Editor's Note

This issue of *Journal of Developmental and Behavioral Pediatrics* brings an exciting new dimension to our publication—Rich Media. The written report can be enhanced now through video, color explorations of images such as fMRIs, and photo capabilities. All these possibilities are now available on the *JDBP* web site. Because behavior is at the core of our specialty, this will add vitality and clarity to the presentation of our work. The printed page will carry links to this wonderful new feature, and the web journal will have a direct link. We are pleased that we are one of the first journals to have this capacity and appreciate LWW putting us at the front of the line in the roll out for this wonderful enhancement. We would appreciate your viewing, use, your feedback, and your submissions using this new feature. Enjoy!

Suzanne Dixon, MD, MPH
Editor

The Utility of a Continuous Performance Test Embedded in Virtual Reality in Measuring ADHD-Related Deficits

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ABSTRACT: ***Objective:*** **Continuous performance tasks (CPT) are popular in the diagnostic process of Attention Deficit/Hyperactivity Disorder (ADHD), providing an objective measure of attention for a disorder with otherwise subjective criteria. Aims of the study were to: (1) compare the performance of children with ADHD on a CPT embedded within a virtual reality classroom (VR-CPT) to the currently used Test of Variables of Attention (TOVA) CPT, and (2) assess how the VR environment is experienced.** ***Methods:*** **Thirty-seven boys, 9 to 17 years, with (n = 20) and without ADHD (n = 17) underwent 3 CPT's: VR-CPT, the same CPT without VR (No VR-CPT) and the TOVA. Immediately following CPT, subjects described their subjective experiences on the Short Feedback Questionnaire. Results were analyzed using analysis of variance with repeated measures.** ***Results:*** **Children with ADHD performed poorer on all CPT's. The VR-CPT showed similar effect sizes to the TOVA. Subjective feelings of enjoyment were most positive for VR-CPT.** ***Conclusion:*** **The VR-CPT is a sensitive and user-friendly assessment tool to aid diagnosis in ADHD.**

(*J Dev Behav Pediatr 30:*2–6, 2009) **Index terms:** attention deficit/hyperactivity disorder (ADHD), continuous performance task (CPT), virtual reality (VR), methylphenidate (MPH).

Attention Deficit/Hyperactivity Disorder (ADHD) constitutes a major cause of school and behavioral problems, affecting over 5% of school age children.[1] The diagnosis of ADHD is clinical and is based on information that is obtained from parents and teachers. Due to the lack of biological markers for ADHD, continuous performance tasks (CPT) have been developed to provide objective criteria to the diagnostic process. Although the American Academy of Pediatrics (AAP) currently does not support the use of CPT in the ADHD diagnostic process (see AAP ADHD Guidelines 2000) because of <70% sensitivity and specificity, it continues to be a very popular tool.

CPT, such as the Test of Variables of Attention (TOVA), are sensitive to attention deficits of ADHD.[2] However, CPT are delivered in sterile environments not replicating the school environment, are tedious and infamous for the negative reaction evoked in the child.

A virtual reality (VR) schoolroom environment has been created specifically to assess ADHD. The rationale for using VR is based on the unique attributes of this technology[3,4] including the (1) opportunity for experiential, active participation that encourages and motivates subjects,[5] (2) ability to objectively measure attention and motor behaviors in challenging, safe and meaningful environments, and (3) maintenance of strict experimental control over stimulus delivery and measurement. In studies

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using a CPT embedded in a VR classroom, small groups of children with ADHD exhibited more omission and commission errors than control children; the VR classroom measures correlated with traditional flatscreen CPT.[6,7]

In our study, we undertook to assess the utility of the VR classroom to detect ADHD-related deficits in a larger sample than those used before. In addition we used the VR classroom with an embedded CPT (VR-CPT) and compared it to a similar CPT (No VR-CPT) and to the TOVA on a flatscreen. Importantly, the 3 types of CPT used in the study differ from each other in many ways, including length of tasks and ratio of go/no go stimuli. The comparison between the different CPTs was meant to examine whether the VR-CPT version can detect attention deficits similarly to a widely used CPT (the TOVA) and whether the addition of the VR component to the CPT affects the ability of the test to detect attention deficits (compared to No VR-CPT). In addition, we examined how positively the VR-CPT is experienced by the subjects compared to the clinically-used TOVA.

