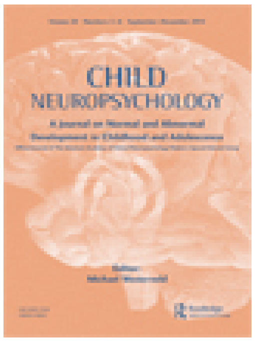

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DISTRACTIBILITY IN ATTENTION/DEFICIT/ HYPERACTIVITY DISORDER (ADHD): THE VIRTUAL REALITY CLASSROOM

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Nineteen boys aged 8 to 14 with a diagnosis of ADHD and 16 age-matched controls were compared in a virtual reality (VR) classroom version of a continuous performance task (CPT), with a second standard CPT presentation using the same projection display dome system. The Virtual Classroom included simulated "real-world" auditory and visual distracters. Parent ratings of attention, hyperactivity, internalizing problems, and adaptive skills on the Behavior Assessment System for Children (BASC) Monitor for ADHD confirmed that the ADHD children had more problems in these areas than controls. The difference between the ADHD group (who performed worse) and the control group approached significance (p = .05; adjusted p = .02) in the Virtual Classroom presentation, and the classification rate of the Virtual Classroom was better than when the standard CPT was used (87.5% versus 68.8%). Children with ADHD were more affected by distractions in the VR classroom than those without ADHD. Results are discussed in relation to distractibility in ADHD.

Keywords: ***Distractibility; Attention deficit/hyperactivity disorder (ADHD); Virtual Classroom; Continuous Performance Test (CPT); Vigil; Behavior Assessment System for Children (BASC) Monitor.***

Attention deficit/hyperactivity disorder (ADHD) is the most common neurodevelopmental disorder of childhood (Rowland, Lesesne, & Abramowiz, 2002) and carries along with it serious consequences, including difficulties with education and employment, as well as increased health care costs (Barkley, 2002). Its worldwide prevalence is estimated at 8% to 12% and is much more common in males than females (Staller & Faraone, 2006). ADHD is highly heritable and is associated with prefrontal cortex deficits (Spencer, Beiderman, Wilens, & Faraone, 2002). ADHD not only affects school performance but also has a profound effect on the child's personal and social development, as well as being a risk factor for the development of other comorbid disorders. Children with ADHD are also more likely to experience problems such as school failure, criminal behavior, and substance abuse (Magyary & Brant, 2002). Despite the frequency and negative

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consequences of this disorder, the specific mechanisms underlying it have not, to date, been clarified.

Continuous Performance Tasks (CPTs) have been used to assess sustained attention and the ability to inhibit responses. Research has indicated that group differences between individuals with ADHD and healthy controls are typically found (Riccio, Reynolds, & Lowe, 2001), even though the ability of CPT tests to make predictions about individual diagnosis is limited (Nigg, Hinshaw, & Halperin, 1996). Specifically, those with ADHD make more omission errors (Barkley, Grodzinsky, & DuPaul, 1992; Epstein, Erkanli, Conners, Klaric, Costello, & Angold, 2003; Shallice et al., 2002), commission errors (Epstein et al.; Rovet & Hepworth, 2001; Shallice et al.) and have poorer performance on overall index scores (Perugini, Harvey, Lovejoy, Sandstorm, & Webb, 2000). These findings have been consistent across child (Barkley et al., 1992; Perugini et al., 2000; Shallice et al., 2002) and adult (Siedman, Biederman, Weber, Hatch, & Faraone, 1998) populations, with most research being conducted on males. However, results vary depending on comorbidity and gender (Newcorn et al., 2001), and phonological awareness (McGee, Clark, & Symons, 2000).

Despite the large body of research that has replicated these findings (Riccio et al., 2001), the specific mechanisms underlying these differences in performance remain unclear. As indicated, the predictive diagnostic utility of CPT tests in differentiating children with ADHD and those without is limited, given the large overlap in performance between the two groups. In other words, these tests are poor in differentiating between children with ADHD and healthy controls because setting the cutoff stringently enough to capture children with ADHD results in incorrect classification of normal children as impaired. Grodzinsky and Barkley (1999) found, for example, that for boys, the CPT scores of “number correct” and “number of commissions” had a positive predictive power (the chance that a child with an abnormal score has ADHD) of over 80%; however, these scores had only moderate negative predictive power (the chance that a child with a normal score did not have ADHD). The authors suggest that while “abnormal scores on the CPT may indicate a relatively high probability for the diagnosis of ADHD…nearly 60% of the ADHD children received normal scores on this test” (Grodzinsky & Barkley, p. 17). Nigg et al. (1996) tested boys aged 6 to 12 years old and found that the CPT was able to distinguish between groups but not identify individual boys with ADHD. One conclusion reached by Nigg et al. was that these results suggested only limited support for the ecological validity of the CPT.

