psychometric properties of these particular stimuli.

DISCUSSION AND FUTURE PLANS

Thus far, initial iterative user-centered design evaluation on the classroom scenario, with 14 nondiagnosed children (age 6 to 12) provided encouraging usability results. No children were observed to have any hesitancy using the HMD; none reported symptoms of cyber-sickness (dizziness, nausea, disorientation, etc.) following 10 to 20 min 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.

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 with regard to performance in the real environment. To accomplish this, we have plans to evolve the testing conditions in a series of future studies. For example, one approach might involve the virtual teacher requesting 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. A successive series of questions would similarly follow. 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 (blackboard) presentation of colors, geometric forms, numbers, letters, single words, full sentences, and illustrations of objects—all requiring some response.

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 occurring with computer/video games. Parents are often puzzled that, although they observe their children intently focusing on video games—teacher reports indicate inattention in the classroom (Greenhill, 1998). This observation may suggest possible directions for computer and VR-delivered approaches to education and cognitive rehabilitation strategies. Yet, it could also 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 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 this work may also help differentiate the various subtypes reported to occur with ADHD (APA, 1994). 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 VR 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 within certain more definable conditions. As well, the head tracking device within the HMD makes possible a determination of where the subject's field of view is located during hit-stimulus delivery. This will allow us to determine if a subject missed the hit-stimulus while actually looking at the board, as opposed to looking at other objects in the scenario. A VE approach in this area would be well suited to address this question.

Further developments in the Virtual Classroom will include other forms of distraction. 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 "day-dream-like" 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 humans (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, initially presented upon introduction to the classroom, and then instructing the subject that, while testing is going on, they can 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 parameters of the environment are better understood, it may be possible to incorporate systematic attention-training trials that more specifically target stimulus conditions under which an individual's performance was been shown to be impaired. This option could be used in a systematic drill-and-practice fashion, within the context of this functionally relevant environment and with the hope of maximizing transfer of attention improvements to real educational settings.

Our future work with this scenario will also involve using this 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). The overall system is designed to contain options allowing for its flexible application. Also, we have extended the design elements of the Virtual Classroom to develop a Virtual Office VE for similar applications with adult populations.

In conclusion, it is our view that VR technology could improve the reliability of neuropsychological assessment by allowing for a more consistent presentation and manipulation of complex test and distraction stimuli, along with more precise measurement of participant responses. 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 toward improving ecological validity. A more precise form of measuring attention performance using VEs modeled after real-life settings should, in theory (Thorndike, 1903), provide better predictions (and training) of performance in experience. If the associated technology continues to advance in the areas of visual displays, computing speed/memory storage, graphics, 3D audio, interface design, 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 independent replication of research findings needed for scientific progress in this field. This view reflects the current thrust of our work.

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