



Covert Orienting of Visual Spatial Attention in Attention Deficit Hyperactivity Disorder: Does Comorbidity Make a Difference?

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Attentional performance in children with attention deficit hyperactivity disorder (ADHD) with and without comorbid disorders was examined using the Covert Orienting of Visuospatial Attention Task (COVAT) and the Continuous Performance Task (CPT). The relationship between these two tasks was also examined. The results showed no overall differences on the attention tasks between children with ADHD alone and those with ADHD plus other disorders. Compared to non-ADHD control children, children with ADHD showed a deficit in the disengage operation of covert visuospatial attention, suggesting a difficulty in the endogenous mode of orienting. The ADHD children also showed a general performance deficit on the CPT. Although there was a general slowing on both attention tasks in the ADHD group, there was no relationship between invalid cue effect sizes on the COVAT and the CPT measures. These results indicate that these two attention tasks may be tapping both similar and independent underlying cognitive processes in ADHD. © 1999 National Academy of Neuropsychology. Published by Elsevier Science Ltd

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Deficits in attentional processes have been recognised as a core feature of attention deficit hyperactivity disorder (ADHD) for many years (Barkley & Grodzinsky, 1994). However, the underlying nature and pathophysiological significance of the attentional dysfunction in ADHD remain unclear (Pennington & Ozonoff, 1996). Although recent studies have highlighted the role of the frontal lobes and basal ganglia (see Benson, 1991; Levy, 1992; Seidman et al., 1995), the precise relationships between fronto-striatal deficits and symptoms of inattention in ADHD are poorly characterised (Benson, 1991; Pennington & Ozonoff, 1996).

Studies of cognitive function in ADHD have focused on different aspects of attentional processing in affected children. Much of the research has been on sustained attention as measured by the Continuous Performance Task (CPT) or one of its variants. This research has supported a general performance deficit in ADHD children that may be independent of, or in addition to, a sustained attention deficit (e.g., Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; Harper & Ottinger, 1992; Hooks, Milich, & Lorch, 1994). There is ongoing debate over the interpretation of performance deficits on the CPT in children with ADHD (for a review, see Ballard, 1996). Central to this debate is the lack of established models to guide interpretation of CPT performance within a brain-behaviour framework (Allport, 1988; Maruff & Currie, 1996).

Despite the common finding of psychiatric comorbidity in children with ADHD, many studies examining the nature of the attentional dysfunction have not assessed or controlled for comorbid symptoms and/or diagnoses. In a recent study, Fischer, Newby, and Gordon (1995) found that clinic-referred ADHD children who performed "normally" on the CPT performed better on other measures of attention than children with "abnormal" CPT scores. These children were also rated by teachers as less inattentive, by parents as having more conduct and psychosomatic problems, and were less likely to respond to stimulant medication.

The effects of comorbidity on attentional processing may be specific to the CPT. Seidman et al. (1995) found similar performance deficits on a variety of executive function tasks (e.g., Wisconsin Card Sorting Test, Stroop Test) in ADHD children with and without comorbid diagnoses of depression, anxiety, and/or conduct disorders. The impaired performance of both groups suggests that the neuropsychological deficits reported were associated with the ADHD symptoms rather than with the comorbid diagnoses. However, tasks thought to measure executive functions in children are factorially complex, and poor performance is not necessarily indicative of frontal lobe impairment (Fletcher, 1996). To better understand attentional function in children with ADHD, it is essential that the tasks used are based on well developed and theoretically valid models of attention.

The Covert Orienting of Visuospatial Attention Task (COVAT) described initially by Posner (1980) provides a valid and reliable measure of an individual's ability to direct visuospatial attention to different areas of the visual field without accompanying eye movements. Primate and human studies suggest that normal performance on the COVAT reflects the integrity of a distributed neural network for directed attention (Corbetta, Miezin, Shulman, & Petersen, 1993; Robinson & Kertzman, 1995). Different cognitive operations (e.g., disengage, move) are thought to be controlled by different nodes of this network. Moreover, the pattern of COVAT performance in both monkeys and humans with predominantly subcortical lesions differs qualitatively from the pattern caused by focal or diffuse cortical damage (Colby, 1991).