This low specificity may reflect the atypical conditions under which CPTs are usually administered, i.e., in quiet office settings with few distractions. This is in contrast with the noisy and distracting classrooms and home environments in which children typically operate. In fact, correlations between parent and teacher ratings of child behavior and CPT scores tend to be weak (Continuous Performance Tests [CPTs] for Diagnosis and Titration of Medication for Attention Deficit Hyperactivity Disorder [ADHD]; U.S. Department of Defense, 2000), raising questions about the validity of standard CPT tests.

One of the clinical characteristics observed in children with ADHD is increased distractibility (see the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision*, 2000, Criterion A, number eight). One way to increase the specificity of a CPT task may be to increase the amount of distraction, since children who are better able to deal with distractions (i.e., controls) should perform better than those who have greater difficulty handling distraction.

Several studies have demonstrated that the introduction of distracters (visual or auditory noise) during continuous performance tests negatively affect performance, but this has generally been found to be true across different population samples, including healthy controls

(Riccio et al., 2001). Increased distractibility in ADHD could be due to several factors, singly or in combination, such as the inability to maintain focus on a task, enhanced orienting to novel stimuli (van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007), or failure to inhibit (or gate) incoming sensory stimuli (Barkley, 1997). The specific stimulus properties that lead to more or less distraction (e.g., novelty, salience, appeal) are other factors to consider.

Unfortunately, the few studies that have addressed distractibility in ADHD have reported inconsistent results, such that sometimes children with ADHD appear to be more negatively affected by distracters than healthy controls (Barkley, Koplowitz, Anderson, & McMurray, 1997; Brodeur & Pond, 2001; Radosh & Gittelman, 1981), sometimes they are reported to perform better (Tirosh, Perets-Dubrovsky, Davidovitch, & Hocherman, 2006; van Mourik et al., 2007), and sometimes there is no difference (West et al., 2000). Given both the paucity of research in this area and the heterogeneity of findings, it is hard to know a priori which distracter attributes will be most effective in reproducing the distractibility these children manifest in real life.

While it has been difficult to present ecological distracters in a controlled manner in the past, advances in virtual reality technology now make it possible to do so. Virtual reality can be seen as “an advanced form of human-computer interface which allows the user to ‘interact’ with and become ‘immersed’ in a computer-generated environment in a naturalistic fashion” (Schultheis & Rizzo, 2001, p. 298). Virtual reality is distinct from other activities, such as watching a movie, in that it allows the person to interact in three dimensions. This is done via the use of tracking systems that are able to determine the position and orientation of the person’s head in space and to use this information to change the image that is displayed. This makes it so that when the person moves his or her head the image he or she sees changes accordingly (Schultheis & Rizzo).

Virtual reality technology can be used to aid in the assessment and rehabilitation of cognitive abilities. Virtual reality offers several benefits when combined with traditional neuropsychological assessment measures, including that it involves more realistic, lifelike environments that may allow persons to “forget” that they are being assessed, the control of stimulus presentation, the safe assessment of hazardous situations, increased standardization of rehabilitation protocols, increased user participation, and increased generalization of learning (Schultheis & Rizzo, 2001). For example, virtual reality can aid in rehabilitation by allowing people to practice cognitive abilities in a simulated environment that is similar to the ones in which they will use these abilities (Rizzo et al., 2000).

