A Review of Virtual Classroom Environments for Neuropsychological Assessment

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Abstract. Differential diagnosis and treatment of neuropsychological disorders require assessments that can differentiate overlapping symptoms. Previous research has most often relied on paper-and-pencil as well as computerized psychometric tests of cognitive functions. Although these approaches provide highly systematic control and delivery of performance challenges, they have also been criticized as limited in the area of ecological validity. A possible answer to the problems of ecological validity in assessment of cognitive functioning in neurological populations is to immerse the participant in a virtual environment. This chapter reviews the potential of various virtual classroom environments that have been developed for neuropsychological assessment.

Keywords: Virtual Reality, Virtual Classroom, Virtual Human, Neuropsychology, Autism, Attention Deficit Hyperactivity Disorder, Brain Injury,

Introduction

Although traditional neuropsychological assessment approaches provide highly systematic control and delivery of performance challenges, they have also been criticized as limited in the area of ecological validity (Parsons, 2011). By ecological validity, neuropsychologists mean the degree of relevance or similarity that a test or training system has relative to the real world, and in its value for predicting or improving daily functioning (Wilson et al., 1998; Chaytor, Schmitter-Edgecombe, and Burr, 2006). Adherents of this view challenge the usefulness of constrained paper-and-pencil tests and analog tasks for addressing the complex integrated functioning that is required for successful performance in the real world. Computer-based neuropsychological assessments offer a number of advantages over traditional paper-and-pencil testing: increased standardization of administration; increased accuracy of timing presentation and response latencies; ease of administration and data collection; and reliable and randomized presentation of stimuli for repeat administrations (Parsons, Notebaert, Shields & Guskewitz, 2009; Shatz & Browndyke, 2002). However, these assessments usually take place in a highly controlled laboratory setting that does little to mimic the real world, and therefore have also been criticized as lacking ecological validity. This problem may be particularly salient in the assessment of individuals with neurodevelopmental disorders impacting frontostriatal function, particularly attention-deficit hyperactivity disorder (ADHD).

Currently approaches to assessment of ADHD rely on converging lines of evidence from behavioral rating scales, paper-and-pencil cognitive assessments, and computerized measures of attention (e.g., continuous performance tasks). An unfortunate limitation to this approach is the dearth of generalizability to activities of daily living. A possible answer to the problems of ecological validity in assessment of ADHD is to immerse the participant in a virtual classroom environment. Work has been done to develop a virtual classroom that assesses executive functioning (Parsons, Bowerly, Buckwalter, & Rizzo, 2007; Rizzo et al., 2006). These virtual environments have been found to offer significant advantages to more traditional methods of diagnosis and observation.

The plan of this chapter will be as follows: In Section 1, current approaches to the assessment of ADHD will be discussed. Section 2 will describe the use of virtual environments for the assessment of neurodevelopmental disorders. Next, in Section 3, the Virtual Classroom will be introduced. Finally, in Section 4, research conducted using the Virtual Classroom will be presented.

Section 1: Attention-Deficit Hyperactivity Disorder

The neurodevelopmental disorder known as ADHD is a heterogeneous disorder of unknown etiology, which is comprised of difficulties with sustained attention, distractibility, impulse control, and hyperactivity (Biederman, 2005). Researchers have proposed that ADHD arises from a core deficit in inhibitory control, resulting in multidimensional deficits in executive functioning (Barkley, 1997, 2000; Scheres et al., 2004). Individuals with ADHD may have difficulty organizing behaviors, solving problems, and shifting mental sets (Schachar et al., 2000). Due to the heterogeneity of his disorder, reaching a consensus on diagnosis has proven to be challenging.

Traditional assessment of ADHD utilizes clinician-administered and self-report rating scales, including the Conner’s Adult ADHD Rating Scales (Conners et al., 1999) and ADHD Rating Scale-IV (DuPaul, Power, Anastopoulos & Reid, 1998). These scales, though psychometrically sound, have limited predictive validity (Lahey et al., 2006) and treatment utility (Scotti et al., 1996). Although these scales may provide insight into an individual's behavior in one or more domain, malingering and reporter bias is always a concern (Abikoff et al., 1993, Sayal & Taylor, 2005). Further, structured interviews are time-consuming for both the parent and the clinician, yielding them less practical and cost-effective. Additionally, when assessing behavior changes over time, structured interviews may lose validity after the initial interview.

