


# The Influence of Methylphenidate on Hyperactivity and Attention Deficits in Children With ADHD: A Virtual Classroom Test

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## Abstract

**Objective:** This study compares the performance in a continuous performance test within a virtual reality classroom (CPT-VRC) between medicated children with ADHD, unmedicated children with ADHD, and healthy children. **Method:**  $N = 94$  children with ADHD ( $n = 26$  of them received methylphenidate and  $n = 68$  were unmedicated) and  $n = 34$  healthy children performed the CPT-VRC. Omission errors, reaction time/variability, commission errors, and body movements were assessed. Furthermore, ADHD questionnaires were administered and compared with the CPT-VRC measures. **Results:** The unmedicated ADHD group exhibited more omission errors and showed slower reaction times than the healthy group. Reaction time variability was higher in the unmedicated ADHD group compared with both the healthy and the medicated ADHD group. Omission errors and reaction time variability were associated with inattentiveness ratings of experimenters. Head movements were correlated with hyperactivity ratings of parents and experimenters. **Conclusion:** Virtual reality is a promising technology to assess ADHD symptoms in an ecologically valid environment. (*J. of Att. Dis.* XXXX; XX(X) XX-XX)

## Keywords

ADHD, continuous performance test, virtual reality classroom, methylphenidate

## Introduction

ADHD is a highly prevalent and highly impairing neurodevelopmental disorder characterized by a cluster of symptoms including inattentiveness, impulsivity, and hyperactivity (American Psychiatric Association, 2013). According to a current study, 3.4% (95% confidence interval ranging from 2.6% to 4.5%) of the childhood population are affected by ADHD (Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015).

The diagnostic procedure requires information about ADHD symptoms in distinct settings, for example, family, school, peer group. Symptoms are basically assessed by means of clinical interviews and standardized behavioral observations from parents, teachers, and clinicians. Cognitive tests may be an aid in the diagnostic procedure. However, they are not yet apt to be standalone diagnostic tools due to lack of sensitivity, specificity, and ecological validity (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Furthermore, actigraphy (monitoring human rest and activity cycles) may be useful in the natural environment to operationalize activity levels shown to be higher in children with ADHD than in children without ADHD (Dane, Schachar, & Tannock, 2000).

One of the most widely used cognitive tests to measure the underlying cognitive mechanisms of attention deficits and impulsivity is the Continuous Performance Test (CPT). In this test, the participant is required to monitor a series of single letters and to click a button if a defined letter (CPT-X, Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956) or letter sequence (CPT-AX, Michael, Klorman, Salzman, Borgstedt, & Dainer, 1981; CPT-XX, Friedman, Vaughan, & Erlenmeyer-Kimling, 1978) appears. Performing this task, the participant can score two types of errors: If the participant does not respond although the target is presented, an error of

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omission occurs, which is an indicator of inattentiveness. If the participant clicks the button in the absence of a target, an error of commission occurs being indicative of impulsivity. Another measure, which can be derived from the CPT is reaction time assumed to indicate sluggish cognitive tempo. However, inconsistent results regarding reaction time in ADHD have been found in previous studies: Although some studies reported substantially slower reaction times in ADHD patients than in healthy controls for different kinds of tasks (Andreou et al., 2007; de Zeeuw et al., 2008), Hervey and co-workers (2006) found that children with ADHD had faster reaction times than healthy controls; if slow responses occurred in the ADHD group, they were caused by attentional lapses in few trials.

As reaction times for children with ADHD compared with healthy controls were variable in various studies (Andreou et al., 2007; Epstein et al., 2003; Klein, Wendling, Huettner, Ruder, & Peper, 2006), intra-participant reaction-time variability has been suggested as the most appropriate measure of neuro-cognitive deficit in ADHD (Castellanos & Tannock, 2002; Klein et al., 2006). Furthermore, substantial decreases in reaction time variability were observed in ADHD children treated with stimulant medication compared with unmedicated ADHD children (Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2005).

To summarize, in spite of some contradictory findings, the CPT is assumed to be a useful tool to differentiate between ADHD children and healthy controls (Corkum & Siegel, 1993). This conclusion is substantiated by two independent meta-analyses (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Losier, McGrath, & Klein, 1996) revealing that children diagnosed with ADHD compared with healthy control children overall make significantly more errors of omission and commission and display slower and more variable reaction times. Furthermore, the meta-analysis by Losier et al. (1996) also found that children with ADHD show significantly reduced rates of omission and commission errors when treated with methylphenidate. These latter findings can be explained by theories postulating a dysfunction in frontosubcortical pathways resulting in diminished executive functions and behavioral inhibition (Barkley, 1997; Scheres et al., 2004; Spencer, Biederman, & Mick, 2007). Stimulant medication improves executive functions and inhibitory control by increasing the availability of dopamine in the frontosubcortical system (Huber, Kirchler, Niederhofer, & Gruber, 2007).

Despite its popularity, the ecological validity of the CPT was often criticized (Barkley, 1991). According to Pollak and colleagues (2009), traditional CPTs take place in sterile environments evoking negative reactions in participants. A viable approach to increase ecological validity is offered by virtual reality (VR) technology. By creating dynamic and immersive three-dimensional environments, VR has become a useful device for neuropsychological assessments

of behavior and cognitions (Neguț, Matu, Sava, & David, 2016; Rizzo & Schultheis, 2002; Schultheis, Himmelstein, & Rizzo, 2002). Some advantages of VR are that the experimental setting is much more controllable than in real life and various measures can be recorded simultaneously. Furthermore, it allows an objective laboratory-based assessment as demanded by researchers (Nichols & Waschbusch, 2004; Rapport, Chung, Shore, Denney, & Isaacs, 2000).

To assess children's attention performance in a more natural setting, Rizzo and colleagues designed a virtual reality classroom (VRC; Rizzo et al., 2006; Rizzo et al., 2004; Rizzo et al., 2000). By means of a head-mounted display (HMD), the participants are immersed in a virtual classroom and have to solve a task (e.g., CPT) presented on a blackboard while distracting visual (e.g., another teacher coming into the room) and auditory (e.g., coughing classmate) stimuli appear. Besides reaction times and errors, participants' head and overall body movements while performing the task can be recorded. Pollak, Shomaly, Weiss, Rizzo, and Gross-Tsur (2010) found that children diagnosed with ADHD experience more joy in a CPT embedded in the VRC (VRC-CPT) than in a classic CPT indicating higher ecological validity of the VRC-CPT. A few studies also investigated the performance of ADHD children in the VRC-CPT. In a study by Pollak et al. (2010), methylphenidate (compared with placebo) reduced omission errors and reaction time variability but neither commission errors nor reaction time in children with ADHD. Two other studies investigated how unmedicated children with ADHD perform in a VRC-CPT in comparison with healthy control children. A pilot study by Parsons, Bowerly, Buckwalter, and Rizzo (2007) comparing 10 unmedicated boys with ADHD with 10 age-matched healthy controls showed that the ADHD group made more omission and also more commission errors in a VRC-CPT. Furthermore, they showed more extensive overall body movements and were more affected by distracters than the controls resulting in increased omission error rates and body movements in distracter-present trials. Finally, VRC measures were correlated both with performance in the traditional CPT and ADHD symptom questionnaires. These results were partially confirmed in a study by Adams, Finn, Moes, Flannery, and Rizzo (2009), as unmedicated children performed slightly worse in the VRC-CPT and were more impaired by distracters than age-matched healthy controls. Another virtual classroom test is the AULA (Spanish for "Classroom") test (Iriarte et al., 2016) that comprises visual and auditory No-X and X tasks (with and without distracters) and two measures of motor activity. Díaz-Orueta et al. (2014) could show that the AULA test is suited to differentiate between medicated and unmedicated children in various measures related to the ADHD symptom clusters. Accordingly, these studies suggest that the VRC-CPT and the AULA test are apt tools to assess all symptom clusters in ADHD children.