The unique match between Virtual Reality (VR) technology assets and the needs of various clinical aims has been recognized by a number of authors and an encouraging body of research has emerged (Glantz, Rizzo, & Graap, 2003; Rizzo, Schultheis, Kerns, & Mateer, 2004; Rizzo, Wiederhold, & Buckwalter, 1998; Rose, Brooks, & Rizzo, 2005). VR has been used with adults in many domains of psychological assessment and intervention, including exposure therapy for anxiety disorders such as fear of flying (Rothbaum, Hodges, Anderson, Price, & Smith, 2002; Rothbaum et al., 2006; Rothbaum, Hodges, Smith, Lee, & Price, 2000), fear of heights (Emmelkamp et al., 2002; Rothbaum et al., 1995), and various other phobias (Anderson, Rothbaum, & Hodges, 2003; Botella et al., 1998; Carlin, Hoffman, & Weghorst, 1997; Garcia-Palacios, Hoffman, Carlin, Furness, & Botella, 2002; Parsons & Rizzo, in press; Powers & Emmelkamp, in press). VR has been usefully implemented with posttraumatic stress disorder (Difede et al., 2007; Difede & Hoffman, 2002; Rizzo, Reger, Gahm, Difede, & Rothbaum, in press; Rothbaum, Hodges, Ready, Graap, & Alarcon, 2001), addictive behaviors (Bordnick, Graap, Copp, Brooks, & Ferrer, 2005), acute pain reduction (Gold, Kim, Kant, & Rizzo, 2005), and for the assessment and rehabilitation of cognitive and motor impairments following stroke, brain injury, and other forms of neurological disorders (Morrow, Docan, Burdea, & Merians, 2006; Rose, Brooks, & Rizzo, 2005; Stewart et al., 2007). To do this, scientists have constructed virtual reality airplanes, skyscrapers, spiders, battlefields, social events populated with virtual humans, fantasy worlds, and the mundane (but highly relevant) functional environments of the schoolroom, office, home, street, and supermarket.

In the area of assessment, virtual reality technology enables more controlled and consistent stimulus presentation, coupled with greater ease of administration (Parsons, Bowerly, Buckwalter, & Rizzo, 2007). Furthermore, the distractions that are presented are designed to approximate real-life events that a child is likely to encounter and may therefore impact performance more than the isolated sounds and visual events typically used in the CPT studies cited above.

The development of a Virtual Classroom provides an opportunity to assess children's performance on a CPT task under conditions that simulate a real-world classroom setting, while simultaneously presenting distracting events under highly controlled conditions. Distracters can be aural, visual, or mixed aural/visual, such as ambient classroom sounds, a paper airplane flying by, a car and bus that drive by an open window, the sound of a voice over the intercom, and a man walking in and out of the classroom. Parsons et al. (2007) reported some initial evidence for the validity of the VR Classroom. Specifically, they reported moderate correlations between the total number of omission and commission errors (for both nondistraction and distraction conditions) and errors and average reaction time on the Connors CPT, as well as correlations with the Strengths and Weaknesses of ADHD symptoms and Normal behavior scale (SWAN) Behavior Checklist.

Rizzo et al. (2006) conducted a clinical pilot study utilizing the Virtual Classroom in a head-mounted display with 8 boys with ADHD and 10 controls ranging in age from 6 to 12 years. They compared the groups in the distracting condition and in a "nondistraction" condition where sound had been turned off and people and objects did not move. The ADHD group performed significantly worse than the control group in both nondistracter and distracter conditions, committing more omission and commission errors and producing more variable reaction times in both. Those with ADHD had slower correct hit reaction times in the distraction condition and higher correct hit reaction time variability in both conditions. In addition, those with ADHD produced more omission errors in the distracting condition than in the nondistracting condition; a finding not seen in the controls.

Using the same experimental paradigm, Parsons et al. (2007) presented data on 10 boys with ADHD and 10 controls in the VR Classroom under distracting and nondistracting conditions. They found that both with and without distraction the boys with ADHD performed worse than the controls on all measures except hit rate. Although they found no differences across the two conditions on change scores in the number of commission and omission errors between the two groups, based on a trend towards more omission errors in the ADHD group and increased body movement during the distraction condition they concluded that participants with ADHD were more impacted by distraction than were the healthy children. Classification rates for the two groups were not reported.

In sum, while distracters have been shown to increase errors in both children with ADHD and without, the question remains as to whether a CPT administered in a controlled environment with simulated "real-world" distracters, compared to a standard CPT without distracters, would be able to more successfully differentiate ADHD children from controls on the basis of their ability to withstand distraction. The present study was an initial attempt to investigate the ability of the Virtual Classroom to discriminate between an ADHD and control group, compared to a standard vigilance test (Vigil). The Behavior Assessment System for Children (BASC) Monitor for ADHD, a parent rating scale, was also administered in order to provide confirmation of differences between the two groups of children and to examine the relationship between this rating scale and performance on the two different CPT presentations (Virtual Classroom versus Vigil).