At least three studies have examined covert visual attention in ADHD. Swanson et al. (1991) found ADHD children with a mixed profile of aggressive/defiant behaviours to have difficulty controlling covert attention over 800-msec intervals when targets ap-

peared in the right visual field following cues presented to the left visual field. The ADHD group performed normally at 100-msec intervals for both visual fields. Similar results were found by Carter, Krener, Chaderjian, Northcutt, and Wolfe (1995) in a study that excluded participants with ADHD and comorbid mood or anxiety disorders. The findings from these two studies suggested that ADHD is associated with disruption to frontal and striatal attentional areas. Using a COVAT with a choice reaction-time procedure, Pearson, Yaffee, Loveland, and Norton (1995) also found that children with ADHD (with and without comorbid symptoms) performed normally when the time between the cue and target was short but became less reliable as this interval was extended to 300 msec. The unreliability at 300 msec was hypothesised to reflect an immature attentional system in children with ADHD.

Despite these studies, the relationship between comorbid symptoms and attentional performance in ADHD remains unclear. Although the CPT and the COVAT are derived from different models of attention, both tasks appear to be sensitive to performance deficits in ADHD. However, the extent to which such deficits are related or independent has not been established. The aim of the present study was to examine and compare COVAT and CPT performance in children with ADHD alone and in children with ADHD plus comorbid diagnoses.

METHOD

Participants

Participants were 39 nonreferred ADHD children and 39 non-ADHD control children who were taking part in the larger Australian Twin ADHD Project (ATAP) and were enrolled in the Australian National Health and Medical Research Council (NHMRC) Twin Registry. Selection criteria for the ATAP and details of the Twin Registry are described elsewhere (Levy, Hay, McLaughlin, Wood, & Waldman, 1996). Although Levy et al. (1996) found the rates of ADHD to be significantly higher in twins compared to their single-born siblings, there were no qualitative differences in the symptom profiles between these two groups. Therefore, in this study, twins were used as an ADHD high risk group, and no attempt was made to address twin specific questions.

Selection criteria for all participants were: (a) IQ estimate of at least 80 as measured by the Vocabulary and Block Design short form (Sattler, 1992) from the Wechsler Intelligence Scale for Children, third edition (WISC-III; Wechsler, 1990); (b) to live at home with at least one biological parent; and (c) to have no history of major medical or neurological illness (e.g., epilepsy, autism, psychosis).

Children in the ADHD group were required to meet DSM-III-R (American Psychiatric Association, 1987) criteria for ADHD according to maternal responses on the Diagnostic Interview Schedule for Children (DISC-P; Emory University Division of Child and Adolescent Psychiatry, 1993) or on the Australian Twin Behaviour Rating Scale (ATBRS; see Levy et al., 1996, for details). None of the children had been treated previously with psychostimulant medication.

Children with ADHD were divided into two groups depending on the presence or absence of comorbidity. Comorbid diagnoses of Separation Anxiety Disorder (SANX), Generalised Anxiety Disorder (GAD), Overanxious Disorder (OAD), Avoidant Disorder (AD), Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD) were assessed with the DISC-P using DSM-III-R criteria. Twenty-four participants were in the ADHD-comorbid group (ADHDc), most of whom (58%) met criteria for comorbid ODD only. One participant had coexisting AD, and one had coexisting CD. Eight

(33%) participants had multiple comorbid diagnoses, six of whom had coexisting ODD and at least one anxiety disorder and/or conduct disorder. The remaining two participants met criteria for two anxiety disorders (AD and SANX, OAD and GAD). There were 15 participants in the “pure” ADHD group (ADHDp) who were rated as having no more than two symptoms for any of the comorbid conditions.

To be included in the control group, participants were required to have no more than two ADHD symptoms on the ATBRS and no more than two symptoms for any comorbid diagnosis on the DISC-P. Control and ADHD participants were matched for age and IQ estimate.