However, study samples were relatively small. In addition, comparing three groups in one study, that is, healthy children, ADHD children without medication, and ADHD children with methylphenidate (MPH) as the first choice medical treatment in ADHD, would help to emphasize the clinical relevance of the measures obtained.

Therefore, this study aimed to examine CPT performance differences in a VRC scenario between medicated and unmedicated ADHD children as well as controls in a larger sample as the aforementioned studies. In addition, we intended to assess all symptom clusters (inattentiveness, hyperactivity, impulsivity) as well as cognitive tempo and to correlate them with clinical symptom ratings and questionnaires. We expected non-medicated children diagnosed with ADHD to make more commission and omission errors than medicated ADHD children and healthy controls. In comparison with the healthy controls and the medicated ADHD children, the unmedicated ADHD children's reaction time was supposed to be slower and more variable and they were expected to show more extensive head movements. Furthermore, we assumed that the unmedicated group would be distracted more easily than the other two groups, resulting in more errors, slower reaction times, higher reaction time variability, and more head movements in trials with a high number of distracters. Finally, we wanted to investigate whether there are interrelationships between VRC performance and traditional questionnaires assessing ADHD symptoms.

## Method

### Participants

In total,  $N = 161$  children participated in the study. Of the  $N = 161$  children,  $n = 107$  children were diagnosed with ADHD and  $n = 54$  were healthy children (control). Of the  $n = 107$  children with ADHD,  $n = 77$  were non-medicated (ADHDunmed) and  $n = 30$  took stimulant medication (methylphenidate) on the day of testing (ADHDmed). Due to a lower number of distraction stimuli during the test because of technical issues,  $n = 20$  healthy control children,  $n = 4$  medicated ADHD children, and  $n = 9$  unmedicated ADHD children were excluded from the analyses. Therefore, the sample for the statistical analyses consisted of  $n = 34$  healthy control children,  $n = 26$  medicated ADHD children, and  $n = 68$  unmedicated ADHD children. Two more children of the unmedicated ADHD group had to be excluded from the head movement analyses due to technical problems with this measure. The children with ADHD were recruited from the Department of Child and Adolescent Psychiatry, Psychosomatics and Psychotherapy, Center of Mental Health, University Hospital of Würzburg. All of them met the criteria for ADHD as listed in the fourth edition of the *Diagnostic and Statistical Manual of Mental*

*Disorders* (4th ed.; *DSM-IV*; American Psychiatric Association, 1994). They had been assessed by experienced physicians and psychologists and had been subtyped according to *DSM-IV* criteria. Children with ADHD were not eligible to take part in the study if they took psychotropic medication except for methylphenidate, and if they had a history of major depression, obsessive compulsive disorder, psychotic episodes, or autism. The children of the control group were recruited through advertisements in the local newspapers. They were free of psychiatric disorders and did not take any psychotropic medication. All participants and their parents received information about the study, and written informed consent was obtained. Questionnaires (as described below) were filled in prior to testing. The study was approved from the ethic board of the medical faculty of the University of Würzburg.

Both children diagnosed with ADHD and healthy controls had IQs greater than 80, measured either by the Kaufmann Assessment Battery for Children (K-ABC; Melchers & Preuß, 2003), the Culture Fair Intelligence Test (CFT-1; Cattell, Weiß, & Osterland, 1997), CFT20-R (Weiß, 1998), or the Hamburg-Wechsler-Intelligence-Test für Kinder [for children] (HAWIK; Petermann & Petermann, 2007; Tewes, Rossmann, & Schallberger, 2002). IQ was assessed in patients within the clinical routine care explaining the use of different measures due to clinical requirements. All controls were assessed by the CFT20-R.

Comparisons on demographic and other relevant variables (see Table 1) showed that groups did not differ significantly with regard to age and intelligence. The gender ratio was significantly different between the groups,  $\chi^2(2) = 6.88$ ,  $p = .032$ : The percentage of girls was higher in the healthy control group than in the ADHD groups. Both ADHD groups had nearly the same subtype ratio, with combined subtypes dominating.

### Apparatus

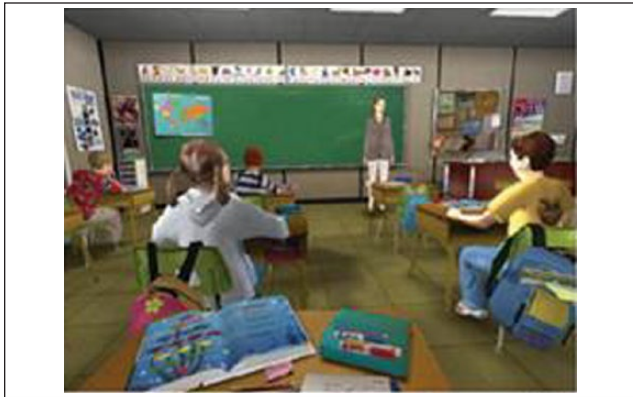
The VRC environment (Virtual Reality Classroom, Version 1.0 [Rizzo et al., 2006; Rizzo et al., 2004; Rizzo et al., 2000]) consisted of a simulation of a standard classroom scenario (see Figure 1) containing desks, a female teacher in front of a blackboard, two doors on the right side wall, and windows looking out onto the street on the left side wall.

This simulation was presented by an HMD (Z800, eMagin Corporation, Hopewell Junction, the United States), which was connected to a notebook with Windows operating system. The children did not have any problems when adjusting to or using the Z800 HMD, and no single test had to be interrupted because of simulator sickness. Classroom sounds and task instructions could be heard over headphones. The head position was monitored by a 3 Degree-of-Freedom (3DOF) magnetic tracking device with sampling

**Table 1.** Characteristics of the Sample by Group.

Variable	Healthy children (n = 34)	Unmedicated ADHD children (n = 68)	Medicated ADHD children (n = 26)	Statistics	p
Age: M (SD)	12.17 (1.55)	11.43 (1.87)	11.89 (1.93)	$F(2, 125) = 2.05$	.133
IQ: M (SD)	112.45 (11.17)	106.66 (13.09)	105.77 (12.06)	$F(2, 123) = 2.94$	.057
Gender: n (%)					
Female	16 (47.1)	16 (23.5)	6 (23.1)	$\chi^2(2) = 6.70$	.035
Male	18 (52.9)	52 (76.5)	20 (76.9)		
ADHD subtype: n (%)					
Combined	–	51 (76.1)	22 (84.6)	$\chi^2(1) = 0.80$	.371
Inattentive	–	16 (23.9)	4 (15.4)		

Note. No participant was diagnosed to have the hyperactive subtype.

