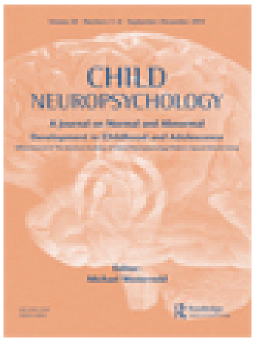

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A CONTROLLED CLINICAL COMPARISON OF ATTENTION PERFORMANCE IN CHILDREN WITH ADHD IN A VIRTUAL REALITY CLASSROOM COMPARED TO STANDARD NEUROPSYCHOLOGICAL METHODS

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In this initial pilot study, a controlled clinical comparison was made of attention perforance in children with attention deficit-hyperactivity disorder (ADHD) in a virtual reality (VR) classroom. Ten boys diagnosed with ADHD and ten normal control boys participated in the study. Groups did not significantly differ in mean age, grade level, ethnicity, or handedness. No participants reported simulator sickness following VR exposure. Children with ADHD exhibited more omission errors, commission errors, and overall body movement than normal control children in the VR classroom. Children with ADHD were more impacted by distraction in the VR classroom. VR classroom measures were correlated with traditional ADHD assessment tools and the flatscreen CPT. Of note, the small sample size incorporated in each group and higher WISC-III scores of normal controls might have some bearing on the overall interpretation of results. These data suggested that the Virtual Classroom had good potential for controlled performance assessment within an ecologically valid environment and appeared to parse out significant effects due to the presence of distraction stimuli.

Keywords: ***Virtual Reality, Attention Deficit Hyperactivity Disorder, Neurocognitive***

Attention deficit-hyperactivity disorder (ADHD) is a heterogeneous developmental disorder of unknown etiology, which is comprised of difficulties with sustained attention, distractibility, impulse control, and hyperactivity (Biederman, 2005). Researchers have postulated that ADHD reflects a core deficit in inhibitory control, which results in multifaceted executive impairment (Barkley, 1997, 2000; Scheres et al., 2004). Individuals with ADHD often exhibit difficulty organizing their behavior and problem solving, as well as impaired cognitive flexibility (Schachar et al., 2000). The deficits associated with ADHD have historically been examined using clinical interviews and behavior rating scales (Barkley, 1991). There are, however, a number of disadvantages related to clinical interviews and behavior rating scales. For example, a great deal of time and effort are required to complete a comprehensive diagnostic evaluation. Further, both clinical interviews and

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behavior rating scales are subject to bias, in that they may be unduly influenced by disparate factors (Abikoff et al., 1993). As a result, there is growing interest in the establishment of alternative, laboratory-based measures for the assessment of ADHD (Barkley, 1991; Nichols & Waschbusch, 2004; Rapport et al., 2000).

Clinical Interviews and Rating Scales

Rating scales are often used to assess whether a patient meets diagnostic criteria necessary for an ADHD diagnosis. While many rating scales are psychometrically sound, they have limited predictive validity (Lahey et al., 2006) and treatment utility (Scotti et al., 1996). The rating scales may also lack sensitivity to low base rates, which raters may underestimate (Fabiano et al., 2004). Further, bias is an inherent possibility in teacher (Abikoff et al., 1993) and parental ratings of ADHD (Sayal & Taylor, 2005). Further, structured interviews may lack practicality in situations where repeated measurements are required. Furthermore, structured interviews require a significant amount of clinician and/or parent time. As a result, they tend to not be cost effective for use in some clinical settings.

Neuropsychological Tests

Other researchers have proposed to assess certain symptoms of ADHD, most notably, decreased executive functioning. The general hypothesis of executive dysfunction in children with ADHD has been supported and replicated in numerous studies over the years (Barkley et al., 1992; Grodzinsky & Barkley, 1999; Schachar et al., 2000; Scheres et al., 2004). Although research has demonstrated variable results in the use of such frontal lobe tests to assess ADHD, a number of measures regularly used to assess executive functioning have been shown to reliably discriminate between the two groups: the Stroop (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). Additionally, traditional neuropsychological testing has 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).

Laboratory-Based Measures

According to Nichols and Waschbusch (2004), laboratory-based measures for the assessment of ADHD have the following advantages: (1) more cost effective and require less time and effort than complete comprehensive diagnostic evaluations; (2) less influenced by extraneous factors; (3) more time efficient descriptions of the impact of treatments on ADHD symptoms; (4) easier use for administers (i.e. teachers and parents) in multifarious settings.

One of the most popular of the laboratory-based measures is the Continuous Performance Test (CPT), which requires participants to maintain vigilance and react to a specific stimulus within a set of continuously presented distracters (Eliason & Richman, 1987). These CPTs are thought to assess arousal, activation, and effort (Corkum & Siegel, 1993) in a boring and repetitive protocol that is difficult for a person with ADHD (Rapport et al., 2000). Hence, CPTs have been shown to differentiate between normals and children with ADHD in numerous studies (Nichols & Waschbusch, 2004). A review of 26 studies found children with ADHD made significantly more errors of omission and commission on CPTs than normal children (Losier et al., 1996). Although CPTs have high specificity, they also have low sensitivity in diagnosing ADHD (Barkley & Grodzinsky, 1994; Grodzinsky & Barkley, 1999). Furthermore, CPTs and behavioral checklists have been found to have similar levels of diagnostic utility.