METHODS

The testing was carried out at the Neuropediatric Unit, Shaare Zedek Medical Center. The subjects were 37 boys, ages 9 to 17 (12.6 ± 2.4) years attending mainstream schools and consenting to participate. Years of mothers' and fathers' education were 15.6 ± 1.8 and 15.6 ± 2.4, respectively. Clinical diagnosis of Attention Deficit/Hyperactivity Disorder (ADHD) was made by a child neurologist at the Neuropediatric Unit, according to the DSM-IV criteria and confirmed by a structured psychiatric interview for the DSM-IV axis I disorders.[8] Exclusion criteria were history or current diagnosis of any serious systemic or neurological condition, severe visual impairment, pervasive developmental disorder or psychotic disorders (DSM-IV axis I). All children were naïve to psychostimulant medication treatment. The experimental group consisted of 20 boys of which 8 were predominately inattentive and 12 were of the combined type.

The control group consisted of 17 boys age matched with no history of ADHD, i.e., who endorsed fewer than 6 of 9 criteria of ADHD in the parent-reported questionnaire. These children did not have other neurological disorders.

Power calculation reveals that 35 subjects are needed for the detection of 0.6 standard deviation with alpha = .05 and beta = .2. The value of 0.6 standard deviation was chosen based on a previous meta-analysis reporting a similar effect size.[9]

The study was approved by the hospital Institutional Review Board for research on human subjects, and written consent of the parents and verbal assent from the boys was obtained.

Instruments

Questionnaires

DSM-IV-based ADHD screener: The Diagnostic Rating Scale (DRS) uses a categorical rating approach to symptoms of ADHD. This questionnaire is widely accepted as a diagnostic tool with sensitivity of 70% to 90% for 6 positive answers (out of 9) in each section.[10]

Subjective feedback questionnaire (SFQ): The SFQ consists of 8 items assessing the participant's subjective feelings during a testing session. All items were administered but we analyzed only questions relevant to this study even though the internal consistency reliability of the SFQ has been demonstrated only for the questionnaire as a whole (α = .70 to α = .81).[11] The questions are: (1) feeling of enjoyment, (3) feeling of success, (7) discomfort during the test, (8) perceived difficulty while performing task. Responses to the items were rated on a scale of 1 to 5 where 1 = not at all and 5 = very much while for item 8 responses were 1 = very easy and 5 = very difficult.

Types of Continuous Performance Tasks

1. Virtual reality-continuous performance tasks (VR-CPT): The VR-CPT classroom was developed originally by Rizzo et al[6] with Digital MediaWorks (2002) (http://www.dmw.ca/) respectively, and modified for Israel by Rizzo et al and Digital MediaWorks Inc. (2006). The Virtual Classroom is a head-mounted display (HMD) VR system for the assessment of attention processes. Within an HMD, researchers and clinicians can provide a controlled stimulus environment where attention challenges can be presented along with the precise delivery and control of "distracting" auditory and visual stimuli within the virtual environment. The research version of the Virtual Classroom scenario consists of a standard rectangular classroom environment containing desks, a female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a street with moving vehicles, and on the opposite wall, a pair of doorways through which activity occurred. The child sits at a virtual desk within the Virtual Classroom and on-task attention is measured in terms of reaction time performance and error profiles on a continuous performance task that is delivered visually on the blackboard (see Video, Supplemental Digital Content 1, http://links.lww.com/A733).