**Figure 1.** Virtual reality classroom.

rate of 75Hz to record head movements and to adapt the field of view to movements (*Minuteman*, Polhemus Corporation, Colchester, the United States). For responses to the CPT, a clicking device was provided.

### Measures of ADHD Symptom Clusters

The Impulsivity Venturesomeness Empathy Questionnaire (IVE; Stadler & Janke, 2003; Stadler, Janke, & Schmeck, 2004) is a German adaptation of the I<sub>6</sub> Impulsiveness Questionnaire (Eysenck, Easting, & Pearson, 1984). The IVE is a self-rating scale for children, which comprises 48 statements describing situations and reactions related to poor behavioral control, sensation-seeking behavior, and empathy. Children are asked to rate each statement as correct (yes) or incorrect (no). Sum scores for the three subscales, Impulsivity, Venturesomeness, and Empathy, were calculated. Cronbach's alpha values range from .77 to .85.

To assess children's behavior problems, the Child Behavior Checklist for Ages 4 to 18 (CBCL/4-18; Arbeitsgruppe Deutsche Child Behavior Checklist, 1998), original version by Achenbach (1991), was administered. This questionnaire is composed of 112 items (ranging from

0 = *not true* to 2 = *very often true*), which are rated by the primary caregiver. Sum scores are calculated for each of the eight subscales Withdrawal, Somatic Complaints, Anxious/Depressed, Social Problems, Thought Problems, Attention Problems, Delinquent Behavior, and Aggressive Behavior. Cronbach's alpha for the eight subscales were reported to range from .66 to .92. Retest-reliability (over a 7-day period) was  $r_{tt} = .92$ .

To measure the extent of children's ADHD symptomatology from parents' point of view, a German rating scale was used (Fremdbeurteilungsbogen für Hyperkinetische Störungen [external scoring sheet for hyperkinetic syndroms]; FBB-HKS; Döpfner & Lehmkuhl, 2003), which asks for symptoms according to *DSM-IV* criteria. Parents had to rate 20 symptoms of inattentiveness, impulsivity, and hyperactivity on a scale ranging from 0 (*not true*) to 3 (*always true*) for their child's off-medication behavior. A total mean score and mean scores for the three subscales were calculated. Cronbach's alpha reaches values exceeding .75. Furthermore, the experimenter completed the rating scale during each testing session.

In the VRC-CPT, inattentiveness was operationalized as the amount of omission errors and impulsivity as the amount of commission errors. Hyperactivity was assessed with head movement sensors as described above. To investigate the cognitive tempo, reaction time and reaction time variability were evaluated.

### Procedure

**Warm-up task.** After the participant had arrived in the laboratory, questionnaires and written informed consents were checked for completeness. Then the experimenter explained the VRC equipment and adjusted the HMD to the child's head. Following this, an eyesight test was conducted in which the child was asked to read letters presented in the HMD. If the participant did not have any difficulties recognizing the letters, the VRC system was started by the experimenter so that the interior of the classroom could be seen.

The participant then was instructed to spend 1 min looking around the classroom. After this, the child was given the first task (warm-up task) by the virtual teacher. It was instructed to view a series of numbers appearing on the blackboard and to hit the button of the responding device every time the number “5” preceded by the number “9” occurred. Each of the numbers remained on the blackboard for 100 ms followed by an inter-stimulus interval of 1,900 ms. Altogether, 20 number stimuli were presented containing five target sequences. If the child had problems, the experimenter explained the task once more and the warm-up trial was repeated. If the child fulfilled this task without making more than one error, the warm-up trial was successful and the second task (main task) started after a short break.

**Main task.** In the main task, the participant was instructed by a virtual teacher to view a series of letters presented on the blackboard. The participant had to press the response button as quickly as possible every time he detected the letter “K” preceded by the letter “A.” Altogether, 320 letter stimuli were presented with a stimulus duration of 100 ms and an inter-stimulus interval of 1,900 ms. Hence, the complete main task lasted 10 min 42 s.

The 320 letter stimuli were equally distributed over four blocks, resulting in 80 stimuli for each block. In each block, 10 target sequences were presented at pseudorandomized time points. Each block lasted 2 min 40 s. A certain amount of standardized distracters appeared in each block. Distracters were either *pure auditory* (typical classroom sounds such as whispering, dropping pencils, etc.), *pure visual* (paper plane flying across the room), or mixed *auditory/visual* (bus noisefully driving by outside left window). In Block 1, 26 distracters appeared (12 auditory, three visual, 11 auditory/visual). In Block 2, 51 distracters were presented (21 auditory, eight visual, 22 auditory/visual). In Block 3, the children experienced five distracters (three auditory, one visual, one auditory/visual). In Block 4, there were 28 distracters (13 auditory, four visual, 11 auditory/visual). Thus, blocks had medium (Blocks 1 and 4), high (Block 2), and low (Block 3) amounts of distracters.

After completion of the main task, the experiment was over and the children received cinema vouchers as a reward for taking part in the study. When the child had left the laboratory, the experimenter rated his or her behavior during the session via the FBB-HKS. The described procedure was identical for each participant. Furthermore, each child was assessed individually.

### Data Analysis

SPSS 21.0 was used for the statistical analyses. The significance level was set to  $\leq .05$ . One-way analyses of variance (ANOVAs) were conducted with the between-participant

factor group (3: ADHDunmed vs. ADHDmed vs. Controls) to evaluate initial differences between the groups for numerical data. Categorical data were analyzed using chi-square tests.

Performance in the VRC main task (omission and commission error rates, reaction time, reaction time variability, horizontal head movements) was analyzed by ANOVA with group as between-participant factor (3: ADHDunmed vs. ADHDmed vs. Controls) and block as within-participant factor (4: Blocks 1 to 4). If the assumption of sphericity was violated, the Greenhouse–Geisser (GG) corrected  $p$  values would be reported. Within the ANOVAs, significant main effects of block were further analyzed by planned contrasts (repeated). Simple contrasts (with the ADHDunmed group as the reference) were applied to examine significant main effects of group. When interaction effects Block  $\times$  Group reached statistical significance, planned contrasts (repeated) and ANOVAs were conducted for a detailed investigation of significant interaction effects. Within all ANOVAs, the partial eta squared statistics ( $\eta_p^2$ ) will be reported as a measure of effect size. Relations between VRC measures and questionnaire data were assessed by correlations. For this purpose, bivariate Pearson correlation coefficients were computed. In the “Results” section of this article, the two-tailed  $p$  values will be reported.