Although laboratory-based instruments such as the CPT may move beyond the limitations of clinical interviews and behavior rating scales, researchers have questioned their utility when evaluated in the context of ecologically relevant variables such as classroom behavior and academic functioning (Rapport et al., 2000). According to Barkley (1991), the ecological validity of most laboratory-based measures is of a low to moderate level. Barkley argues that future advances in the ecological validity of laboratory-based measures may result from: (1) assessments of the target behaviors in natural settings; and (2) the combination of the more promising laboratory-based measures into a standardized battery.

Virtual Reality Technology

Virtual Reality technology is increasingly being recognized as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities (Buckwalter & Rizzo, 1997; Rizzo & Buckwalter, 1997a,b; Rose et al., 2005; Schultheis et al., 2002). 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 assessment methods. In this regard, VR applications are now being developed and tested which focus on component cognitive processes including: attention processes (Cho et al., 2002a; Clancy et al., 2006), spatial abilities (Baumgartner et al., 2006; Burgess et al., 2006; McClusky et al., 2005; Pani et al., 2005; Parsons et al., 2004; Wolbers et al., 2004), memory (Brooks & Rose, 2003; Brooks et al., 2004; Burgess et al., 2006; Parslow et al., 2005; Phelps et al., 2004), and executive functions (Baumgartner et al., 2006; Elkind et al., 2001; Morganti, 2004).

Virtual Reality and Attention

Within VR it is possible to systematically present cognitive tasks targeting attention performance beyond what are currently available using traditional methods (Barkley, 2004; Cho et al., 2002a,b, 2004; Clancy et al., 2006; Lengenfelder et al., 2002; Rizzo et al., 2006). Reliability of attention assessment can be enhanced in VR by better control of the perceptual environment, more consistent stimulus presentation, and by more precise and accurate scoring. Virtual environments (VE) may also improve on the validity measurement via the quantification of more discrete behavioral responses, allowing for the identification of more specific cognitive domains. Virtual reality could allow for attention 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.

We have developed the Virtual Classroom for the assessment of ADHD as our first functional scenario in this area (Rizzo et al., 2006; Rizzo et al., 2000, 2003, 2004). Given the findings of previous CPT studies, we hypothesized that in this initial pilot study, we would find the following: (1) there would be differences in Virtual Classroom Performance (VCP) between children with ADHD and nonclinical controls. These differences would be detected in response time (reaction time) between stimulus and response and number of commission and omission errors. Specifically, we proposed that children with ADHD would show a greater response time and more total errors on a Go/No-Go task. In addition, the degree of hyperactivity as measured by "head turning" and arm/leg tracking devices was also of interest. It was hypothesized that children with ADHD would show greater levels of hyperactivity than controls as measured by their total body movement. We also hypothesized that (2) the children with ADHD would display more distractibility than controls as measured by their responses to systematically delivered pure auditory, pure visual, and mixed distractors. The extent to which VCP measures (commission/omission errors, average reaction time on hits, body movement) were consistent (concurrent validity) with tests traditionally used in diagnosing ADHD, most notably the behavior checklist and CPT, was also of interest. It was predicted that (3) Virtual Classroom measures would be correlated with traditional psychometric measures of attention and parent reports of inattention, impulsivity, and hyperactivity.

Our goal was to conduct the initial pilot study of a Virtual Classroom scenario that employs a standard CPT for the assessment of ADHD. As such, the specific design parameters of the study (sample size, inclusion and exclusion criteria, etc.) correspond to the early stage of this tool's development. The exploratory nature of the study and results is underscored.

METHODS

Participants

Ten boys diagnosed with ADHD and ten normal control boys participated in the study. As shown in Table 1, the groups did not significantly differ in mean age, grade level, ethnicity, or handedness. Participants with ADHD had a mean age of 10.6 years (range=8–12). Normal controls had a mean age of 10.2 years (range=8–12). The entire sample consisted of four boys in 3rd grade, one in 4th grade, seven in 5th grade, six in 6th

Table 1 Demographic Characteristics of Entire Sample by Group.

	ADHD ($n=10$)		Normal ($n=10$)			
Variables	*M*	*SD*	*M*	*SD*	*f*	*p*
Age at Testing	10.60	1.51	10.20	1.32	0.63	*ns*
Grade	Frequency		Frequency		χ^2	*p*
3	2 (20%)		2 (20%)		3.14	*ns*
4	1 (10%)		0 (0%)			
5	4 (40%)		3 (30%)			
6	3 (30%)		3 (30%)			
7	0 (0%)		2 (20%)			
Ethnicity						
Caucasian	8 (80%)		9 (90%)		39	*ns*
Non-caucasian	2 (20%)		1 (10%)			
Handedness						
Right	10 (100%)		7 (70%)		3.53	*ns*
Left	0 (0%)		3 (30%)			

Note. Frequency values are percentage of each subgroup. *ns*=not significant.

grade, and two in 7th grade. There were 17 Caucasian boys, two African-American boys, and one boy of mixed descent (Caucasian and African-American). Seventeen participants were right-handed and three were left-handed.

Inclusion criteria for all participants included: All study participants had to be males aged 8–12, of stable neurological condition, with good bilateral visual acuity, and preserved dominant handedness. These same inclusion criteria were applied to the normal control group. Normal control participants had to be males, aged 8–12, with no psychiatric diagnosis or observed psychiatric difficulty. ADHD diagnosis was made by licensed child psychologists and/or developmental pediatricians and was substantiated by careful multimodal review of assessment results. This included a full neuropsychological battery of tests, classroom behavioral ratings, and flatscreen computer delivered CPT results. Only children diagnosed with ADHD, primarily hyperactive-impulsive type or ADHD, combined type, were included in the participants with ADHD Group.