METHOD

Participants

Thirty-five boys, 8 to 14 years of age, participated in this study. Nineteen were diagnosed with ADHD and were recruited through newspaper advertising. Sixteen control children volunteered from local elementary and middle schools and were recruited by sending a letter home to parents. Parents interested in having their child participate in the study were contacted by telephone and on the basis of interview questions, those children with ADHD with comorbid diagnoses were excluded from the study. Controls were selected on the basis of having no premorbid history of psychiatric or neurological illnesses or disorders. Diagnoses were provided by licensed mental health professionals or pediatric physicians, and parents provided written consent to have medical records reviewed for confirmation of diagnosis. Since these children had been diagnosed by clinicians, for whom subtypes are of relatively little practical interest, little effort was made to differentiate children on this basis. All participants were Caucasian and came from an ethnically and socioeconomically homogeneous area in New Hampshire. Participants were enrolled as they became available and when no more volunteers were forthcoming the groups were compared for age and found to be closely matched. The average age of the ADHD group was 10.1 (*SD* = 1.74) and of the controls was 10.5 (*SD* = .89).

Of the 19 participants with ADHD, according to parental report 10 had taken medication on the day of testing. Medications included methylphenidate HCl (*n* = 6), methylphenidate (*n* = 2), dexmethylphenidate HCl (*n* = 1), and atomoxemtine HCl (*n* = 1). None of the controls were taking any stimulant medication; one was taking Allegra for allergies. No child was taking more than one medication. Due to Institutional Review Board (IRB) guidelines, participants in the ADHD group were not requested to discontinue their medication on the day of testing. Parents of nine children nonetheless withheld the medication in the morning. All testing was conducted in the middle of the afternoon to avoid medication effects as much as possible. Comparison of the ADHD children on versus off medication revealed no significant differences in performance on any measure except for the Interpersonal Problems scale of the BASC Monitor, on which the children who were taking medication scored higher ($M = 82.2$, $SD = 13.35$) than those who were not ($M = 52$, $SD = 27.79$, $U = 11.5$, $p = .02$).

Materials and Equipment

The Virtual Classroom was developed at the Integrated Media Systems Center at the University of Southern California in Los Angeles. The classroom consists of three rows of desks, a teacher's desk at the front of the room, a blackboard on the front wall, and a female virtual teacher standing between the desk and the blackboard (see Figure 1; color versions of figures available online at journal Web site). On the left wall of the room is a large window through which a playground, buildings, vehicles, and people can be seen. On the right wall there are two doors through which a virtual man enters and exits.

Figure 1 The Virtual Classroom.

Figure 2

Both versions of the CPT (with and without the Virtual Classroom) were presented to the participants on a 3-D virtual reality dome by Elumens. This provides a field of view (horizontal and vertical) of 140 degrees. A sensor placed on the participants' heads allowed the participants to observe changes in the classroom in response to their head movement, such that when the children turned their head the scene changed accordingly (see Figure 2).

The participants were instructed to view a series of letters on the blackboard and to hit the response button when they viewed the letter “X” preceded by the letter “A.” The stimuli consisted of the following letters A, B, C, D, E, F, G, H, K, L, and X. Each letter appeared on the screen for 150 msec, such that 400 stimuli were presented during the 6-minute testing session. The letter X and the letter A followed by the letter X each appeared with a 10% probability, A and H appeared with a 20% probability, and all other letters appeared with a 5% probability (Rizzo et al., 2000).

Distracters included: auditory distracters such as whispering, pencils dropping, and chairs moving out of sight of the student; visual distracters such as a 3-D paper airplane flying across the participant’s field of view; and mixed aural and visual distracters such as a car rumbling by the outside window, a man coming in and going out of different doors, doors creaking, footsteps, and hallway activity could be heard. Distracters were presented throughout the duration of the task.

Following administration of the program, participants were asked what they remembered seeing or hearing and were given a 36-item yes/no recognition task (e.g., participants were asked if they had heard someone sneeze [no] and if they had heard someone cough [yes]). This provided information regarding their ability to attend to and to register specific distracting events.