## Results

### Commission Errors

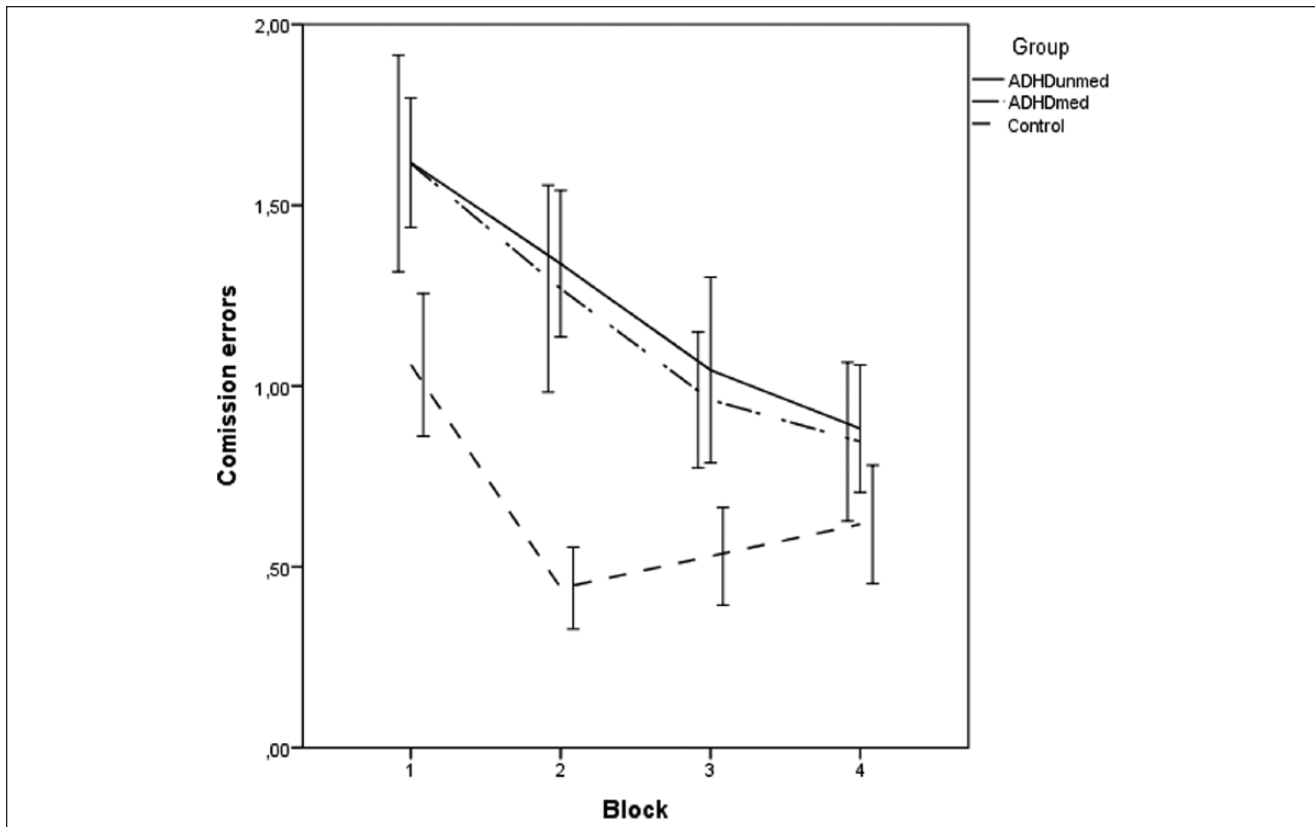
The overall ANOVA revealed a significant main effect block,  $F(3, 375) = 9.05$ ,  $GG-\Sigma = .83$ ,  $p < .001$ ,  $\eta_p^2 = .07$ , and a tendency for the main effect group,  $F(2, 125) = 2.81$ ,  $p = .064$ ,  $\eta_p^2 = .04$ . The interaction Group  $\times$  Block did not attain significance,  $F(6, 375) = .82$ ,  $GG-\Sigma = .83$ ,  $p = .539$ ,  $\eta_p^2 = .01$ , indicating that groups did not react significantly different over blocks (see Figure 2).

Planned contrasts (repeated) for the main effect block showed that error rates in Block 2 were significantly lower than in Block 1,  $F(1, 125) = 11.38$ ,  $p = .001$ ,  $\eta_p^2 = .08$ . No significant differences were observed when comparing Block 2 with Block 3,  $F(1, 125) = 1.41$ ,  $p = .237$ ,  $\eta_p^2 = .01$ , or Block 3 with Block 4,  $F(1, 125) = .14$ ,  $p = .712$ ,  $\eta_p^2 = .001$ .

Explorative simple contrasts for the factor group indicated more commission errors in the unmedicated ADHD group than in the healthy control group (simple contrasts:  $p = .023$ ).

### Omission Errors

There was a significant difference in omission error rates between groups,  $F(2, 125) = 4.38$ ,  $p = .014$ ,  $\eta_p^2 = .07$ , and a significant main effect of block,  $F(3, 375) = 4.83$ ,  $GG-\Sigma = .91$ ,  $p = .004$ ,  $\eta_p^2 = .04$ . The interaction effect Group  $\times$



**Figure 2.** Commission error rates by group and block ( $M \pm 1SE$ ).

Block also attained statistical significance,  $F(6, 375) = 2.57$ ,  $GG-\Sigma = .91$ ,  $p = .023$ ,  $\eta_p^2 = .04$ , which indicates that groups showed a different pattern of omission errors over blocks (see Figure 3).

Planned contrasts (simple) for the main effect group revealed that this effect was due to higher error rates in the unmedicated ADHD group compared with the healthy control group ( $p = .006$ ). The unmedicated ADHD group tended to show less omission errors than the medicated ADHD group, but this tendency did not reach statistical significance ( $p = .077$ ).

For the main effect block, planned contrasts (repeated) showed that more omission errors were scored in Block 2 than in Block 1,  $F(1, 125) = 7.83$ ,  $p = .006$ ,  $\eta_p^2 = .06$ . Error rates did not change significantly from Block 2 to Block 3,  $F(1, 125) = .00$ ,  $p = .995$ ,  $\eta_p^2 = .000$ . In Block 4, omission error rates were slightly but not significantly higher than in Block 3,  $F(1, 125) = 2.01$ ,  $p = .158$ ,  $\eta_p^2 = .02$ .