Exclusion criteria for all participants were the presence of: epilepsy, Axis I psychiatric diagnosis other than ADHD, other psychiatric problem (specifically, there could be no history of oppositional defiant disorder, conduct disorder, depression, or anxiety), learning disability, medical illness, vestibular problems, or severe cognitive disorders. All participants with ADHD were taking stimulant medication as treatment for their diagnosed condition. None of the children with ADHD were on medication during the experiment. Those children ($n = 10$) taking methylphenidate had been off medication for at least 24 h. No medication other than methylphenidate was used. Participants with ADHD were excluded from the study if they presented with co-morbid autism, mental retardation, Full Scale IQ score <85, or head injury with loss of consciousness greater than 30 min. These same exclusion criteria were applied to the normal control group.

Eligible participants were recruited from local agencies in the greater Los Angeles area that our lab has established collaborative agreements with, including the University of Southern California's (USC) Children's Hospital and the Semel Institute for Neuroscience and Human Behavior University of California, Los Angeles (UCLA). Prospective participants were contacted by phone after receiving a flyer describing the nature of the study. Upon agreement to participate, prospective participants (both child and parent) were educated as to the procedure of the study, possible risks and benefits, and alternative options (non-participation). Prior to actual participation, they completed written informed consents (parent) and assents (child) approved by the USC Institutional Review Board and Fuller Graduate School of Psychology Human Participants Review Committee. As indicated above, all participants were administered the same battery of tests, including neuropsychological tests, classroom behavioral ratings, and flatscreen computer delivered continuous performance test results. Again, participants with ADHD were tested prior to taking any medications and the VR exposure for all participants lasted approximately 30 min.

Measures

A trained research assistant administered all psychometric tests. The Simulator Sickness Questionnaire (Kennedy et al., 1992; SSQ) was used to determine whether the participant felt sick as a result of the Virtual Classroom experience. The SWAN Behavior Checklist (Swanson et al., No Date) and Conners' CPT II (Conners, 2000) were chosen as prototypical ADHD assessment measures. The SWAN Behavior Checklist was designed to be filled out by parents, teachers, or both. High scores on the SWAN are indicative of more ADHD-like behavior (inattention, impulsivity, hyperactivity).

A number of neuropsychological measures were selected purposefully among those that are commercially available or that have an extensive literature base in order to increase generalizability and applicability in the clinical context. These tests are regularly used to reliably discriminate between persons with ADHD and those without. The Stroop (Golden, 1978) and Trail Making tests (Reitan, 1971, 1992; Reitan & Wolfson, 2004) appear especially good in discriminating between children with and without ADHD (Barkley et al., 1992; Golden, 1978; Nigg, 1999). Visual Attention from the NEPSY was chosen because of the role of attention control in visual search processes (Bleckley et al., 2003). Although tests of verbal and nonverbal fluency have yielded mixed results, we made use of design fluency (from the NEPSY) because persons with ADHD have been found to commit more perseverative and non-perseverative errors than controls (Rapport et al., 2001). Verbal Fluency (from the NEPSY) was chosen because of the findings using the Controlled Oral Word Association Test (Grodzinsky & Diamond, 1992; Korkman et al., 1997). From the from the WISC-III (Wechsler, 1991), we made use of Digit Span (measures both simple and complex attention), Coding B (measure of processing speed), Arithmetic (related to freedom from distractibility), and Vocabulary (measure of verbal comprehension). Finally, the Judgment of Line Orientation (Benton et al., 1983) was used to provide a motor-free test of visual perception. All tests used current norms and, when available examiner's used norms that proffered demographic (age, education, ethnicity, and sex) corrections.

Procedure

Participants were informed about the study via a flier requesting they contact the examiner if interested in participating. All participants completed informed consent/assent forms prior to participation. Testing was conducted in the morning at the USC main campus, usually on weekends. This time was chosen so that children diagnosed with ADHD would be able to resume their normal medication regimen as soon as they finished testing. When possible, normal controls were tested in the morning as well to try and minimize potential testing effects due to testing at different time of the day. All participants were administered the same neuropsychological battery, and all participants were assessed in the Virtual Classroom.

Following completion of the USC Human Participants Research Review Committee procedures and once informed consent was obtained, each participant sat at a standard "school desk" and a lab technician assisted in adjusting the fit of the Virtual Research V8 head mounted display (HMD) to the child's head. An ascension tracking device was then fitted to the participant's non-dominant hand and opposite knee. At this point the system presenting the Virtual Classroom was activated and the participant saw the interior of the classroom in the HMD. The scenario consisted 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 (VT) between the desk and blackboard, on the left side wall a large window looking out onto a playground with buildings, vehicles, and people, and on each end of the wall opposite the window—a pair of doorways, through which activity occurs. The VT then instructed the participant to spend a minute looking around the room and point and name the various objects that they observed. This served to assist the participant in becoming familiar with the components of the classroom environment. Following this one-min period, the VT told the participant that they were now going to "play a game". The VT instructed the participant to hold the remote mouse in his dominant hand and press the button when the teacher said "go". This served to familiarize the participant 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 was then recorded from a series of 20 hit commands that were presented at random intervals during a one min period. The VT then instructed the participant that a new game would begin and the testing proper phase commenced.