Prior to immersion in the Virtual Classroom participants were again encouraged (having already been so informed in the written consent form read to them) to inform the examiner at any time if they felt ill or in any way uncomfortable and were told that they could stop at any time without penalty. The Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) was administered following the Virtual Classroom task to determine whether they had experienced any symptoms similar to those of motion sickness due to being in a virtual environment. Since the participants had not previously been in a virtual environment, this questionnaire was administered after their experience in the Virtual Classroom. Additionally, Rizzo et al. (2000) indicated in their initial pilot study that no children reported side effects as measured by posttest interviews using the SSQ.

The Behavior Assessment System for Children (BASC) Monitor for ADHD parent report form (Reynolds & Kamphaus, 1998) is a parent rating scale on which parents circle “never,” “sometimes,” “often,” or “always” in response to statements regarding their child’s behavior. It consists of four subscales: Attention Problems, Hyperactivity, Internalizing Problems, and Adaptive Skills. On the first three scales, higher scores are indicative of greater difficulty, while on the Adaptive Skills scale a higher score is better.

Norms are provided by age range and gender. Test-retest reliability based on a sample of 3,477 parental ratings for the four subscales ranged from .57 to .90. Validity has been established using correlations to other instruments, intercorrelations with the full BASC, and scale content based on factor analysis.

The Vigil (Psychological Corporation, 1996), a continuous performance test, was projected into the dome (in the absence of the virtual classroom). The cued condition was used, which requires participants to strike a computer key when the letter K appears immediately after the letter A. Targets appear for a duration of 85 msec; there are 25 targets in the cued condition. Test-retest reliability was established using a two-tailed Pearson correlation for all measurement variables, with values ranging from .74 to .87 ($p < .001$). Face validity was established using the operational criteria developed by Mackworth’s (1957) definition of a vigilance task. Concurrent validity was demonstrated by correlating the Mesulam Figure Cancellation task and the FAS word fluency test with Vigil (Cegalis, 1991).

Procedure

Permission to conduct this study was obtained by the Institutional Review Board at the institution where the research took place. Following the signing of an informed consent by parent or guardian, and oral and written consent by the child, participants were escorted into the testing room. Parents were escorted into another room where they could watch their child on a closed-circuit television. While their child was being tested, parents filled out a demographic questionnaire and the BASC Monitor for ADHD. In the other room, a head-tracking sensor was placed on the participant's head. At this point, participants were placed in front of the Elumens dome and allowed to familiarize themselves with the Virtual Classroom by briefly gazing around while the examiner set up the warm-up task. This involved pressing a button every time the number nine appeared over the period of a minute.

They then engaged in the Virtual Classroom assessment. Following this assessment, the experimenter asked the participant a series of questions regarding their memory for items and events observable in the Virtual Classroom. They were also queried regarding symptoms of virtual reality sickness using items from the Simulator Sickness Questionnaire (Kennedy et al., 1993). Each participant then completed the Vigil. Since this was conceived of as a small-scale study, the two CPT conditions were not counterbalanced. The VR Classroom was administered first so that worse performance would not be attributed to fatigue but to the more distracting aspect of this condition, compared to the Vigil.

RESULTS

To examine group differences, the Mann Whitney *U t*-test was computed because there was unequal variance between the groups for all of the dependent measures used in this study except for commission errors in the VR Classroom and the BASC Monitor for ADHD subscale scores. Likewise, the Spearman correlation coefficient was utilized as a nonparametric correlation coefficient. Family-wise Bonferroni corrections to adjust for multiple comparisons were used, with the original alpha set at .05. A descriptive analysis of the variables indicated that one individual in the ADHD group had scores that fell more than three standard deviations from the mean on several variables, and this person's data was therefore removed. Therefore the final *n* for the ADHD group was 18.

There were no significant age differences between groups, with the ADHD group reporting a mean of 10.5 years (*SD* = 1.74) and a control group mean of 10.1 years (*SD* = 89), $t(32) = 0.94$, $p > .05$.