More recently, research has examined the assessment of executive functions in children with ADHD. The hypothesis of executive dysfunction in children with ADHD has been supported in a number of studies (Barkley et al., 1992; Grodzinsky & Barkley, 1999; Schachar et al., 2000; Scheres et al., 2004). Measures that have been shown to differentiate children with ADHD from typically developing children include: the Stroop task (Barkley et al., 1992; Nigg, 1999), Controlled Oral Word Association Test (Grodzinsky & Diamond, 1992), and Picture Arrangement from the Wechsler Intelligence Scale for Children-III (Pineda et al., 1998). While these tests are highly validated and provide adequate predictive validity, they have also been criticized as limited in the area of ecological validity (Chaytor et al., 2006; Farias et al., 2003; Gioia & Isquith, 2004; Odhuba et al., 2005; Plehn et al., 2004; Ready et al., 2001; Silver, 2000). Testing usually takes place in a quiet, well-controlled environment with little if any of the distractions that are common in the real world. This lack of ecological validity may weaken predictions about real-world functioning.

Assessment of executive functioning is a principal objective of neuropsychological evaluations. These executive function are accomplished by the supervisory attentional system and accomplish functions such as: selective attention, inhibitory control, planning, problem solving, and some aspects of short-term memory (Baddeley 1996; Baddeley & Hitch, 1974; Norman & Shallice, 1986; Burgess & Simons 2005, Diamond, 2013). Some theories of executive functions and attentional processing consider executive functioning to be unitary construct, while others consider attentional processing to be a system of independent networks (Raz & Buhl, 2006). Given that attention deficits are the basis of many pathological disorders in children and adults, it is important to understand the different facets of attentional processes as well as the anatomical sites at which they are carried out. Because deficits in executive functioning underlie many disorders, including ADHD (Rothbart & Bates, 2009), it is essential to understand all aspects of executive functions as well as the underlying anatomical sites at which they are accomplished. Because different disorders result in different patterns of attentional deficits, it is imperative to be able to differentiate different attentional processes (Posner & Rothbart, 2007). Novel assessments of attention are needed that can enhance ability to differentiate specific attentional processes, because different pathologies show different patterns of attentional deficits (Chaytor & Schmitter-Edgecombe, 2007; Posner & Rothbart, 2007; Parsons et al., 2007).

Posner and Rothbart (2007) proposed an attention network theory, in which the human attentional system is subdivided into three functionally and anatomically independent networks: alerting, orienting, and executive attention (see also Fan, McCandliss, Fossella, Flombaum, Posner, 2005; Posner & Petersen, 1990). The Attention Network Task (ANT) is a computerized assessment of attention that was developed by Posner and colleagues to measure the three aspects of the attention network (Fan, McCandliss, Sommer, Raz, Posner, 2002). The ANT combines cued detection (Posner, 1980) with a flanker-type paradigm (Eriksen & Eriksen, 1974) and allows for the behavioral assessment of attentional dimensions of alerting, orienting, and executive function via specific reaction time (RT) patterns (Fan et al., 2002). The ANT has been argued to hold particular promise for assessment of attention deficits in ADHD. A number of studies using the ANT have shown specific deficiencies in the alerting and executive control substystems (Johnson et al. 2008; Abbes et al., 2009). It is important to note that Adólfsdóttir, Sørensen, and Lundervold (2008) have argued that the ANT's main contribution to ADHD assessment is its accuracy and variability measures rather than measures of the three attention subsystems. The ANT is also purported to be useful in distinguishing between subtypes of ADHD (Lundervold et al., 2011; Oberlin, Alford, & Marrocco, 2005).