All participants were White and predominantly middle class. Most children were right-handed (92%). Demographic information is summarised in Table 1. Although the sample contained more twins (82.1%) than siblings (17.9%) and was predominantly male (64.1%), there were no significant group differences on any of the demographic variables.

Tasks

The COVAT. The COVAT display and timing routines have been described in detail previously (Maruff, Hay, Malone, & Currie, 1995; Petersen, Robinson, & Currie, 1989). Briefly, the task was presented on a computer screen located approximately 35 cm from the participant. There was a 1-msec timing accuracy for stimulus display and the recording of reaction times. A red cross, subtending 0.2 degrees of visual angle, served as a central fixation point. The cross was flanked by two green circles, each subtending 2 degrees and located 4 degrees to the left and right of fixation on the same horizontal plane. Participants were instructed to keep their eyes fixed on the central cross and to press a response button as quickly as possible whenever they detected a target in either of the two outer circles. The target was a 0.2-degree red spot that appeared pseudorandomly in the left or right visual field with equal probability. Targets remained present until participants made a response. Spatial cues, consisting of a 75-msec doubling of the luminance of one of the two peripheral circles, preceded the appearance of a target. The cues were either valid (i.e., correctly indicating target location) or invalid (i.e., indicating the circle contralateral to subsequent target location). The number of trials was kept to a minimum of 200 in order to maintain children’s alertness and to minimise the effects of fatigue and distractibility. Therefore, the study was not designed to investigate lateralised performance deficits. One hundred eighty trials were spatially cued, and 20 were catch trials where no target followed the cue. Eighty percent of the spatially cued trials were

TABLE 1
Demographic Information for Children in the Pure ADHD, Comorbid ADHD,
and Non-ADHD Control Groups

	ADHDp (<i>n</i> = 15)	ADHDc (<i>n</i> = 24)	Controls (<i>n</i> = 39)	<i>p</i>
Mean (SD) age (in years)	9.79 (2.48)	9.63 (1.92)	10.36 (2.29)	.41 ^a
Gender (male:female)	12:3	17:7	21:18	.14 ^b
IQ estimate	100.42	104.8	104.00	.60 ^a
Twin (first-born; second-born): sibling status	8:3:4	11:9:4	15:18:6	.51 ^b

Note. ADHDp = pure attention deficit hyperactivity disorder. ADHDc = comorbid attention deficit hyperactivity disorder.

^aAnalysis of variance.

^bChi-square.

valid, and the remaining 20% were invalid. A neutral cuing condition was not included because no theoretically sound neutral cue has been defined for the COVAT with peripheral cues (Rafal & Henik, 1994). According to Jonides and Mack (1984) it is better not to include neutral cues when an unequivocal neutral condition cannot be guaranteed. Instead, the effect of the independent variable on the different levels of the dependent variable (in this case reaction time to the different cue types) should be determined by investigating relative changes in performance across different cue-to-target intervals or stimulus onset asynchronies (SOAs). In this study, the SOA was pseudorandomised between 150 msec and 350 msec. Eye movements were monitored by the experimenter (see Maruff, Hay, et al., 1995; Maruff, Malone, et al., 1995); where fixation instability was evident, the participant was instructed to keep his or her eyes fixed on the central point, and the trial was excluded from the analysis. Participants were not informed about the probability of the different cue types.

CPT. An X-version of the CPT described by Levy (1980) was used in this study. Eighty letters with 20 randomly distributed Xs were presented on a computer. The stimuli were displayed for 2.0 sec with an interstimulus interval of 1.5 sec. The total task time was 5 min. Participants were instructed to respond as quickly as possible by pressing a button each time they saw the letter X. Errors of omission, errors of commission, and reaction times for each correct X response were recorded. Mean reaction time was calculated as the average reaction time when a response to the X was made. The first two trials were practice trials and were not included in the analysis.

Procedure

Participating families were visited in their homes. Mothers were administered the DISC-P by trained interviewers who were blind to the diagnostic group of the children. Twins were tested on the COVAT and CPT separately by different examiners but, in most cases, not by the same person who gave the maternal diagnostic interview for that child.