Virtual Classroom and Vigil

Nine out of 18 (50%) participants with ADHD scored at or above 90% on the percent of targets correctly identified in the Virtual Classroom, and eight (42%) scored above 90% accuracy on the Vigil. A strong correlation was found between scores of percent correct on the Virtual Classroom and the Vigil, $r_s(33) = .64$, $p < .001$. For group differences, the percent correct in the Virtual Classroom trended towards significance ($U = 88.5$, $p = .05$; adjusted significance is $p = .02$, see Table 1), such that the control group scored higher compared to the ADHD group ($d = 0.98$, overlap percent = 44.6%).

Table 1 Performance of the ADHD and Control Groups on the Virtual Classroom, the Vigil CPT, and Four Subtests of the BASC Monitor for ADHD.

	ADHD ($n = 18$)		Control ($n = 16$)		Statistic (Mann-Whitney U)	Probability (p)
	M	SD	M	SD		
VClassroom Percent Correct	78.2	21.1	93.9	8.3	88.5	$p = .05$†
VClassroom Omissions	13.1	12.6	3.7	5.0	88.0	$p = .08$
VClassroom Commissions	12.3	20.2	4.7	4.1	76.9	$p = .03$†
VClassroom Cued Recall	28.06	1.91	28.06	2.54	134	$p > .05$
Vigil Percent Correct	80.25	18.48	90.23	8.7	114.0	$p > .05$
Vigil Omissions	25.82	24.93	14.5	12.48	114.0	$p > .05$
Vigil Commissions	21.11	25.72	10.31	8.06	118.5	$p >. 05$
BASC MFA Attention Problems	95.89	5.28	31.81	23.90	2.0**	$p <. 001$
BASC MFA Hyperactivity	90.39	18.96	22.88	18.22	6.5**	$p <. 001$
BASC MFA Interpersonal Problems	69.89	24.25	38.75	30.39	65**	$p <. 01$
BASC MFA Adaptive Skills	37.89	29.08	69.06	27.13	64**	$p <. 01$

**significant with adjusted $p < .01$; † = trend towards significance, adjusted alpha = .02.

Using logistic regression, with percent correct as the predictor and diagnosis as the criterion, 50% of the ADHD group and 87.5% of the controls were correctly classified, resulting in an overall accuracy of 67.6%. The percent correct on the Vigil was not significantly different between groups ($d = 0.70$, overlap percent = 57%). Using Vigil, 50% of the ADHD and 68.8% of the controls were correctly classified in a logistic regression, using percent correct and diagnosis again as the predictor and criterion variables, respectively, resulting in an overall correct classification of 58.8%.

There was no statistically significant difference between the ADHD and control group in the number of omissions committed in the Virtual Classroom ($d = 0.98$, overlap percent = 45.6), although more omission errors were committed by the ADHD group than the control group. The difference between groups in the number of omission errors committed during Vigil was also not significant.

There was a trend towards a significant difference between groups in the number of commission errors made in the Virtual Classroom $U = 76.9$, $p = .03$; adjusted significance is $p = .02$; $d = 0.52$, percent overlap = 67, with more errors being committed by the ADHD group than the control group. No group differences were found on commission errors on the Vigil, $U = 118.5$, $p > .05$.

There was no significant difference between groups on the recognition task.

Simulator Sickness Questionnaire

The majority of participants experienced no or minimal discomfort. Although participants were encouraged to tell the investigator if they experienced discomfort so the study could be stopped, none of the participants requested that the study be discontinued. In addition, there were no significant differences between groups for ratings on the Simulator Sickness Questionnaire virtual reality sickness, $U = 57$, $p > .05$.

BASC Monitor for ADHD

Group differences (in the expected direction) were found on each of the four subscales of the BASC Monitor for ADHD, the Attention Problems scale, the Hyperactivity Subscale, the Interpersonal Problems subscale, and the Adaptive Skills subscale (see Table 1). For the ADHD group, results indicate a significant relationship between the percent of correct responses in the Virtual Classroom and the Attention Problem subscale of the BASC Monitor for ADHD (see Table 2), but no other significant relationships were found.

For the control group there was a significant correlation between the percentage of correct responses in the Virtual Classroom with the Attention Problems subscale and with the Adaptive Skills subscale of the BASC Monitor for ADHD, but no significant relationship with the Hyperactivity and Interpersonal Problems scales. The correlation between percent correct on Vigil and the Attention Problems subscale of the BASC was significant for the control group, as was the correlation between the Hyperactivity subscale and number of omissions, r_s (14) = .55, $p = .04$. There were no other significant correlations for either group between the standard Vigil and any of the BASC Monitor for ADHD Scales, or between number of commissions on either the Virtual Classroom or standard Vigil and the BASC.