The alterations of the Hebrew version were digits used instead of letters and instructions in Hebrew. The task required the child to tap the mouse button as quickly and accurately as possible, using their dominant hand when the digit 7, preceded by the digit 3, appeared on the virtual classroom blackboard. The stimuli remained on the screen for 150 ms with a fixed inter stimulus interval of 1350 ms. Participants were instructed to withhold response to any other sequence of digits. The test lasted 10 minutes during which 400 stimuli (100 of them were 7 after 3) were presented accompanied by 20 distracters (e.g., pure audio [classroom noises], pure visual [paper airplane flying across the visual field] and mixed audiovisual [a car "rumbling" by a window, person walking into classroom with hall sounds when door opened]). Distracters were each displayed for 5 seconds and presented in randomly assigned intervals of 10, 15 or 25 seconds.

2. No VR-CPT: The same CPT that was embedded in the VR-CPT was displayed on a standard computer monitor. In addition, the speaker was turned off and only the center of screen, where digits were presented, was visible to the participant.
3. Test of Variables of Attention (TOVA): The test of variables of attention (TOVA) CPT[2] incorporates a standardized 2-second inter-stimulus interval during a 21.6 minute test. The test presents stimuli over a consistent 3.5:1 ratio. There are 2 target paradigms, target infrequent and target frequent. In the first part of the test, a 3.5:1 ratio of nontargets to targets is presented while in the second part the ratio is reversed. The participant is instructed to press the microswitch as quickly as possible when the target appears on the computer screen. The stimulus is a single square within a square.

Four measures were automatically calculated by the computer software when the CPTs were administered: response time, response time variability, omissions (missing target), and commissions (identifying the nontarget incorrectly as target). Administration of the 3 CPTs was counter balanced. Subjects responded to the SFQ after each CPT.

Data Analysis

Means and standard deviations (M ± SD) of CPT parameters (i.e., reaction times, variability of reaction time, omissions and commission) were calculated. ANOVA with repeated measures was used with ADHD versus control as an independent variable, type of CPT as a within subjects independent variable and the different measures of the CPT as multiple dependent variables. Between group effects and group by type of CPT interactions were analyzed. Post hoc analyses determined specific group by type of test differences.

Calculating a cutoff score for discriminating between passing and failing a CPT is problematic due to the various variables of the test. One approach to overcome this problem is to compute the average and standard deviation of each variable for each subject and if any of the variables is larger than 2 standard deviations above the average of the control group, that subject is considered to fail the test.[12] We used this definition to measure the sensitivity and specificity of each CPT in discriminating between children with and without ADHD.

M ± SD of the four SFQ items were calculated. ANOVA with repeated measures was used with ADHD versus control as an independent variable, type of CPT as within subjects independent variable and the four selected items of the SFQ as multiple dependent variables. Between group effects and group by type of test interactions were analyzed, followed by planned contrasts and Tukey post hoc analysis.

RESULTS

Age of subjects and parents' years of education were similar for both children with Attention Deficit/Hyperactivity Disorder (ADHD) and control children. Scores on inattention and hyperactivity/impulsivity scales of the Diagnostic Rating Scale (DRS) were significantly higher in the ADHD group (t (35) = 6.2 and 2.7, $p < .001$ and $p < .01$, for inattention and hyperactivity/impulsivity symptoms, respectively). Among the children with ADHD, 95% scored in the clinical range of the TOVA compared to 24% among the controls (χ^2 (1) = 20.0, $p < .001$).

Effect of Attention Deficit/Hyperactivity Disorder on the Continuous Performance Tasks Measures

Averaged performance on the continuous performance tasks (CPT) parameters is shown in Table 1. Compared to control children, participants with ADHD showed slower reaction time (RT), higher variability in RT and more errors of omission and commission. Analysis of variance (ANOVAs) on each of the CPT parameters resulted in a significant group by type of test interaction only for RT and omission rate (F (2,68) = 3.8 and 9.9, $p < .05$ and $p < .001$, respectively). Post hoc analysis revealed a significant difference between groups in RT in the virtual reality (VR-CPT) and significant difference between groups in omission errors only in the VR-CPT and No VR-CPT.