Experimental Conditions

Three 10-min conditions followed the 1-min hit command phase. The first two conditions used basic visual stimulus challenges found in commonly used flatscreen computer delivered CPTs. The participant was instructed to view a series of letters presented on the blackboard and to hit the response button only after he viewed the letter "X" preceded by an "A" (successive discrimination task). The AX version of the CPT consisted of the letters A, B, C, D, E, F, G, H, J, L, and X. The letters were white on a gray background (the virtual blackboard) and presented in a fixed position directly in front of the participant. The stimuli remained on the screen for 150 ms, with a fixed interstimulus interval of 1350 ms. Four hundred stimuli were presented in the 10-min condition. The target letter X (correct hit stimuli) and the letter X without the A (incorrect hit stimuli) each appeared with equal probability of 10%. The letters A and H both appeared with a frequency of 20%. The remaining eight letters occurred with 5% probability. Participants were 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.

Condition 1 (AX task without distraction): was administered without distractions, while *Condition 2* consisted of the same tasks with distractions included. The order of presentation of all conditions was counterbalanced across all participants. The order of presentation of the hit stimuli was administered based on the following rules: letters appeared on the board at a constant rate of one letter per 1.5 s (40× per min); four correct hit stimuli per minute were presented ("X" preceded by an "A") in a fixed order that occurred every 200 s. This means that three blocks of 200 s. "orders" were created; four incorrect hit stimuli per minute were presented ("X" NOT preceded by an "A") in the same format as outlined in step #2; 32 non-hit stimuli were presented during each minute.

Condition 2 (AX task with distraction): Condition 2 consisted of the identical stimulus challenges as were presented in Condition 1, however these occurred in the presence of pure 3D immersive audio distracters, pure visual distracters, or mixed 3D audio/visual distracters. Distracters consisted of the following: (1) *pure auditory*—ambient classroom sounds (i.e., whispering, pencils dropping, chairs moving, etc.) "behind" the student; (2) *pure visual*—3D paper airplane flying directly across the participant'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 were presented in a consistent manner in 200-s blocked segments that corresponded to the 200-s "blocked" stimulus presentations. This allowed for the comparison of performances in each subsequent identical 200-s block over time. Distracters were each displayed for 5 s, and presented in randomly assigned equally appearing intervals of 10, 15, or 25 s. Thirty-six distraction intervals (12 of each) and 36 distracters (nine of each) were included in the 10-min condition.

Condition 3 (BNT Match): Condition 3 consisted 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 appeared on the "blackboard". These drawings were taken from the Boston Naming Test (Kaplan et al., 1983) and the VT called out the item's name, either correctly or incorrectly. The participant was asked to listen to the VT, observe the "blackboard", and to hit the response pad every time the VT incorrectly named the object. Stimulus drawings were presented at a rate of one every five seconds. After 4.5 min the criterion for response shifted to requiring the participant to hit the response pad after correct matches between the visual stimulus and the auditory name emanating from the VT. This condition was presented with the same distraction sequencing and the same types of distractions that occurred in Condition 2 above. While the stimulus challenges used in Conditions 1 and 2 were not typical of what is found in a real classroom environment, the cognitive challenge that characterized Condition 3 more closely mimicked "real-world" attention challenges. This task created challenges that combined both visual and auditory sensory stimuli and possibly allowed for a more ecologically valid assessment of higher levels of attention.

Response Measurement

Reaction time and response variability were used as performance measures, while "head turning" and gross motor movement were recorded by the tracking devices on the HMD and on the hand/leg 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 had full protocols for with each of these participants). 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 were still rather simple, the considerable standardization data on the Boston Naming Test allowed us to examine performance in a meaningful way armed with a rich history of objective results on the psychometric properties of these particular stimuli.

Treatment of Data

One way analysis of variance (ANOVA) and chi-square analyses were conducted comparing participants with ADHD and normal controls on all demographic variables (see Table 1). One way ANOVAs were also used to compare group means on psychometric tests (see Table 2) and Virtual Classroom measures. Raw scores were used in the comparison of means on the SWAN Behavior Checklist and Judgment of Line Orientation Test. It was determined that if any participant scored more than three standard deviations from the mean on any given variable, then that participant would be excluded from the analysis of that variable. Additional ANOVAs and multiple regression analyses were conducted to tease out the effects of distraction on the groups (Tables 3). Further, we calculated Cohen's *d* to proffer a measure of effect size for comparison of means for the Virtual Classroom measures between participants in the ADHD Group and those in the Normal Control Group. Correlations (a further measure of effect) were utilized to assess associations between Virtual Classroom measures and psychometric measures for participants. An α level of .05 was used for all statistical tests.

Table 2 Comparison of Means for Psychometric Measures between ADHD Group and Normal Control Group.