Other computer-based measures of ADHD have been developed that offer a number of advantages over traditional comprehensive self-report measures, including: enhanced cost and time effectiveness and improved usability for administrators (Nichols & Waschbusch, 2004). One of the most used computerized assessments of ADHD is the Continuous Performance Test (CPT). CPT tests require participants to remain vigilant to a specific stimulus in a continuous stream of distractors (Eliason & Richman, 1987). Individuals with ADHD find this protocol long and tedious, and thus it has been shown to differentiate between typically developing children and children with ADHD by assessing arousal, activation and effort (Rapport et al., 2000; Nichols & Waschbusch 2004; Corkum & Siegel, 1993).

While computer-based measures are more advanced in the area of stimulus presentation and response measurement, responding to continuously presented symbols on an otherwise blank computer screen lacks the complexity individuals face in the real world. Although these neuropsychological measures have been found to have adequate predictive value, their ecological validity may diminish predictions about real-world functioning. Traditional neurocognitive measures may not replicate the diverse environment in which persons with ADHD and other neurodevelopmental disorders live. Additionally, standard neurocognitive batteries tend to examine isolated components of neuropsychological ability, which may not accurately reflect the distinct cognitive domains found in neurodevelopmental disorders impacting frontostriatal functioning (Dodrill, 1999; Parsons, Rizzo, & Buckwalter, 2004; Parsons et al., 2005; Wilson, 1993). Although today's neuropsychological assessment procedures are widely used, neuropsychologists have been slow to adjust to the impact of technology on their profession. While there are some computer-based neuropsychological measures (see discussion above) that offer a number of advantages over the traditional paper-and-pencil testing, the ecological validity of these computer-based neuropsychological measures is less emphasized. Only a handful of neuropsychological measures have been developed with the specific intention of tapping into everyday behaviors like interacting with a teacher and peers in a virtual school setting, navigating one's community, grocery shopping, and other activities of daily living. Of those that have been developed, even fewer make use of advances in computer technology. In summary, current diagnosis of ADHD relies on an accumulation of clinical interviews, behavior rating scales, and computerized neuropsychological tests. These instruments each lack the essential component of ecological validity necessary to make predictions about real-world functioning. Additionally, because of the heterogeneity and different presentations of this disorder, comprehensive assessment is necessary for a diagnosis of ADHD.

Section 2: Assessment of Neurodevelopmental Disorders using Virtual Environments

One viable approach is to capitalize on advances in virtual reality (VR) technology. Virtual environments can provide platforms for child attention assessment and intervention that are sufficiently rich in terms of ecologically validity, while also providing scientifically rigorous control, manipulation and bio-behavioral data recording options (Parsons, Bowerly, Buckwalter & Rizzo, 2007; Parsons & Courtney, 2011; Parsons & Reinebold, 2012). Virtual Reality is a form of human–computer interface that allows the user to "interact" with and become "immersed" in a computer-generated environment (Parsons, 2011a). VR paradigms also allow for the sophisticated, objective, real-time measure of participants' behaviors (e.g. visual attention) and training outcomes. Recent cost reductions in VR technologies have led to the development of more accessible, usable and clinically relevant VR applications that can be used to address a wide range of physical and cognitive ailments and conditions (Parsons, Rizzo, Rogers, & York, 2009).