DISCUSSION

The goal of this study was to collect initial information about the utility of the Virtual Classroom in distinguishing between ADHD and healthy children and to evaluate the effect of ecologically valid distracters. In this study, children with and without ADHD were compared in their performance on a standard CPT (Vigil) and on a virtual reality presentation of a CPT (Virtual Classroom). Diagnoses of ADHD were made by independent physicians or clinicians. Results from the BASC Monitor for ADHD served to further validate these diagnoses. Participants experienced minimal to no discomfort during the Virtual Classroom task, as evidenced by scores on the Simulator Sickness Questionnaire. This is consistent with the report of Parsons et al. (2007), who indicate that none of their children reported sickness.

Significant differences were found between the ADHD and control groups on all subtests of the BASC Monitor for ADHD. Specifically, ADHD children had higher scores on the Attention Problems, Hyperactivity, and Internalizing Problems subscales and lower

Table 2 Spearman Correlations Between Percent Correct on VR Classroom and Vigil CPT tests and BASC Monitor for ADHD Scales.

	Virtual Reality Classroom				Vigil			
	ADHD Controls				ADHD Controls			
BASC Monitor for ADHD Scales	r_s	p	r_s	p	r_s	p	r_s	p
Attention Problems	−.41*	.04	−.61**	.01	−.17	.26	−.59**	.01
Hyperactivity	−.18	.23	−.33	.11	−.15	.28	−.46	.04
Internalizing Problems	.10	.21	−.24	.20	.24	.17	.07	.41
Adaptive Skills	.26	.14	.63**	.01	.08	.38	.29	.15

** significant with $p < .01$; * significant with $p < .05$.

scores on the Adaptive Skills subscale compared to control children. These findings are consistent with those reported in the BASC Monitor for ADHD manual and software guide (Reynolds & Kamphaus, 1998). However, despite these group differences, few correlations were observed between performance of the ADHD group in either the Virtual Classroom or Vigil and the BASC Monitor subscales. This was likely due to the fact that parental ratings for the boys in our ADHD group clustered at the more extreme end of the scale, producing a very restricted range.

There was a trend towards significant differences between the ADHD group and the control group on measures of overall percent correct as well as total number of commission errors in the Virtual Classroom, with ADHD children performing worse than controls. In contrast, on a standard CPT, Vigil, this trend was not observed. While our results indicate that the two groups did not differ statistically on these tasks, it is worth noting that the effect size for each is large ($d = 0.91$ for Virtual Classroom and 0.71 for Vigil).

The classification rate of the Virtual Classroom was better than that of the standard CPT in correctly identifying controls (87.5% versus 68.8%), thus improving specificity (but not sensitivity, since the classification of ADHD children remained at 50% for both versions). This difference is due to the fact that the overlap percent is larger (57%) in the standard Vigil presentation, with controls doing better, but smaller in the Virtual Classroom (44.6%). This finding is consistent with research done by Grodzinsky and Barkley (1999), also using an AX-CPT task, who found that for boys nearly 60% of the ADHD children received normal scores on a continuous performance task.

The difference in specificity between the VR Classroom and the standard Vigil presentation may be due, at least in part, to the increased complexity and distractions provided by the Virtual Classroom, which is closer to the real-life experience of children. It appears that the novelty of the Virtual Classroom, with its attendant distractions, was easier for the controls to cope with than it was for the boys with ADHD. The larger discrepancy in performance between the two groups in the simulated “real-world” environment offered by the Virtual Classroom compared to the standard CPT supports earlier studies indicating a greater detrimental effect of distracters on children with ADHD. Radosh and Gittelman (1981) had hyperactive and control children complete a computerized arithmetic test in which problems were either surrounded by a border with either no appeal (white), low appeal (colorful), or high appeal (filled with cutout of magazine pictures of toys, animals, etc.). While both the hyperactive and control children made more errors in the high appeal than low appeal condition, and in the low appeal condition relative to the no-appeal condition, the hyperactive children had a significantly greater increase in errors from the no appeal to the high appeal condition, relative to controls. Similarly, Barkley et al. (1997) compared time estimation in ADHD versus control children with and without the distraction of a pop-up jack-in-the-box. The children with ADHD became significantly worse with the distracter while performance of the controls was unaffected.