RESULTS

Statistical Analysis

The distributions of COVAT reaction times for each participant were inspected for anticipatory and abnormally slow responses. Reaction times less than 100 msec and trials where an eye movement occurred were treated as anticipations (Maruff & Currie, 1996; Maruff, Hay, et al., 1995; Maruff, Malone, et al., 1995). Abnormally slow responses were calculated individually for each participant and expressed as percentages of the total number of trials performed, which were then compared between the ADHD and control groups using nonparametric tests. There were no significant differences between participant groups for the median percentage of trials on which anticipations or response failures occurred (anticipations: control group median = 2.1, range 0–13; ADHDp group median = 4.1, range 0–12; ADHDc group median = 1.3, range 0–7; Kruskal–Wallis test = 120.5, $p > .05$; response failures: control group median = 2.1, range 0–4; ADHDp group median = 1.8, range 0–3; ADHDc group median = 1.9, range 0–3; Kruskal–Wallis test = 120.5, $p > .05$). These trials were excluded from further analyses.

Group (i.e., ADHDp and ADHDc) differences on the COVAT were examined by submitting each participant's mean reaction times for the COVAT conditions to a $2 \times 2 \times 2$

analysis of variance (ANOVA) with participant group as the between-groups factor and SOA and cue type as within-group factors. The invalid cue effect size at each SOA was defined as the difference between the median reaction times for trials with valid cues and for trials with invalid cues. These measures indicate the speed with which covert visual attention can be redirected following misdirection by an invalid cue (Maruff, Hay, et al., 1995; Petersen et al., 1989).

Attentional Performance

The ANOVA comparing mean reaction times for trials with valid and invalid cue types at each SOA for the ADHDp and ADHDc groups indicated significant main effects for cue type, $F(1, 37) = 63.1, p < .0001$, but not for SOA, $F(1, 37) = 2.0, p = .17$, or group, $F(1, 37) < 1$, and no significant interactions. On the CPT, there was no significant difference between ADHDp and ADHDc groups for the percentage of errors of omission (Mann-Whitney U Test [MWU] = 121, $p = .06$), percentage of errors of commission (MWU = 156, $p = .2$), or mean reaction time ($t < 1$). Given that there were no differences between the ADHDp and ADHDc groups on the COVAT or CPT, the two groups were collapsed into a single group and compared to controls.

The ANOVA comparing the ADHD group to controls on the COVAT showed significant main effects for group, $F(1, 76) = 5.1, p = .02$, cue type, $F(1, 76) = 81.1, p < .0001$, and SOA, $F(1, 76) = 15.7, p < .0001$. Figure 1 shows the significant group \times cue type \times SOA interaction, $F(1, 76) = 5.3, p = .02$.

Subsequent ANOVAs investigating the group \times cue type interaction at 150-msec SOA showed a significant main effect for cue type, $F(1, 76) = 81.2, p < .0001$, and group, $F(1, 76) = 4.07, p = .03$, but no significant group \times cue type interaction, $F(1, 76) < 1$. For the 350-msec SOA, there were significant main effects for group, $F(1, 76) = 6.7, p = .01$, and cue type, $F(1, 76) = 41.9, p < .0001$, and a significant group \times cue type interaction, $F(1, 76) = 4.19, p = .03$. The significant interaction effect occurred because the invalid cue effect sizes at 350 msec SOA were significantly larger in the ADHD group than in the control group, $t(69) = 2.37, p = .01$. There was no such difference between groups for the 150-msec SOA, $t(69) = 0.8, p = .9$ (see Figure 1). For controls, there were significant reductions in reaction time as SOAs increased from 150 msec to 350 msec for valid trials, $t(38) = 3.31, p = .002$, and invalid trials, $t(38) = 3.77, p = .001$. For the ADHD group, there was a significant reduction in reaction time for valid trials as SOAs increased from 150 msec to 350 msec, $t(38) = 2.42, p = .02$, but not for invalid trials, $t(38) < 1$ (see Table 2). In the ADHD group, there was no significant difference in reaction times to targets appearing in the left visual field or right visual field for valid trials, $t(38) < 1$. No attempt was made to investigate lateralised performance effects for invalid trials because of insufficient data. On the CPT, the only significant difference between the total ADHD group and controls was the slower mean reaction time for correct responses in the ADHD group, $t(70) = 2.68, p = .009$ (see Table 2).