Virtual environment applications that focus on treatment of cognitive (Parsons, Rizzo, Rogers, & York, 2009; Rose, Brooks, & Rizzo, 2005) and affective disorders (Parsons & Rizzo, 2008a; Powers & Emmelkamp, 2008) as well as assessment of component cognitive processes are now being developed and tested: attention (Parsons et al, 2007; Law, Logie & Pearson, 2006; Parsons & Rizzo, 2008b; Parsons et al., 2009) spatial abilities (Beck et al., 2010; Parsons et al., 2004), retrospective memory (Parsons & Rizzo, 2008c) , prospective memory (Knight & Titov, 2009), spatial memory (Astur et al., 2004; Goodrich-Hunsaker & Hopkins, 2010; Parsons et al., 2013) and executive functions (Armstrong et al., 2013; Parsons, Courtney, Arizmendi, & Dawson, 2011; Parsons et al., 2012; Parsons, Courtney, & Dawson, 2013; Parsons & Courtney, 2014). The increased ecological validity of neurocognitive batteries that include assessment using virtual scenarios may aid differential diagnosis and treatment planning. Within a virtual world, it is possible to systematically present cognitive tasks targeting neuropsychological performance beyond what are currently available using traditional methods (Parsons, 2011b; Parsons, 2012). Reliability of neuropsychological assessment can be enhanced in virtual worlds by better control of the perceptual environment, more consistent stimulus presentation, and more precise and accurate scoring. Virtual environments may also improve the validity of neurocognitive measurements via the increased quantification of discrete behavioral responses, allowing for the identification of more specific cognitive domains (Gaggioli et al., 2009). Virtual environments could allow for neurocognition to be tested in situations that are more ecologically valid. Participants can be evaluated in an environment that simulates the real world, not a contrived testing environment (Gorini, Gaggioli, Vigna & Riva, 2008). Further, it offers the potential to have ecologically valid computer-based neuropsychological assessments that will move beyond traditional clinic or laboratory borders.

To review, a possible solution to problems of ecological validity in traditional assessment is to utilize technological advances in virtual reality. Advantages of virtual reality computerized testing include the following: 1) enhanced ecological validity by “immersing” the individual into an environment; 2) ability to present and control ecologically valid distractions; 3) ability to objectively record behavioral data; and 4) enhanced reliability increased control over the perceptual world and stimulus presentation. Thus far, a number of virtual environments have been tested on a number of clinical and non-clinical populations.

Section 3: Assessment of Neurodevelopmental Disorders using Virtual Environments

An optimal ecologically valid approach to diagnosis and treatment of individuals with neurodevelopmental disorders may be to use VR methods to simulate classroom social-educational environments under controlled conditions (Parsons, 2014). Impairments in attention are a common and debilitating occurrence in a number of clinical populations. Clinical populations affected by attention deficits include individuals with ADHD, traumatic brain injury, autism spectrum disorders, and a host of other neurodevelopmental and neurodegenerative disorders. Using VR with these populations may be particularly practical due to increased control over the procedure and fewer extraneous distractions.

The Virtual Classroom project represents a joint venture between the University of Southern California and Digital Media Works in Canada (Rizzo et al., 2000, 2004). The Virtual Classroom was designed for the study, assessment, and rehabilitation of cognitive and functional processes, particularly in clinical populations with central nervous system (CNS) dysfunction. The vision of this project saw the Classroom as way to advance the scientific study of typical cognitive and behavioral processes as well as to improve the capacity to understand, measure, and treat impairments in this clinical populations. Initially, the Virtual Classroom project focused on the assessment of attention in individuals with ADHD. Due to the heterogeneous nature of the disorder, reaching a consensus on the proper diagnosis and treatment of the disorder has proven to be difficult. Currently, assessment focuses on a number of behavior checklists given to parents and teachers. Diagnosis is made from converging evidence based on these scales. Such scales are vulnerable to a number of errors, such as reporter bias, and so may be inconsistent. Thus, the VR Classroom aims to be a reliable and objective measure of attention functioning in ADHD (Rizzo et al., 2006).

The VR Classroom employs a head-mounted display (HMD) with which individuals view the environment. HMDs are able to occlude extraneous distraction and focus the participant's attention within the VR environment where presentation of distracting auditory and visual stimuli is tightly controlled. In this way, VR is able to identify precisely when individuals make errors due to distraction, and what type of distraction precluded the error. In addition, it is possible to use a number of tracking devices on the head, arms, and legs to track movements besides head movements as a concurrent index of hyperactivity symptoms. Hence, the Virtual Classroom is able to objectively assess not only cognitive abnormalities in ADHD, but also behavioral abnormalities, effectively integrating information traditionally only available from cognitive measures and behavioral rating scales administered separately (Rizzo et al., 2006).