	ADHD (n=9)*		Normal (n=10)		Entire Sample (n=19)			
Measures	*M*	*SD*	*M*	*SD*	*M*	*SD*	*f*	*d*
SWAN[a]	0.83	0.88	–1.54	1.11	–0.35	1.56	–5.29**	2.37
Conners CPT II[b]								
Omission	60.14	21.67	45.05	4.73	52.59	17.12	–2.15*	0.96
Commission	52.12	6.42	43.64	8.56	47.88	8.55	–2.51*	1.12
Hit RT	55.45	14.37	47.00	4.77	51.22	11.29	–1.76†	0.79
Stroop Test[c]								
Word	50.00	4.71	49.60	5.40	49.80	4.94	–.18	0.08
Color	48.60	9.71	48.80	4.24	48.70	7.29	0.06	–0.03
Color-Word	46.00	7.89	55.20	6.48	50.60	8.46	2.85*	–1.27
NEPSY[d]								
Visual Attention	10.10	2.92	13.20	3.01	11.65	3.30	2.34*	–1.05
Design Fluency	11.50	1.84	12.30	1.77	11.90	1.80	0.99	–0.44
Verbal Fluency	12.20	3.29	14.90	2.18	13.55	3.05	2.16*	–0.97
WISC-III[e]								
Digit Span	9.90	2.81	13.40	1.58	11.65	2.85	3.44**	–1.54
Coding B	9.30	3.68	10.90	2.89	10.10	3.32	1.08	–0.48
Arithmetic	8.90	2.08	12.80	2.04	10.85	2.83	4.23**	–1.89
Vocabulary	12.60	3.72	15.20	2.35	13.90	3.31	1.87†	–0.84
Trail Making Test[f]								
Part A	0.78	0.68	0.70	0.48	0.74	0.57	–0.32	0.14
Part B	0.37	1.18	1.02	0.40	0.70	0.92	1.65	–0.74
JLO[g]	19.60	5.32	25.40	2.68	22.50	5.06	3.08**	–1.38

Note: ADHD = Attention-deficit/hyperactivity disorder. [a]SWAN Behavior Checklist raw scores. [b]Age- and gender-corrected standardized scores based on Conners CPT II. General Population Norms were used for comparison. [c]Age-corrected standardized scores were generated for comparison on the Stroop Color and Word Test. [d]NEPSY age-corrected standardized scores. [e]Wechsler Intelligence Scale for Children-Third Edition age-corrected standardized scores. [f]Trail Making Test age- and gender-corrected standardized scores. [g]Judgment of Line Orientation Test raw scores. **$p < .01$, *$p < .05$, †$p < .10$. Cohen's *d* (measure of effect size) = "d".

RESULTS

Group comparisons were made on all demographic variables. Means and frequencies of age, grade, ethnicity, and handedness variables for children with ADHD and normal controls are summarized in Table 1. One way ANOVAs were conducted comparing participants with ADHD and normal controls on all psychometric tests (see Table 2). One outlier case from the children with ADHD group was omitted from this analysis because this participant consistently scored more than three standard deviations from the mean on multiple variables. Notably, none of the children reported simulator sickness following VR exposure as measured by the SSQ. Age and gender-corrected scores were used when available.

Hypothesis One: Group differences in Virtual Classroom performance

Condition 1 (AX task without distraction). Results from the assessment of the AX task without distraction are presented in Table 3. Participants with ADHD performed worse than normal controls on all measures except Hit RT and scored more errors of omission and commission errors. More overall hyperactivity was present in participants with ADHD as measured by all six measures of total body movement.

Table 3 Comparison of Means for Virtual Classroom Measures Between ADHD Group and Normal Control.

Measures		ADHD[a]		Normal		Entire Sample			
		M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*d*
Condition 1 (AX Task without Distraction)									
Omission[b]		16	10.34	4	2.98	9.68	9.48	−3.52**	1.57
Commission		16.33	10.54	3.4	4.5	9.53	10.17	−3.55**	1.60
Hit RT[c]		0.52	0.24	0.6	0.07	0.57	0.17	1.05	−0.45
Body Movement[d]	X	37.78	27.03	9.7	9.86	23	24.1	−3.07**	1.38
	Y	27.44	17.19	9.1	5.82	17.79	15.39	−3.19**	1.43
	Z	102.44	88.98	25.8	22.31	62.11	72.9	−2.64*	1.18
	R	14349	10253	3805	5833	8800	9643	−2.79*	1.26
	P	7150	4889	1628	1685	4244	4479	−3.37**	1.51
	H	15742	13534	2632	2752	8842	11420	−3.00**	1.34
Condition 2 (AX Task with Distraction)									
Omission		22.89	10.06	7	5.52	14.53	11.25	−4.33**	1.96
Commission		12.11	8.81	2	1.89	6.79	7.95	−3.55**	1.58
Hit RT		0.56	0.29	0.59	0.09	0.58	0.2	0.33	−1.4
Body Movement	X	59.67	30.39	12.2	10.58	34.68	32.55	−4.65**	2.09
	Y	40.44	19.74	10	6.6	24.42	20.95	−4.61**	2.07
	Z	135	92.1	30.9	23.07	80.21	83	−3.47**	1.55
	R	27434	24727	6770	6005	16558	20053	−2.57*	1.15
	P	10794	5257	2437	2310	6395	5773	−4.57**	2.06
	H	27579	18367	5418	5588	15915	17169	−3.64**	1.63
Condition 3 (BNT Match)									
Omission		0.33	0.71	0	0	0.16	0.5	−1.5	0.66
Commission		6.67	6.42	2.6	3.41	4.53	5.34	−1.75[†]	0.79
Hit RT		0.57	0.06	0.58	0.06	0.58	0.06	0.46	−0.17
Body Movement	X	26.22	14.18	11.2	9.2	18.32	13.82	−2.77*	1.26
	Y	19.11	11.04	8.6	4.62	13.58	9.69	−2.76*	1.24
	Z	65	34.23	30.5	20.98	46.84	32.46	−2.68*	1.22
	R	12802	12905	3518	2754	7916	10025	−2.23*	0.99
	P	5635	3223	2212	1895	3136	2249	−2.86*	1.29
	H	13982	15731	4796	4318	7217	6320	−1.78[†]	0.80

Note: [a]One outlier case in the ADHD Group was omitted from this analysis. [b]Omission and commission errors are raw scores. [c]Hit Reaction Time is raw data measured in milliseconds. [d]Body Movement data represent position (X,Y,Z) and orientation (R,P,H) and are measures of total body movement (leg, arm, and head trackers) in a given condition. $^{**}p < .01$, $^{*}p < .05$, $^{\dagger}p < .10$. Cohen's *d* (measure of effect size) = "d".