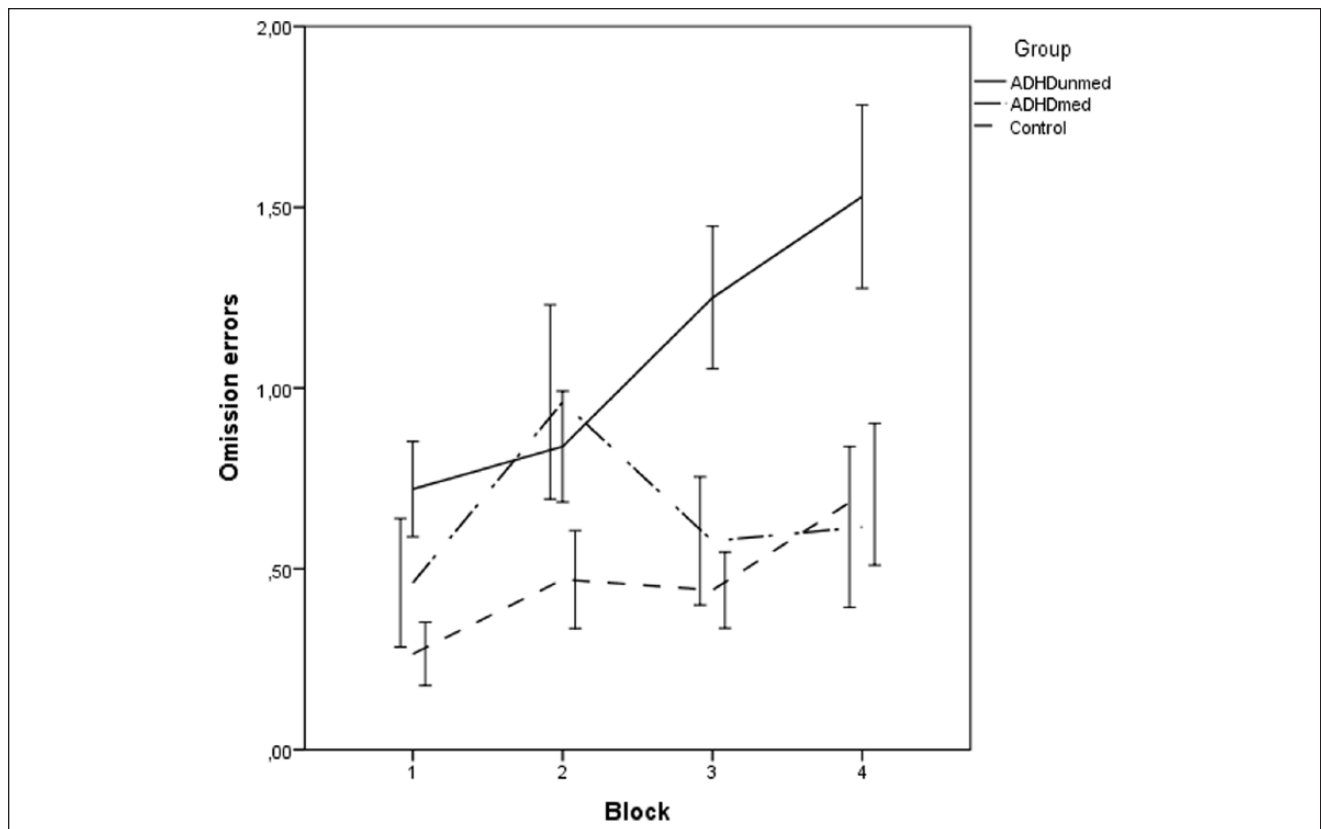
To follow up the significant interaction effect Group  $\times$  Block, repeated contrasts were performed, which showed no significant differences between the groups when Block 1 was compared with Block 2,  $F(2, 125) = 1.31$ ,  $p = .272$ ,  $\eta_p^2 = .02$ , and when Block 3 was compared with Block 4,  $F(2, 125) = .28$ ,  $p = .753$ ,  $\eta_p^2 = .005$ . However, the contrasts

revealed that the groups differed from each other when Block 2 was compared with Block 3,  $F(2, 125) = 4.85$ ,  $p = .009$ ,  $\eta_p^2 = .07$ . To examine the group-specific change rates of omission errors between Block 2 and Block 3, ANOVAs for each group were conducted. These analyses revealed that omission errors substantially increased from Block 2 to Block 3 in the unmedicated group,  $F(1, 67) = 6.75$ ,  $p = .012$ ,  $\eta_p^2 = .09$ . In contrast, the medicated group showed a tendency toward decreased error rates from Block 2 to Block 3,  $F(1, 25) = 2.99$ ,  $p = .096$ ,  $\eta_p^2 = .11$ , and the control group showed no change at all from Block 2 to Block 3,  $F(1, 33) = .04$ ,  $p = .838$ ,  $\eta_p^2 = .001$ .

### Reaction Time

With regard to reaction time, a significant main effect of group and of block emerged,  $F(2, 125) = 3.67$ ,  $p = .028$ ,  $\eta_p^2 = .06$ , and  $F(3, 375) = 14.25$ ,  $GG-\epsilon = .77$ ,  $p = .000$ ,  $\eta_p^2 = .10$ , respectively. Because the interaction effect Group  $\times$  Block was not statistically significant,  $F(6, 375) = 1.13$ ,  $GG-\epsilon = .77$ ,  $p = .343$ ,  $\eta_p^2 = .02$  (see Figure 4), reaction time over blocks seems not modulated by group.

Planned contrasts (simple) for the main effect group showed that the unmedicated children with ADHD reacted



**Figure 3.** Omission error rates by group and block ( $M \pm ISE$ ).

more slowly to targets than healthy controls ( $p = .015$ ). Moreover, the reaction time of the unmedicated ADHD group tended to be slower than the reaction time of the medicated ADHD group ( $p = .069$ ).

Planned contrasts (repeated) for the main effect block revealed that reaction times were significantly higher when Block 2 was compared with Block 1,  $F(1, 125) = 7.54$ ,  $p = .007$ ,  $\eta_p^2 = .06$ , and when Block 4 was compared with Block 3,  $F(1, 125) = 7.39$ ,  $p = .008$ ,  $\eta_p^2 = .06$ . No significant differences existed between Block 2 and Block 3,  $F(1, 125) = 1.30$ ,  $p = .257$ ,  $\eta_p^2 = .01$ .

### Reaction Time Variability

The statistical analysis for reaction time variability revealed a significant main effect of group and of block,  $F(2, 125) = 7.66$ ,  $p = .001$ ,  $\eta_p^2 = .11$  and  $F(3, 375) = 6.79$ ,  $GG-\epsilon = .89$ ,  $p = .000$ ,  $\eta_p^2 = .05$ , respectively. The interaction Group  $\times$  Block did not reach significance,  $F(6, 375) = .80$ ,  $GG-\epsilon = .89$ ,  $p = .556$ ,  $\eta_p^2 = .01$ , indicating that groups reacted in a similar way over blocks (see Figure 5).