The Virtual Classroom utilizes a continuous performance task paradigm (CPT) commonly used in the assessment of ADHD. Participants are instructed to view a series of letters presented continuously on a blackboard. They are asked to respond via a mouse click only after they view the letter “X” preceded by the letter “A.” Emphasis is placed on speed and accuracy. Individuals with ADHD have generally been shown to make more omission errors (failing to respond to a target) and commission errors (responding to a non-target) on CPT tests. Omission error are considered indicative of inattention while commission errors are indicative of hyperactivity (Nichols & Waschbusch, 2004). In the high distraction task, external interference control is also assessed. To begin the task, the participant is immersed in the classroom, and seated in a desk near the center of the classroom with a view of other children, a teacher, and a window, among other things. After instructions are communicated to participants via computer speakers, the task begins. The participants are instructed to respond via a mouse click to each target (the letter “X” preceded by the letter “A”) and to withhold a mouse click for all non-targets. The Virtual Classroom presents distractors in various areas of the classroom. Audio-visual distractors include a school bus driving by, an SUV driving by, a book dropping to the floor, children passing notes, a child raising his hand, the teacher answering the classroom door, and the principal entering the room. Visual distractors include a paper plane flying through the room. Audio distractors include the sound of paper crumpling, a pencil hitting the floor, an airplane passing overhead, a voice from the intercom, the bell ringing, a sneeze and a cough. These distractors are dispersed throughout the left, center, and middle of the classroom. An important feature of the Virtual Classroom is its ability to mimic the complexity of the real world in a controlled environment. Individuals are immersed in this environment and are surrounded by desks, children, a teacher, and a white board much like they would be in a real-world classroom. Additionally, auditory and visual distractors, much like those that would be present in the real world can be enabled or disabled, allowing the researcher to manipulate the complexity of the environment. This ability to manipulate complexity in a virtual environment allows neuropsychologists to generalize results of these standard tests to an individual's real-world functioning.

Section 3: The Virtual Classroom for ADHD

In a clinical trial of the Virtual Classroom, Parsons et al (2007) compared performance of ten children with ADHD with ten typically developing children. In this study, children with ADHD performed differently from typically developing children in a number of different ways: 1) children with ADHD made more commission and omission errors 2) children with ADHD exhibited more overall body movement; and 3) children with ADHD were more impacted by distracting stimuli. Additionally, performance measures in the VR Classroom were significantly correlated with traditional measures and behavior checklists (Parsons et al., 2007). Thus, the Virtual Classroom was able to assess not only attentional abnormalities but also behavioral abnormalities concurrently.

Another study of ADHD using the Virtual Classroom focused on distractibility in ADHD. Nineteen adolescent boys with ADHD and sixteen age-matched typically developing adolescents were compared on performance in the Virtual Classroom CPT with and without real-world distractors and on a traditional CPT without distractors. The Virtual Classroom was able to distinguish between ADHD and control groups more so than the traditional CPT, with adolescents with ADHD committing more commission errors and overall errors. Additionally, the Virtual Classroom was more specific, correctly identifying 87.5% of controls, compared to only 68.8% in the standard CPT. Additionally, ecologically valid distractors presented in the task seemed to have a greater impact on the adolescents with ADHD compared to those without. Adam et al. attributed poorer performance in the ADHD group to these distractions, explaining the adolescents with ADHD were less able to cope with the novelty of the situation than those in the control group (2009).

Pollak et al. investigated the use of the Virtual Classroom in assessing the effect of methylphenidate (MPH), a drug used in the treatment of ADHD. Twenty-seven children with ADHD completed the Virtual Classroom CPT, the traditional CPT, and the Test of Variables of Attention (TOVA). These children were divided into MPH and non-MPH (placebo) groups. Ingestion of MPH decreased omission errors in all measures; however, compared to the TOVA and traditional CPT, ingestion of MPH reduced omission errors in the Virtual Classroom to a greater degree. These results suggest the Virtual Classroom may be more sensitive to attention deficits than traditional measures. Additionally, children rated the Virtual Classroom to be more enjoyable than either the TOVA or the traditional CPT (2010).