Condition 2 (AX task with distraction). Results from the assessment of the AX task with distraction are presented in Table 3. Participants with ADHD performed worse than normal controls on all measures except Hit RT and scored more errors of omission and commission. Again, more overall hyperactivity was present in participants with ADHD as measured by all six measures of total body movement.

Condition 3 (BNT Match). Results from the assessment of the BNT match are presented in Table 3. No significant differences between the two groups were found in omission errors, or in Hit RT. Participants with ADHD, however, scored more commission errors, and had more overall hyperactivity as measured by all six measures of total body movement.

Hypothesis Two: Children with ADHD would display more distractibility than controls

Results from the assessment of distractibility in children with ADHD are presented in Table 4. No significant differences were found between the two groups on change scores derived from errors of omission or commission. Participants with ADHD, however, displayed more overall hyperactivity as measured by 5 out of six measures of total body movement. On the remaining measure of total body movement positioning along the *Z*-axis, there was a trend toward more body movement among participants with ADHD.

After controlling for baseline performance, a trend emerged, in which participants with ADHD exhibit more errors of omission errors than normal controls. Significant differences were still not found between the two groups on change scores derived from errors of commission errors, or Hit RT. After controlling for baseline performance, four out of six measures of total body movement retained significant differences in change scores when comparing participants with ADHD to those without.

Hypothesis Three: Virtual Classroom correlated with traditional psychometric measures

For the correlations between the Virtual Classroom and traditional psychometric measures we only considered those correlations that met the criterion of $p < .05$ to be meaningful. Given our small sample size we kept α at this level, despite the risk of Type I error with multiple correlations. All of our significant correlations were associated with at least moderate effect sizes. For example, our smallest correlation was $r = .39$, which accounts for 15% of the variance.

On the AX task (CPT) total, omission and commission errors in the Virtual Classroom were moderately correlated with parent behavioral ratings on the SWAN Behavior checklist ($r = .51$; and $r = .59$, respectively). Correlations of Virtual Classroom body

Table 4 Comparison of Virtual Classroom Performance Degradation from Condition 1 to Condition 2 between ADHD Group and Normal Control Group.

	ADHD[a] ($n = 9$)		Normal ($n = 10$)			
Measures[b]	*M*	*SD*	*M*	*SD*	*f*	r^c
Omission	6.89	6.57	3.00	5.60	–1.39	1.94†
Commission	–4.22	6.57	–1.4	3.81	1.16	1.00
Hit RT	0.04	0.15	–0.01	0.10	–0.89	0.81
Body Movement						
X	21.89	14.99	2.50	6.40	–3.74**	3.07**
Y	13.00	9.72	0.90	4.33	–3.57**	2.81*
Z	32.56	28.92	5.10	13.45	–2.70*	2.37*
R	13085	16564	2965	6448	–1.79†	0.51
P	3644	2598	809	1434	–2.99*	2.46*
H	11838	8189	2786	4359	–3.05**	1.67

Note: [a]One outlier case in the ADHD Group was omitted from this analysis. [b]Change scores were calculated by subtracting performance values on Condition 1 (AX Task without Distraction) from performance values on Condition 2 (AX Task with Distraction) for each Virtual Classroom measure. [c]Multiple regression analysis was performed using baseline performance as a covariate. $^{**}p < .01$, $^{*}p < .05$, $^{\dagger}p < .10$.

movement with behavior ratings were slightly higher in the distracting condition ($r = .61$) than the non-distracting condition ($r = .47$). On the “incorrect match” BNT task condition, commission errors but not omission errors in the Virtual Classroom were moderately correlated ($r = .51$) with parent behavioral ratings on the SWAN Behavior checklist. On the “correct match” BNT condition, however, neither omission nor commission errors in the Virtual Classroom were correlated with parent behavioral ratings on the SWAN Behavior checklist. Virtual Classroom body movement measures were moderately correlated with parent behavioral ratings in both BNT task conditions ($r = .41$; and $r = .49$, respectively), and the strength of these correlations did not differ significantly between the conditions.

In the non-distracting condition (Condition 1), commission errors but not omission errors in the Virtual Classroom were correlated with errors, and average reaction time for hits on the Conners' CPT II ($r = .51$; and $r = .75$, respectively). When distractions were introduced, commission errors in the Virtual Classroom were still correlated with errors, and average reaction time for hits on the Conners' CPT II ($r = .44$; $r = .79$, respectively). In the non-distracting condition, Virtual Classroom body movement was correlated with omission errors ($r = .73$), commission errors ($r = .46$), and average reaction time for hits ($r = .49$) on the Conners' CPT II.