Relationship Between Attentional Measures in the ADHD Group

For the ADHD group, invalid cue effects for the 350-msec SOA did not correlate with reaction times to valid trials at the 150-msec SOA ($r = .18, p = .58$) or valid trials at the 350-msec SOA ($r = .9, p = .5$). Significant correlations were found between mean reaction times on the CPT and COVAT for 150 msec SOA valid ($r = .46, p = .006$) and invalid ($r = .55, p = .001$) trials and for 350 msec SOA valid ($r = .61, p < .0001$) and invalid ($r = .57, p < .0001$) trials.

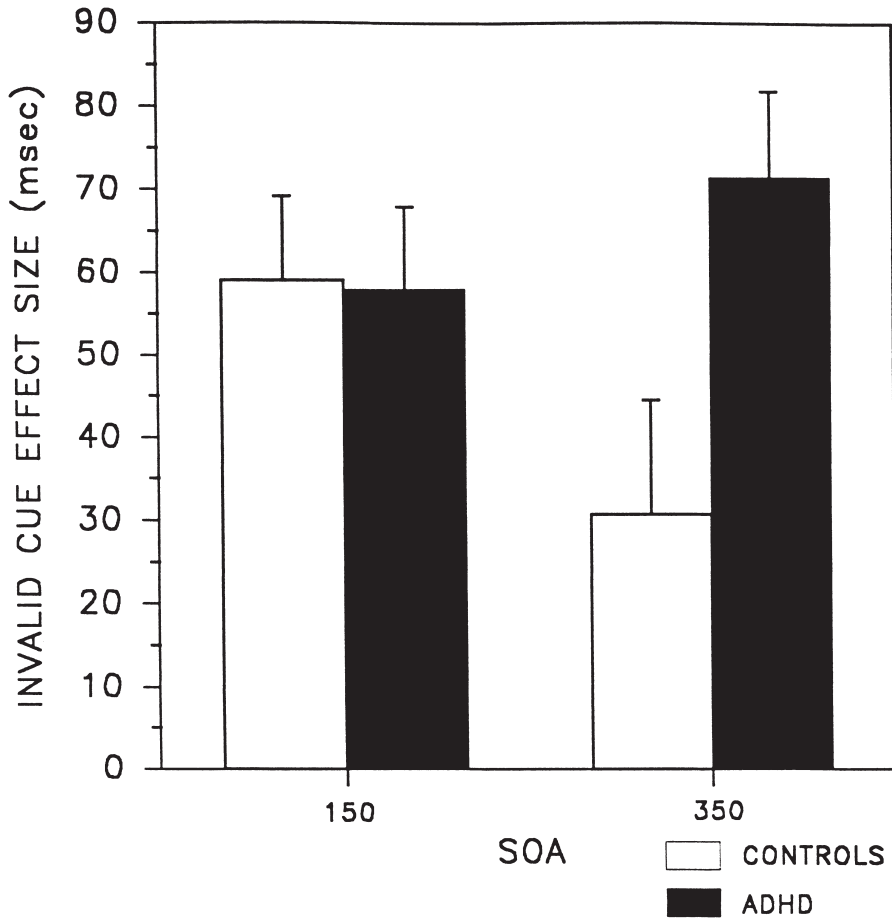


FIGURE 1. Mean (+ standard error) invalid cue effect size for 150 msec and 350 msec stimulus onset asynchrony (SOA) in attention deficit hyperactivity disorder (ADHD) and control groups.