Planned comparisons (simple) for the main effect group showed that this effect was due to a significantly higher reaction time variability in unmedicated children with

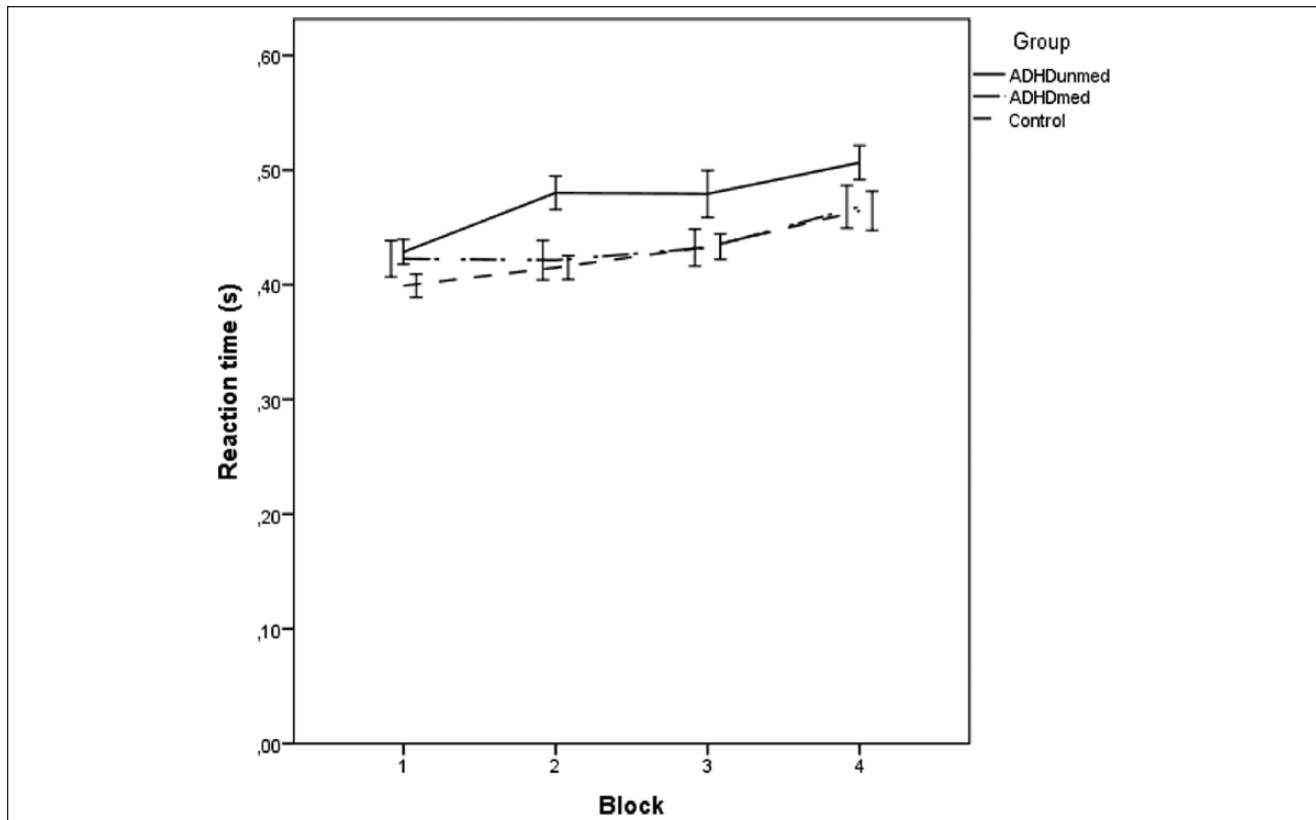
ADHD compared with healthy controls ( $p = .001$ ) and also compared with medicated children with ADHD ( $p = .009$ ).

The planned contrasts (repeated) for the main effect block showed that reaction time was significantly more variable in Block 4 compared with Block 3,  $F(1, 125) = 8.24$ ,  $p = .005$ ,  $\eta_p^2 = .06$ . No significant differences emerged when Block 1 was compared with Block 2,  $F(1, 125) = 1.12$ ,  $p = .291$ ,  $\eta_p^2 = .01$ , or when Block 2 was compared with Block 3,  $F(1, 125) = .01$ ,  $p = .915$ ,  $\eta_p^2 = .00$ .

### Horizontal Head Movements

Although the main effect of group of the conducted ANOVA just failed to reach statistical significance,  $F(2, 123) = 3.025$ ,  $p = .052$ ,  $\eta_p^2 = .05$ , a significant main effect of block emerged,  $F(3, 369) = 27.59$ ,  $GG-\epsilon = .80$ ,  $p = .000$ ,  $\eta_p^2 = .18$ . The interaction Group  $\times$  Block was not statistically significant,  $F(6, 369) = 1.70$ ,  $GG-\epsilon = .80$ ,  $p = .138$ ,  $\eta_p^2 = .03$  (see Figure 6).

Planned repeated contrasts for the main effect block showed significant increases in head movements from Block 1 to Block 2,  $F(1, 123) = 9.77$ ,  $p = .002$ ,  $\eta_p^2 = .07$ , and from Block 3 to Block 4,  $F(1, 123) = 17.81$ ,  $p = .000$ ,  $\eta_p^2 = .13$ . The difference between Block 2 and Block 3



**Figure 4.** Reaction time by group and block ( $M \pm ISE$ ).

failed to reach statistical significance,  $F(1, 123) = 3.86$ ,  $p = .052$ ,  $\eta_p^2 = .03$ .

To further explore the tendency toward statistical significance regarding the main effect group, contrasts (simple) were performed. They showed that the unmedicated ADHD group produced more head movements than the healthy control group ( $p = .027$ ).