Nonetheless, the fact that sensitivity of both CPT versions in classifying boys with ADHD was no better than 50% is a reflection of the variability in functioning characteristic of this population and is a significant limitation of the CPT paradigm. It also speaks to the need to develop and to implement better ways to capture the variability in attention manifested over time, such as the procedure suggested by Teicher, Lowen, Polcari, Foley, and McGreenery (2004). Unfortunately, the current version of the Virtual Classroom does not allow data to be analyzed according to their procedure, although hopefully future versions will implement this and other options.

In light of the findings of van Mourik et al. (2007), who noted reduction in errors of omission when novel sounds preceded the task in the ADHD group, it might be argued that the novelty of the virtual reality environment serves to enhance attention on the part of the ADHD group. This is unlikely, however, because when Parsons et al. (2007) administered the Virtual Classroom with and without distracters (with order of administration counterbalanced across all participants), there was a trend for the ADHD group to produce more errors of omission relative to controls in the distraction condition, after subtracting out performance in the nondistracting condition. Because the virtual environment was identical across the two conditions (and hence the novelty of the task itself was controlled for), their findings support a negative effect of distracters on performance, rather than serving to increase focus. On the other hand, given the novelty of the task, more information about the experience of the sample with technology and virtual reality in particular needs to be collected, and its role assessed. One limitation of this study was our failure to focus more on these aspects of our sample. Future studies should collect information pertinent to this issue.

Another limitation of this study was that approximately half of the ADHD sample had taken their medication in the morning, while the other half had not. Although no differences between those on versus those off medication were observed in performance in this study, it is conceivable that larger effects would have been observed had none of the children been on medication. Future studies should attempt to control more carefully for medication effects. Furthermore, our sample was not classified according to subtype. While West et al. (2000) failed to find any significant differences between children with different subtypes on a time estimation task performed by ADHD and control children, they also failed to find a differential effect of distraction on performance by group (ADHD all types combined versus controls). It is conceivable that differences between subtypes would emerge on the Virtual Classroom, and indeed this would provide an opportunity to further assess components of the environment that most affect one subtype versus another. Ultimately this could lead to better understanding of the attentional networks affected in each (see Corbetta & Shulman, 2002, for a useful review of attentional networks pertinent to the issues discussed here). Future studies with larger samples that allow for analysis of the impact of subtypes will be critical in this regard.

Although findings must be interpreted with caution in this preliminary study in light of the limitations discussed above, we found that the Virtual Classroom resulted in improved specificity compared to a standard CPT task without distractions, although sensitivity in identifying children with ADHD was relatively poor in both conditions, consistent with the literature on this subject. Future studies employing a larger sample size will be useful in further elucidating these issues, especially given the relatively large effect size obtained with respect to differences in percent correct and number of commission errors. Changes to the virtual environment and further refinements in data analysis capabilities may result in an improved ability to distinguish the two groups, particularly in combination with other measures that add to diagnostic discriminability.

This study found that in a comparison of boys with and without ADHD, the Virtual Classroom provided a means of examining lifelike distracters in a controlled environment. While differences between the two groups did not attain statistical significance, there was a strong trend towards a significant difference in percent of targets correctly identified and in number of commission errors. Furthermore, compared to a standard CPT (Vigil), specificity was improved. The addition of distracters in improving classification of the two groups is consistent with prior studies indicating increased vulnerability of children with ADHD to distraction.

In conclusion, the Virtual Classroom is a novel tool for exploring mechanisms underlying the difficulties of individuals with ADHD. Reductions in the cost of equipment needed to implement a virtual environment, currently less than $2000.00, means that it is no longer prohibitive for diagnostic use in clinical settings. With time, and with increasing virtual reality applications in treatment, rehabilitation, and training, the value of this technology continues to grow (Schultheis, Himelstein, & Rizzo, 2002; Schultheis & Rizzo, 2001). Advantages of the Virtual Classroom include the introduction of lifelike distractions, making it a more ecologically valid test, while at the same time offering a standardized environment in which to carry out controlled research and to improve diagnostic accuracy.

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