Section 4: The Virtual Classroom Extended

The Virtual Classroom has also been used in study assessing attention in adolescents with sports concussions. Twenty-five sports-concussed adolescents were compared with twenty-five non-sports-concussed adolescents in the Virtual Classroom and on a traditional CPT task. The Virtual Classroom proved to have greater sensitivity in detecting subtle attention deficits due to the sports concussion than did the traditional CPT, detecting a significantly higher number of head movements and commission errors in the adolescents with a sports concussion than in those without (Nolin et al., 2012).

Gilboa et al. utilized the Virtual Classroom to assess attention deficits in children with Neurofibromatosis type 1 (NFI), an inherited neurological disorder with symptoms including attention deficits (2009). NF1 is highly comorbid with ADHD, with 30-50% of individuals meeting diagnostic criteria for both (Keyhan, Minden & Ickowicz, 2006). Twenty-nine children with NF1 and 25 typically developing children completed the Virtual Classroom CPT and the Conners' Parent Rating Scales-Revised: Long (CPRS=R:L; Conners, 1997), a questionnaire used to assess ADHD. Children with NF1 performed significantly poorer than typically developing children making more commission and omission errors. Additionally, significant correlations between the rating scale and performance on the Virtual Classroom were observed (Gilboa et al., 2009).

Researchers at the University of Victoria have developed a version of the VR Classroom capable of measuring interference control via the Stroop task. The Stroop task is widely used and well-replicated task which requires participants to inhibit a prepotent response to read the name of a color and name the conflicting ink color it is printed in. In a validity study, the VR Classroom Stroop task elicited similar "interference effects" to the traditional Stroop task. Reaction times to the VR Classroom Stroop were slower overall, possibly due to the increased processing demand. Nevertheless, the VR Classroom Stroop proved to be a valid assessment of interference control (Rizzo et al., 2006).

In sum, research suggests the Virtual Classroom is an ecologically valid, highly specific, and enjoyable assessment of attention deficits in multiple populations. Performance on the Virtual Classroom has been correlated with many other well-validated measures of attention including the CPT, TOVA, and behavioral rating scales. Future research should assess a broad range of populations. Additionally, the Virtual Classroom has been expanded beyond the CPT to include a Stroop task. Further development of the Virtual Classroom seeks to expand the clinical utility of the Virtual Classroom beyond executive assessment to rehabilitation and therapy.

Conclusions

This chapter reviewed the ways in which previous research has most often relied on paper-and-pencil and computerized psychometric tests of executive functions. Again, although these approaches provide highly systematic controlled and delivery of performance challenges, they have also been criticized as limited in the area of ecological validity. A possible answer to the problems of ecological validity in assessment of executive functioning is to immerse the child in a virtual classroom environment.

Virtual reality technology is able to replicate real world environments and present standardized neuropsychological tasks within those environments. Additionally, controlled presentation of real-world distractions is possible. These capabilities enhance ecological validity by immersing individuals in a controlled environment that mimics their every-day life to complete neuropsychological assessments. It follows that the results of these assessments are more generalizable and more closely representative of an individual's real world functioning.

The Virtual Classroom was initially developed as an assessment of attention functioning in ADHD. A number of preliminary studies have confirmed its utility for this purpose. The Virtual Classroom is able to distinguish children with ADHD from normal controls on the basis their performance on a CPT test embedded within the environment as well as from behavioral data. Additionally, participants reported enjoying the Virtual Classroom more than the standard CPT.

The Virtual Classroom has been expanded for use in different populations, and also has been expanded to include different neuropsychological task (e.g. the Stroop task). Because initial success has been obtained in these studies, use of the Virtual Classroom should be explored in other populations as well. One possible population in which the Virtual Classroom may be particularly useful is individuals with autism spectrum disorder (ASD). Due to the high overlap between symptoms ADHD and ASD, reliable and specific diagnosis is crucial. Special considerations should be made due to the sensory issues of many individuals with ASD. Consequently, future research in virtual reality technology should investigate a less invasive method of presenting the virtual environment than HMDs.

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