### Relations Between VRC Measures and Psychometric Data

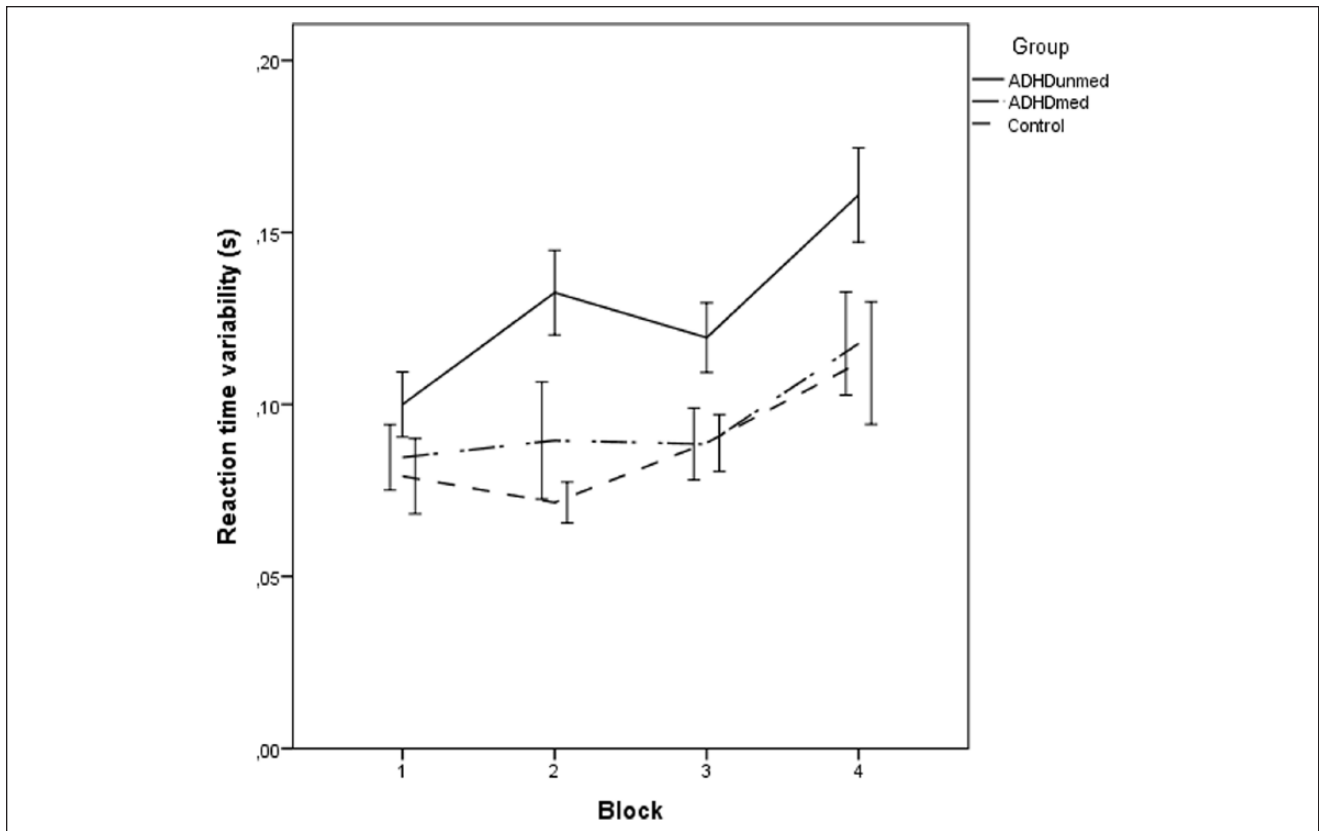
Correlations were computed only for the unmedicated ADHD sample and the control group. The medicated ADHD group was excluded from analyses as questionnaires asked for ADHD children's behavior without medication. Results are depicted in Tables 2 to 4.

As commission errors are supposed to be indicative of impulsivity, correlations were computed between questionnaires measuring impulsivity (IVE, Impulsivity subscale of the FBB-HKS: parents/experimenter) and the sum of commission errors across all trials (see Table 2). It can be seen that commission error rates were associated neither with the parental nor with the experimenter's impulsivity ratings nor with the Impulsivity subscale of the IVE.

Because omission errors are assumed to reflect attention problems, correlations between inattention subscales (CBCL, Attention subscale of the FBB-HKS: parents/experimenter) and omission error scores (across all trials) were computed (see Table 3). A significant association emerged only for experimenter's rating of children's inattentiveness and omission error rates in the ADHD group ( $r = .286$ ,  $p < .05$ ). Neither the CBCL subscale measuring attention problems nor the parents' inattentiveness ratings were correlated with omission error rates.

Children's horizontal head movements (left/right) during the CPT can be considered indicative of hyperactivity. Thus, correlations between parents'/experimenter's hyperactivity ratings (Hyperactivity subscale of the FBB-HKS: parents/experimenter) and children's head movements (again across all trials) were computed. As can be seen in Table 4, a positive correlation emerged for parents' hyperactivity rating and children's head movements in the ADHD group ( $r = .32$ ,  $p < .01$ ) but not in the healthy control group. For both groups, positive correlations existed between experimenter's rating of children's hyperactivity and head movements (unmedicated ADHD group:  $r = .50$ ,  $p < .01$ ; healthy control group:  $r = .44$ ,  $p < 0.01$ ).