Group effect was a moderate to large value on most of the measures, with greater effect size for the VR-CPT on RT, for test of variables of attention (TOVA) on variability of RT and for the No VR CPT on the rate of commission errors.

Using a cutoff of 2 standard deviations above the average of the control group on at least one measure, the sensitivity and specificity of the TOVA were 65% and 94%, respectively, the sensitivity and specificity of the No VR-CPT were 84% and 88%, respectively, and the sensitivity and specificity of the VR-CPT were 79% and 94%, respectively.

Correlational analysis within the ADHD group revealed significant positive relationships between DRS total number of ADHD symptoms and the following measures: variability of RT in the VR-CPT test (r = .36, $p < .05$) and rate of omissions and commissions in the TOVA (r = .38 and .49, $p < .05$, respectively).

Effect of Type of Continuous Performance Tasks on the Subjective Feedback Questionnaire

Mean scores for the 4 items on the Subjective feedback questionnaire (SFQ) are shown in Table 2. ANOVA revealed significant feedback differences for the 3 CPT on the scales of enjoyment, success and difficulty (F (2,70) = 19.3, 3.0 and 4.3, $p < .05$, respectively). Planned contrasts aimed to compare subjective feedback on the VR-CPT and the TOVA revealed significant differences only on the enjoyment

Table 1. Effect of ADHD on CPT Parameters

CPT Parameter	Type of Test	Group	Mean	SD	Effect Size Approximately	Statistic–Group Effect
Reaction time (ms)	TOVA	Control	393	65	.64	F (1,34) = 4.6*
		ADHD	451	114		
	No VR-CPT	Control	578	89	.24	
		ADHD	609	178		
	VR-CPT	Control	546	83	1.16	
		ADHD	677	142		
Variability of reaction time (ms)	TOVA	Control	115	39	.80	F (1,34) = 5.6*
		ADHD	154	61		
	No VR-CPT	Control	121	49	.57	
		ADHD	150	51		
	VR-CPT	Control	128	26	.47	
		ADHD	145	46		
Errors of omission (%)	TOVA	Control	.29	48	1.32	F (1,34) = 28.8*
		ADHD	3.05	3.69		
	No VR-CPT	Control	2.65	1.58	1.62	
		ADHD	11.75	9.69		
	VR-CPT	Control	5.06	5.10	1.75	
		ADHD	22.34	14.67		
Errors of commission (%)	TOVA	Control	2.63	3.15	.90	F (1,34) = 16.0*
		ADHD	5.85	4.03		
	No VR-CPT	Control	.56	.58	1.53	
		ADHD	1.86	1.11		
	VR-CPT	Control	.94	.84	1.04	
		ADHD	2.37	1.91		

The values represent mean (±SD) of the different measures of the TOVA, the No VR-CPT and the VR-CPT in the control and ADHD groups. Data were analyzed by ANOVA with repeated measures. ~Cohen's d' values represent the size of the group effect on each of the measures. CPT, continuous performance tasks; VR, virtual reality; TOVA, test of variables of attention; ADHD, attention deficit/hyperactivity disorder. *$p < .05$.

item, indicating the greater pleasure experienced by subjects on the VR-CPT compared to the TOVA.

Significant interactions between group and type of test were found in the items of success and discomfort (F (2,70) = 3.5 and 3.7, respectively). Planned contrasts comparing subjective feedback on the VR-CPT and the TOVA revealed a significant interaction with group on the success scale, reflecting the tendency of participants with ADHD to estimate their success on the VR-CPT as higher and on the TOVA as lower, compared to control participants, even though their actual performance on all CPT was poorer than the control group.