Correlations between Virtual Classroom measures and the Conners' CPT II were more variable between the two BNT task conditions. In both conditions, commission errors in the Virtual Classroom were correlated with errors, and average reaction time for hits on the Conners' CPT II ($r = .39$; and $r = .70$, respectively). The pattern for Virtual Classroom omission errors, however, was more variable. Omission errors in the Virtual Classroom were not correlated with any Conners' CPT II variables in the incorrect match BNT condition, but they were moderately correlated with Conners' CPT II omission errors and average reaction time on hits in the correct match BNT condition ($r = .52$).

Virtual Classroom body movement measures were not related to any of the Conners' CPT II variables in either of the two BNT task conditions. When correlations were calculated separately for each group, however, it was noticed that in the correct match BNT condition very strong individual group correlations were working in opposite directions and actually reducing the total sample correlation for one measure. Specifically, it was found that strong positive correlations exist between Virtual Classroom body movement and commission errors on the Conners' CPT II for the normal control group ($r = .77$). In contrast, strong negative correlations exist between Virtual Classroom body movement and commission errors on the Conners' CPT II for the participants with ADHD ($r = -.82$).

DISCUSSION

The results of this study indicate that: (1) participants with ADHD exhibited more omission errors, commission errors, and overall body movement than normal control children in the Virtual Classroom; (2) participants with ADHD were more impacted by distraction than normal control children in the Virtual Classroom; (3) Virtual Classroom measures were correlated with traditional ADHD assessment tools, the behavior checklist and flatscreen CPT. Additionally. No negative side effects were associated with use of the Virtual Classroom.

Hypothesis One: Group differences in Virtual Classroom Performance

Participants with ADHD scored more omission and commission errors than normal controls. This finding is consistent with the literature on CPT performance differences found between participants with ADHD and normal controls (Corkum & Siegel, 1993; Losier et al., 1996). It lends support to the idea that ADHD is indeed marked by inattention and impulsivity and that participants with ADHD are more inattentive (omission errors) and impulsive (commission errors) than normal controls. Participants with ADHD also exhibited more overall body movement than normal controls, which is also consistent with the literature on performance of participants with ADHD. These body movement differences, however, which lend support for the hyperactivity component of ADHD, have typically been limited to assessment by qualitative observation via behavioral questionnaires. The Virtual Classroom is the first ADHD assessment tool to quantify the inattention, impulsivity and hyperactivity components of ADHD in a virtual "classroom environment", which is thought to be a more ecologically valid environment that approximates what a participants with ADHD might experience in the real world.

Hypothesis Two: Children with ADHD would Display more Distractibility than Controls

For both the participants with ADHD group and normal control group, the introduction of distractions into the AX task scenario resulted in more omission and commission errors and more overall body movement. This is intuitively what we would expect of a good distraction from the AX task, and this finding lends support to the idea that Virtual Classroom distractions are indeed distracting. We found that when a given stimulus was truly distracting an individual from paying attention to a task, performance was reduced on that task. Further, more evidence was found of missed targets (omissions) and a smaller number of false hits (commissions) due to being distracted from the task at hand. Additionally, we found that when a given stimulus was truly distracting and attending to that stimulus required more body movement than attending to the task at hand, more evidence of total body movement due to distraction was apparent.

Condition 1 (AX task without distraction). In the non-distracting condition, commission errors but not omission errors in the Virtual Classroom were correlated with omission errors, commission errors, and average reaction time for hits on the Conners' CPT II. This finding appears to be consistent with findings in the literature that errors of commission on CPT tasks may be more likely than those of omission to discriminate participants with ADHD from normal children (Barkley, 1991). If these findings regarding commission errors on CPT tasks were indeed true, then a measure of CPT commission errors set within the context of a Virtual Classroom environment would be more likely to correlate with other measures known to discriminate between participants with ADHD and normal children (i.e. Conners' CPT II) than other CPT measures which might be set within that same environment.

Increased Virtual Classroom body movement was more closely related to an increase in Conners' CPT II omission errors for the participants with ADHD group than for normal controls. Hence, increased hyperactivity in children will result in greater inattention given to a task. If one assumes that hyperactivity is consistent across tasks (and this was the rule, not the exception in the current sample of participants), then a child who was hyperactive in the Virtual Classroom would also exhibit hyperactivity while completing the Conners' CPT II. The presence of hyperactivity while completing the Conners' CPT II would in turn result in greater inattention to the task and more omission errors. Virtual classroom body movement was more closely related to commission errors on the

Conners' CPT II for normal controls than the participants with ADHD group. This finding fits with the idea that increased Virtual Classroom body movement among the participants with ADHD group in not closely related to increased impulsivity as measured by commission errors on the Conners' CPT II, which also makes sense if one accepts the notion that greater overall hyperactivity results in greater inattention to the task and less commission errors. For normal controls increased body movement was more related to decreased average reaction time for hits (i.e. faster reaction time) on the Conners' CPT II.

Condition 2 (AX task with distraction). In the distracting condition, Virtual Classroom body movement measures were correlated with omission errors on the Conners' CPT II, but not commission errors or average reaction time for hits. Compared to the non-distracting condition, these correlations between body movement measures and omission errors are a little lower. We would expect to see this reduction due to the presence of systematic distractions in the VC scenario, however, which are not found in the Conners' CPT II paradigm. The tendency for an increase in Virtual Classroom body movement to be related to an increase in Conners' CPT II omission errors was truer for the participants with ADHD group than the normal control group. Yet still, this finding makes intuitive sense given the finding presented earlier that this participants with ADHD group exhibited more hyperactivity and distractibility as measured by overall body movement than the normal control group.