DISCUSSION

Children with ADHD with and without comorbid diagnoses performed similarly on two measures of attention but significantly worse than non-ADHD control children. Although responses to valid and invalid trials on the COVAT were slower in the ADHD children, both participant groups showed a facilitation of reaction times to valid trials when compared to invalid trials. This indicates that the children with ADHD were able to use the cues to direct attention to the target location before it appeared and that they performed the task correctly. Consistent with previous COVAT studies, reaction times to valid and invalid trials decreased with increasing SOA for control participants (Posner, 1980). For the ADHD group, reaction times to valid trials decreased with SOA to the same extent as in the control group, but there was no reduction in reaction time for invalid trials as SOAs increased from 150 to 350 msec (Figure 1). Thus, the reaction-time advantage normally conferred by increasing SOA was not evident in the ADHD group for invalid trials. Consequently, the invalid cue effect sizes at the 350 msec SOA were significantly larger in the ADHD group than in the control group.

TABLE 2
Performance on COVAT and CPT for Control and ADHD Subgroups and ADHD Total Group

	Controls (<i>n</i> = 39)	ADHDp (<i>n</i> = 15)	ADHDc (<i>n</i> = 24)	ADHD total (<i>n</i> = 39)
COVAT				
RT = 150 msec				
Valid	418.4 (13.9)	477.5 (33.0)	451.3 (17.4)	461.3 (16.5)
Invalid	478.7 (18.1)	531.3 (40.9)	510.0 (20.7)	518.2 (19.9)
RT = 350 msec				
Valid	396.6 (13.1)	463.3 (35.7)	451.3 (17.4)	443.7 (16.6)
Invalid	432.3 (19.8)	522.9 (46.3)	505.5 (21.4)	512.2 (21.8)
CPT				
% errors of omission ^a	0 (0–3)	1 (0–5)	1 (0–5)	1 (0–5)
% errors of commission ^a	0 (0–3)	1 (0–5)	3 (0–8)	3 (0–8)
Mean RT (msec)	611.9 (90.2)	668.2 (84.5)	675.5 (112.6)	672.8 (101.7)

Note. Unless noted otherwise, all values are expressed as mean (+ standard error). ADHDp = pure attention deficit hyperactivity disorder. ADHDc = comorbid attention deficit hyperactivity disorder. COVAT = Covert Orienting of Visuospatial Attention Task. CPT = Continuous Performance Task. RT = reaction time.

^aValues are expressed as median (range).

According to the COVAT theory (Posner, 1980; Posner & Petersen, 1990), the cognitive operations required to shift attention are time locked; the successful completion of the disengage, engage, and move operations requires that there is sufficient time between presentation of the cue and the target. The normal invalid cue effect size at the 150-msec SOA in the ADHD group suggests that they were able to complete the disengage, move, and engage operations as efficiently as the control group when the time between cue and target was brief. Recent studies have shown that peripheral cues at SOAs of approximately 150 msec initiate a reflexive or exogenous orienting mode. It was only at the longer SOA that the difficulty with invalid trials became evident in the ADHD group and the invalid cue effect size increased. The addition of probability information to peripheral cues initiates a more voluntary or endogenous orienting mode (Rafal & Henik, 1994). Orienting attention to peripheral cues at longer SOAs also requires more voluntary control over attentional systems (Maruff, Hay, et al., 1995; Rafal & Henik, 1994). The pattern of COVAT performance in the ADHD group points to a difficulty in disengaging attention when voluntary control is required. The endogenous orienting mode is thought to be dependent on the activation of cortical attentional areas, whereas the superior colliculus is thought to control the exogenous orienting mode (Rafal & Henik, 1994). Although no lateral asymmetries in reaction times to valid trials were found in the ADHD group, this study was not designed to investigate asymmetrical performance, and so this finding should be treated cautiously and investigated in studies using a larger number of trials.