**Figure 5.** Reaction time variability by group and block ( $M \pm 1SE$ ).

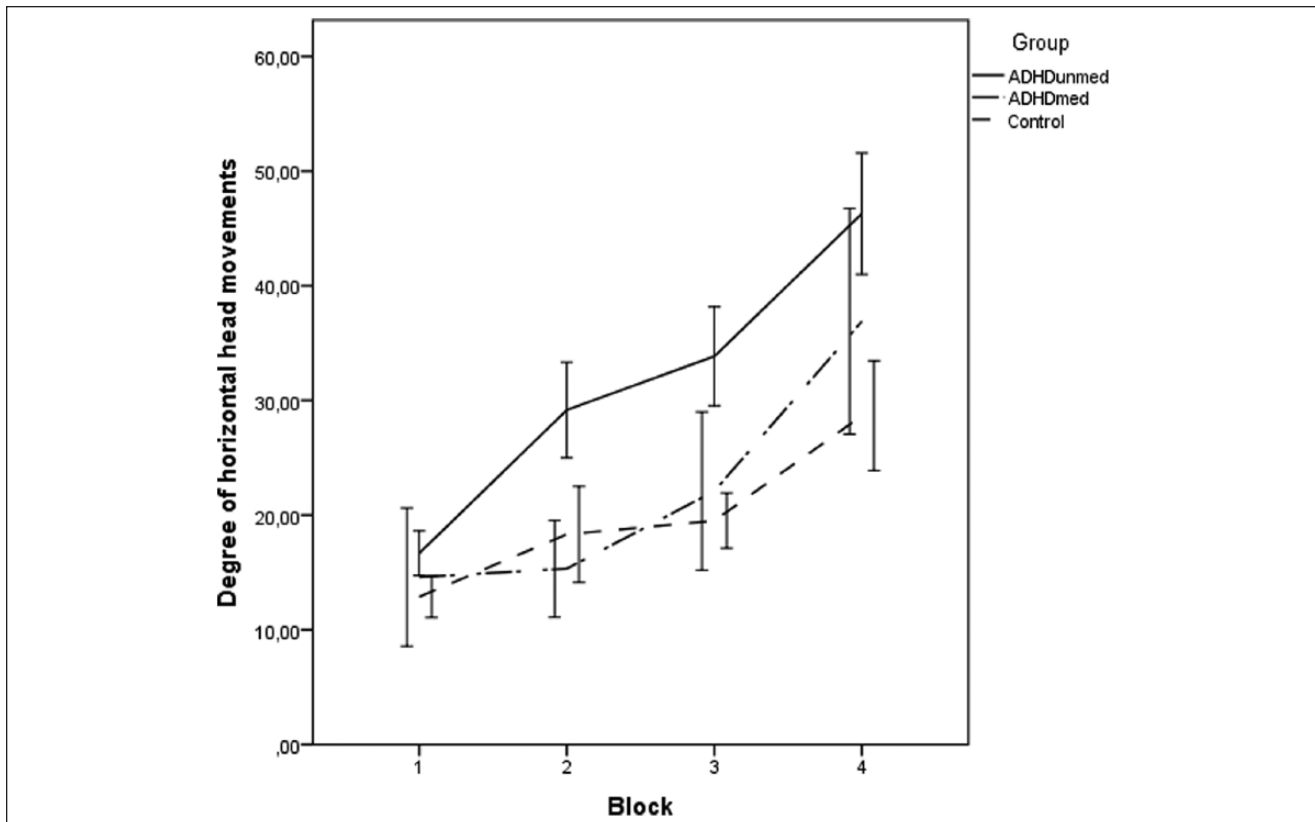
## Discussion

The current study investigated how healthy children as well as medicated and unmedicated children with ADHD perform in a CPT embedded in a VRC with standardized distracters. Concerning omission errors, the unmedicated group showed more errors than the healthy control group. Moreover, the medicated ADHD group tended to make less omission errors than the unmedicated ADHD group, but this tendency just failed to reach statistical significance in the study at hand. The three groups did not differ significantly in their commission errors, but the unmedicated ADHD group tended to show more commission errors than the healthy control group. The results for omission errors are in line with literature on CPT performance (Díaz-Orueta et al., 2014; Huang-Pollock et al., 2012; Losier et al., 1996), whereas the non-significant effect for commission errors does not support the theory that stimulant medication increases inhibitory control, as found in previous studies (Huber et al., 2007). A possible explanation is that medicated children were more focused on the task and therefore at higher risk of scoring commission errors than the unmedicated children who possibly looked around more often and

thus did take less notice of the letters presented on the blackboard.

With regard to reaction time and reaction time variability, our hypotheses were partially confirmed. Unmedicated children with ADHD had slower and more variable reaction times than healthy control children, which might stand for sluggish cognitive tempo. A medication effect occurred as the medicated ADHD group had lower reaction time variability than the unmedicated group, which corroborates findings by Boonstra et al. (2005) and Díaz-Orueta et al. (2014). Although reaction time and reaction time variability seemed to increase in unmedicated children with ADHD when a block with more distracters followed a block with less distracters (see Figures 4 and 5), there was no statistically significant interaction effect between group and block. Hence, it cannot be convincingly concluded that unmedicated children with ADHD are more affected by distracters than medicated children with ADHD or healthy control children.

Head movements were not significantly different between the groups. Contrary to this result, Díaz-Orueta et al. (2014) reported that medicated ADHD children show



**Figure 6.** Horizontal head movements by group and block ( $M \pm ISE$ ).

**Table 2.** Correlations Between Commission Errors and Impulsivity Ratings.

	IVE	FBB-HKS Impulsivity: Parents	FBB-HKS Impulsivity: Experimenter
ADHDunmed group (n = 68)	.190	-.021	.165
Healthy control group (n = 34)	.115	-.098	-.103

Note. FBB-HKS: Fremdbeurteilungsbogen für Hyperkinetische Störungen [external scoring sheet for hyperkinetic syndroms]; IVE = impulsivity venturesomeness empathy.

significantly less motor activity than unmedicated ADHD children in the AULA test. However, there was a tendency that healthy control children produce less head movements than unmedicated ADHD children in the present study, a result also found by Parsons et al. (2007). Although the interaction effect between group and block did not attain statistical significance, it can be seen in Figure 6 that the groups did not deviate from each other regarding head movements in the first block, but the unmedicated ADHD group tended to show more head movements than the other

**Table 3.** Correlations Between Omission Errors and Attentionness Ratings.

	CBCL VI	FBB-HKS Attention: Parents	FBB-HKS Attention: Experimenter
ADHDunmed group (n = 68)	-.019	.094	.286*
Healthy control group (n = 34)	-.192	.011	.054

Note. FBB-HKS: Fremdbeurteilungsbogen für Hyperkinetische Störungen [external scoring sheet for hyperkinetic syndroms].  
\* $p < .05$ .

two groups in later blocks. It could therefore be postulated that unmedicated children with ADHD only show more hyperactivity than medicated children with ADHD or healthy children when a task is repeated and therefore loses its novelty and attractiveness. Furthermore, task length might be an important factor (Bioulac et al., 2012). Finally, further sensors at the hands or feet might be useful to investigate whether hyperactivity measured as body movements increases more over blocks in ADHD children than in healthy children.

**Table 4.** Correlations Between Head Movements and Hyperactivity Ratings.

	FBB-HKS Hyperactivity: Parents	FBB-HKS Hyperactivity: Experimenter
ADHD unmed group ( $n = 66$ )	.320*	.508***
Healthy control group ( $n = 34$ )	.196	.441**

Note. FBB-HKS: Fremdbeurteilungsbogen für Hyperkinetische Störungen [external scoring sheet for hyperkinetic syndroms].

\* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .

For all reported measures, no group-specific distracter effects occurred as the groups did not show significantly different reactions to blocks with a high number of distracters. Moreover, no general distracter effects—as reported by Adams and colleagues (2009)—emerged as neither error rates nor reaction time measures nor head movements decreased from Block 2 (51 distracters) to Block 3 (five distracters) and subsequently increased from Block 3 (five distracters) to Block 4 (28 distracters).

For the unmedicated ADHD group, positive correlations between specific VRC measures and specific components of ADHD as measured by traditional questionnaire data were only found for head movements and omission errors but not for commission errors and impulsivity scales. Correlations would probably have been stronger if analyses had been done separately for each of the three ADHD subtypes. This is one major shortcoming of the current study: The sample mainly consisted of combined subtypes and few predominantly inattentive subtypes being too few for a separate analysis. There was no predominantly hyperactive subtype. Future studies could avoid this problem by investigating one subtype only or include equally large subtype samples.

Another shortcoming of the study is the different gender ratio between the three groups. Performing separate analyses for boys and girls was not possible because cell size for medicated ADHD was too small. As gender has been shown to affect commission errors in ADHD children (Hasson & Fine, 2012), the gender difference between groups should be kept in mind when interpreting the results.

Besides, it would be informative to use an eye-tracking device as an indicator of distraction effects. In the current study, we could not differentiate head movements due to boredom or hyperactive symptoms from head movements caused by distracters. Thus, eye tracking could provide additional information and would be a more reliable indicator of distraction effects.

In sum, the results indicate that the VRC is a useful device for the assessment of ADHD within an ecologically

valid environment. VR is sensitive for the detection of ADHD symptoms and medication effects, which speaks for the clinical relevance of the obtained measures (see also Neğuç et al., 2016). Future research might vary in lengths of assessment or time and the number of distracters more precisely to enhance the sensitivity. Furthermore, studies should differentiate subtypes of ADHD and consider alternative assessments for distraction effects such as eye tracking.

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## Declaration of Conflicting Interests

The author(s) disclosed receipt of the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: A. Mühlberger and P. Pauli are stakeholders of a commercial company that develops virtual environment research systems. The authors declared no further potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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