Hypothesis Three: Virtual Classroom Correlated with Traditional Psychometric Measures

Again, for correlations between the Virtual Classroom and traditional psychometric measures we only considered those correlations that met the criterion of $p < .05$ to be meaningful. Given our small sample size we kept α at this level, despite the risk of Type I error with multiple correlations. All of our significant correlations were associated with at least moderate effect sizes. For example, our smallest correlation was $r = .39$ (commission errors in the Virtual Classroom correlated with errors on the Conners' CPT II), which accounts for 15% of the variance.

Virtual classroom body movement measures were moderately correlated with parent behavioral ratings in both BNT task conditions, and the strength of these correlations did not differ significantly between the conditions. Apparently, an increase in overall body movement on the BNT task conditions of the Virtual Classroom is related to an increase in more ADHD-like behavior (inattention, impulsivity, hyperactivity) as measured by parent ratings of behavior.

It was found that strong positive correlations exist between Virtual Classroom body movement measures and commission errors on the Conners' CPT II for the normal control group. In contrast, strong negative correlations exist between Virtual Classroom body movement measures and commission errors on the Conners' CPT II for the participants with ADHD group. Apparently, increased Virtual Classroom body movement is related to an increase in commission errors on the Conners' CPT II for the normal control group. On the other hand, increased Virtual Classroom body movement is related to a decrease in commission errors on the Conners' CPT II for participants with ADHD. These differences do make intuitive sense and follow the line of thinking presented earlier. If one accepts the notion that greater overall hyperactivity could result in greater inattention to the task and in turn less commission errors, then the finding makes intuitive sense that increased

Virtual Classroom body movement among the participants with ADHD group was not closely related to increased impulsivity but rather decreased impulsivity (less omissions) as measured by the Conners' CPT II.

Correlations of Virtual Classroom body movement variables with behavior ratings were slightly higher in the distracting condition than the non-distracting condition, but this is what we would expect from a good distraction. A good distraction should, in effect, evoke more body movement. On the "incorrect match" BNT task condition, commission errors but not omission errors in the Virtual Classroom were moderately correlated with parent behavioral ratings on the SWAN Behavior checklist. On the "correct match" BNT condition, however, neither omission nor commission errors in the Virtual Classroom were correlated with parent behavioral ratings on the SWAN Behavior checklist. It is difficult to explain why this correlation would be found in the incorrect match condition and not in the correct match condition. The lack of a significant finding of strong correlations between these laboratory methods of assessing attention and parent ratings of behavior, however, fits generally well with what has been described in the literature (Barkley, 1991).

Limitations and Projections for Future Studies

Our findings should be understood in the context of some limitations. First, it is important to note that the normal controls tended to have higher scores on the WISC-III. Future studies should make attempts at reducing the disparity between such measures between groups. For the current study, we acknowledge that this may have some bearing on the overall interpretation of results. Furthermore, these findings are based on a fairly small sample size. As a necessary next step, the reliability and validity of the test needs to be established using a larger sample of participants. This will ensure that the current findings are not an anomaly due to sample size. Additionally, as indicated above, the diagnostic utility of this ADHD assessment tool must be determined. The ability of the Virtual Classroom to accurately classify participants into ADHD and non-ADHD groups based on carefully established critical values must be evaluated. This will involve the generation of specific cut-off points for classifying a positive (ADHD likely) or negative (ADHD unlikely) finding. The Virtual Classroom's prediction of ADHD will need to be evaluated by the performance indices of sensitivity, specificity, predictive value of a positive test, and predictive value of a negative test. Even though reliability is considered to be a unique asset of testing in computer-generated VEs, issues of test–retest reliability need to be addressed. Complementary comparisons of the Virtual Classroom with behavioral and cognitive tests developed to assess ADHD are also warranted to determine the construct validity of the test. Finally, the ability of the Virtual Classroom to accurately classify participants not involved in the initial validation study will need to be examined for cross-validation purposes.

Our goal was to conduct an initial pilot study of a Virtual Classroom scenario that employs a standard CPT for the assessment of participants with ADHD. We believe that this goal was met, as all of our hypotheses about the Virtual Classroom were confirmed. We recognize, however, that the current findings are only a first step in the development this tool. Many more steps need to be taken in order to continue the process of test development and to fully establish the Virtual Classroom as a measure that contributes to existing assessment procedures for the diagnosis of ADHD.

Whilst the Virtual Classroom as a measure needs to be fully validated, current findings provide preliminary data regarding the validity of the virtual environment as an

ADHD measure. The Virtual Classroom was able to differentiate between participants with ADHD and normal control children very effectively. Furthermore, the Virtual Classroom was correlated with two of the most widely used ADHD assessment tools, the behavior checklist and flatscreen CPT. Nevertheless, the fairly small sample size and higher WISC-III scores of normal controls require that the reliability and validity of the Virtual Classroom be established using a larger sample of well-matched participants. This will ensure that current findings are not a sample size or intelligence related anomaly. As indicated above, the diagnostic utility of the Virtual Classroom for ADHD must be determined. The ability of the Virtual Classroom to accurately classify participants into ADHD and non-ADHD groups based on carefully established critical values must be evaluated. This will involve the generation of specific cut-off points for classifying the likelihood of an ADHD finding. Extensive comparisons of the Virtual Classroom with behavioral and cognitive tests developed to assess ADHD are also warranted to adequately establish the construct validity of the test. Finally, the ability of the Virtual Classroom to accurately classify participants not involved in the initial validation study will need to be examined for cross-validation purposes.

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