Performance on the CPT was also poorer in the ADHD group than in the control group. Children with ADHD showed slower reaction times to CPT targets than controls, but they did not make significantly more errors of omission or errors of commission. Previous studies have also found reaction times to CPT targets to be slower in children with ADHD. Many of these studies also reported increased error rates in children with ADHD (see Ballard, 1996). There are two possible reasons why the present sample of ADHD children was comparable to control children for accurate target detection and absence of impulsive responding. First, the sample was not selected from a clinic setting but was identified from a population survey of a group at increased risk for ADHD (Levy et al., 1996). Although children clinically referred for ADHD may perform well

on the CPT (Fischer et al., 1995), performance deficits may be more evident than in a nonclinical population because of greater symptom severity. Second, although previous research has found the X version of the CPT to be sensitive to attentional deficits in a clinic sample of children with ADHD (Levy & Hobbes, 1981), this task may not be sufficiently demanding to elicit errors of omission or commission in nonreferred participants who may have a milder form of the condition. Previous studies have also found that to elicit attentional deficits in children at risk or in the early stages of a psychiatric illness, it is necessary to increase the demands of CPT tasks (Maruff & Currie, 1996; Rutschmann, Cornblatt, & Erlenmeyer-Kimling, 1986). However, despite the normal error rates, the general performance deficit on the CPT in the present ADHD sample suggests a difficulty in the ability to respond to information and process it rapidly.

The equivalence of deficits in COVAT and CPT performance between ADHD children with and without comorbid diagnoses suggests that the impairments found in the ADHD group were not an artefact of the comorbid symptoms but rather specific to ADHD. This finding is consistent with, and extends the findings from, previous studies using COVAT or CPT paradigms in children with ADHD, which have not controlled for comorbid symptoms or have excluded children with ADHD and comorbid symptoms (Carter et al., 1995; Harper & Ottinger, 1992; Hooks et al., 1994; Pearson et al., 1995; Swanson et al., 1991). The current sample size was too small to warrant separate analyses for each of the comorbid diagnoses, and so it is still unclear whether performance on the attention tasks used in this study is affected differentially by the specific nature of the comorbid condition. However, past research suggests that other disruptive behaviour disorders such as conduct disorder are not associated with executive function deficits as measured by different neuropsychological tasks (Pennington & Ozonoff, 1996). This reinforces that the cognitive deficits seen in this study and past research are likely to be due to the ADHD symptoms rather than to the comorbid behaviours. However, as Pennington and Ozonoff (1996) pointed out, the presence of a cognitive deficit in the comorbid group may influence the severity and duration of the comorbid condition.

There was a correlation between the general speed of performance on the COVAT and the speed of target detection on the CPT, suggesting that some aspects of the two measures reflect similar cognitive processes. However, there were no correlations between COVAT invalid cue effect sizes and CPT performance. Invalid cue effect sizes have been shown to provide valid estimates of the speed with which attention can be directed across the visual field (Colby, 1991; Posner, 1980), whereas the CPT is largely used for measuring sustained attention (Ballard, 1996). The absence of an association between these two measures suggests that the inability to sustain attention and to shift attention in children with ADHD may reflect disruption to different underlying attentional processes.

The significance of generalised slowing on COVAT paradigms has not been established. It may reflect other group-related factors that are not directly connected to attentional processes, such as fatigue, motivation levels, or motor deficits (Maruff & Currie, 1996; Maruff, Hay, et al., 1995). Perceptual, attentional, and motor information has to be processed for participants to respond to any COVAT target, and reaction times reflect the speed of this processing. Similar perceptual and motor processes are involved when responses are made to targets following valid and invalid cues. However, responses differ in the extra processing required for target detection when covert visual attention is initially misdirected by an invalid cue (Maruff, Hay, et al., 1995; Posner, 1980). Therefore, analysis of the difference between COVAT conditions within subjects provides an estimate of attentional performance that is independent of factors associated with motivation, depression, or fatigue (Maruff, Malone, et al., 1995; Robinson & Kertzman,

1990). Finally, future studies should investigate the relationship between performance on more demanding CPT paradigms and the COVAT. Such an investigation may provide further insight into general attentional deficits associated with ADHD, as well as isolating deficits that are restricted to specific attentional processes.

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