DISCUSSION

Using a virtual classroom environment, we were able to demonstrate that the performance on the virtual reality-continuous performance tasks (VR-CPT) distinguished children with and without Attention Deficit/Hyperactivity Disorder (ADHD) on all measures tested, i.e., reaction time, variability of reaction time, and rate of errors of omission and commission. The results were similar to those obtained when the same children underwent a No VR-CPT and the Test of Variables of Attention (TOVA). These findings are consistent with a meta-analysis demonstrating differences between ADHD and controls on CPT parameters.[9]

Post hoc analyses suggested that for ADHD, the VR-CPT was more sensitive than the TOVA on reaction time (RT) and rate of omission errors. Perhaps the unique aspects in the design of the VR-CPT integrate more realistic attention and processing demands that highlight the attention deficits in ADHD. The VR-CPT follows the popular A-X CPT form, in which a response is made only if a specific digit is followed by another specific digit. This type of CPT requires attention, short-term memory and number processing skills, domains considered impaired in ADHD, while the TOVA was designed to avoid these factors.[2] Moreover, a large amount of visual and auditory distracters are embedded in the VR-CPT, again in contrast to the "sterile" and less realistic character of the TOVA.

In terms of subjective experience, VR-CPT was perceived as more enjoyable compared to the TOVA and at the same time was not inferior to the TOVA in revealing cognitive deficits of the ADHD. Both the VR-CPT and the TOVA elicited similar levels of challenge, success and discomfort. The finding that the VR-CPT is a user-friendly

Table 2. Effect of Type of Test on Short Feedback Questionnaire (SFQ)

Measure	Type of Test	Group	Mean	SD
Enjoyment	TOVA	Control	2.18	1.29
		ADHD	2.35	1.27
	No VR-CPT	Control	3.06	.75
		ADHD	3.35	1.27
	VR-CPT	Control	3.59	1.00
		ADHD	3.85	.93
Success	TOVA	Control	3.71	.85
		ADHD	3.25	.64
	No VR-CPT	Control	4.29	.47
		ADHD	3.85	.88
	VR-CPT	Control	3.59	.71
		ADHD	3.80	.83
Discomfort	TOVA	Control	2.82	1.19
		ADHD	2.80	1.28
	No VR-CPT	Control	1.76	.66
		ADHD	3.00	1.38
	VR-CPT	Control	2.41	1.12
		ADHD	2.90	1.25
Difficulty	TOVA	Control	2.59	1.16
		ADHD	2.95	1.10
	No VR-CPT	Control	2.00	.87
		ADHD	2.35	.88
	VR-CPT	Control	2.62	.99
		ADHD	2.90	1.07

The values represent mean (±SD) of the different measures of the SFQ reports on the TOVA, the No VR-CPT and the VR-CPT. Data was analyzed by ANOVA with repeated measures. SFQ, short feedback questionnaire; CPT, continuous performance tasks; VR, virtual reality; TOVA, test of variables of attention.

tool is in harmony with VR literature for children with conditions including ADHD, autism, and intellectual disability.[13–15] In all these studies, participant enjoyment of virtual environments has been consistently positive. Moreover, data from the current study demonstrated that the concern that use of a head device such as the head-mounted display would be disturbing or uncomfortable to the participants was unjustified. Indeed, there were no reports of cyber-sickness-like side effects, a finding confirmed in the recent study of children with ADHD who used the same environment.[13]

The applicability of the results to the larger population of children and adolescents with ADHD is limited because of characteristics of the sample, including the wide age range of the participants, all of whom were males, and the fact that all of the children were naive to psychostimulants. However, the results are encouraging in that they are in line with previous outcomes, demonstrate the relative superiority of results when testing in a more realistic environment while highlighting the user-friendly features of VR environments.

In summary, VR environments provide test and training situations that are ecologically valid, motivating and dynamic. The VR-CPT allows for controlled performance assessment within a classroom environment.[7] Naturalistic visual and auditory distractors can be easily inserted and used to elicit varied behavioral responses and alter test parameters, such as duration, number, and type of stimuli. Consequently, the VR-CPT has the potential to serve as an efficient tool for conducting attention performance measurement while also allowing for the monitoring and measurement of head movement thus providing an additional behavioral response. The validity of the VR-CPT in the context of ADHD and the positive experience it elicits may prove to be an effective asset for both assessment and intervention purposes.

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