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Alerting, Orienting, and Executive Attention in Children With ADHD

Jennifer C. Mullane[1,2], Penny V. Corkum[1], Raymond M. Klein[1], Elizabeth N. McLaughlin[2], and Michael A. Lawrence[1]

Abstract

Objective: This study evaluated the alerting, orienting, and executive attention abilities of children with ADHD and their typically developing (TD) peers using a modified version of the adult attention network test (ANT-I). **Method:** A total of 25 children with ADHD, Combined Type (ADHD-C, mean age = 9.20 years), 20 children with ADHD, Predominantly Inattentive Type (ADHD-I, mean age = 9.58 years), and 45 TD children (mean age = 9.41 years) matched on age and intelligence to the ADHD group completed the ANT-I. **Results:** As hypothesized, children with ADHD (*n* = 45) displayed significantly weaker alerting and executive attention than TD children (*n* = 45) but did not differ from TD children in orienting ability. Children with ADHD-C (*n* = 25) did not differ from children with ADHD-I (*n* = 20) on any of the three networks. **Conclusions:** Results supported the growing body of evidence that has found alerting and executive attention deficits in children with ADHD. *(J. of Att. Dis. 2010; XX(X) 1-XX)*

Keywords

ADHD, Attention Network Test, Children

Cognitive researchers seeking to understand the attentional difficulties of children with ADHD have faced a number of challenges. First, the construct of "attention" is complex and multidimensional. Numerous cognitive processes have been identified as components or systems of attention, and there remains no comprehensive and fully agreed-upon definition (Burack & Enns, 1997). Researchers studying attention in ADHD have tended to parse the various systems or components of attention in different ways, and this has resulted in inconsistent and sometimes incomparable findings across studies (Nigg, 2005). Second, the operational definitions of the various components of attention being investigated have also differed widely. Consequently, it is not always clear that the specific attentional system being investigated has been adequately isolated (Nigg, 2005). Third, ADHD is a heterogeneous disorder associated with a variety of different symptom profiles both within and across the three *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-IV-TR*; 4th ed., text-revision, American Psychiatric Association [APA], 2000) subtypes (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003). Although some theorists have hypothesized that children with ADHD, Predominately Inattentive Type (ADHD-I) display a differential pattern of cognitive deficits (e.g., Barkley, 1997; Milich, Balentine, & Lynam, 2001), this has not always been borne out in the research (e.g., Riccio, Homack, Pizzitola Jarratt, & Wolfe, 2006; Solanto et al., 2007). However, some notable ADHD subtype–related differences have been reported in the literature when attention is studied within theory-driven frameworks (e.g., Booth, Carlson, & Tucker, 2007; Lockwood, Marcotte, & Stern, 2001).

To address these challenges, the behavioral symptoms of inattention observed in ADHD should be examined within an empirically based cognitive framework of attention (Booth et al., 2007). The well-validated attention network theory (Posner & Petersen, 1990) is one such theory that has received increasing interest from ADHD researchers. It proposes three large-scale neural networks associated with specific and separable forms of attention known as *orienting*, *executive*, and *alerting*. The orienting network is responsible for the movement of visual attention in space and the selection of locations for further processing (Berger & Posner, 2000). The executive network is composed of a number of processes involved in the effortful control of attention, including error monitoring and interference control (Posner & DiGirolamo, 1998). The

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alerting network serves to achieve and maintain an optimally alert attentional state (Posner & Rothbart, 2007).

Drawing on the results of neurobiological and behavioral research with children and adults with ADHD, Berger and Posner (2000) hypothesized that individuals with this disorder have impairments in alerting and executive attention but not in orienting attention. Since that time, a growing body of literature has found support for these predictions. Neuroimaging studies of children and adults with ADHD have most consistently reported decreased activation in areas associated with executive attention (for a review, see Durston & Konrad, 2007) and several reviews of the behavioral literature have found that children with ADHD display weaker alerting attention (e.g., Corkum & Siegel, 1993; Losier, McGrath, & Klein, 1996; Nigg, 2006) and executive attention (e.g., Lansbergen, Kenemans, & van Engeland, 2007; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2009) but intact orienting attention (e.g., Huang-Pollock & Nigg, 2003).

The attention network test (ANT) is a simple computerized reaction time (RT) task that was developed to measure alerting, orienting, and executive attention in adults (Fan, McCandliss, Sommer, Raz, & Posner, 2002) and children (Rueda et al., 2004). The ANT is a hybrid of a visual orienting task (to measure orienting attention) and a flanker task (to measure executive attention) that includes noninformative visual warning cues on a proportion of the trials (to measure alerting attention). Functional magnetic resonance imaging (fMRI) has demonstrated that the ANT activates the expected neural networks of attention in adults (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). Consequently, the ANT has been described as a "marker task" that provides information about the functioning of the neural networks underlying performance on this task (Posner & Rothbart, 2007).

The ANT may be useful for studying the attention network functioning of children with ADHD. To the best of our knowledge, only two published studies (Booth et al., 2007; Konrad, Neufang, Hanisch, Fink, & Herpertz-Dahlmann, 2006) and one unpublished dissertation (Penny, 2008) have compared the performance of children with ADHD and a group of their typically developing (TD) peers on the ANT. All three studies reported no differences in orienting attention between the ADHD and the TD groups, as predicted by Berger and Posner (2000), but the pattern of group differences for alerting and executive attention were inconsistent. There are a number of possible explanations for the conflicting results. Most important, the subtype composition, recruitment sources, and mean IQ for the three ADHD samples were discrepant among the three studies. Additional research, therefore, is required to determine whether null effects were due to a true lack of difference between groups or whether they were due to the moderating effect of one or more sample-related variable(s) that differed across the three studies.

Second, two versions of the ANT were used and several important differences exist between them. The child ANT is more colorful and interactive. The stimuli are yellow animated cartoon fish that blow bubbles after correct responses. Children also receive auditory feedback after correct and incorrect responses. In contrast, the stimuli on the adult ANT are black arrows presented against a gray background, and no feedback is provided. It is possible that the more colorful and interactive nature of child ANT differentially enhanced the performance of children with ADHD. This could have obscured group differences in the studies by Booth et al. (2007) and Penny (2008). The adult ANT is also more difficult for both children and adults to perform (Rueda et al., 2004). Therefore, it is possible that the Flanker component of the child ANT did not sufficiently tax the executive system to allow group differences to be observed. Further study of the performance of children with ADHD on the visually less stimulating adult version of this test is required, particularly with a larger sample.

To address these methodological issues, the current study compared the performance of a clinic-referred sample of children with ADHD to a carefully matched group of TD children on a modified version of the adult ANT, known as the ANT-Interaction (ANT-I; Callejas, Lupianez, & Tudela, 2004). The ANT-I may have some advantages over the original ANT in its measurement of alerting (i.e., use of auditory warning cues, instead of visual warning cues) and orienting attention (i.e., use of valid and invalid orienting cues, instead of only valid cues). It also includes two different measures of executive attention. Although our choice of the ANT-I (over the original ANT) is based on conceptual advantages noted by Callejas et al., it is also the case that a study directly comparing them has demonstrated that the ANT-I is at least, if not more, reliable than the ANT (Ishigami & Klein, in press).

The specific goals of the present study were as follows: (a) to test Berger and Posner's (2000) hypothesis that children with ADHD will display alerting and executive attention deficits relative to their TD peers but show no difference in orienting attention, (b) to clarify conflicting results reported in the small body of literature on this topic by addressing important methodological and task-related moderating variables, and (c) to replicate the recent finding that children with ADHD-I displayed weaker alerting attention than children with ADHD-C (i.e., Booth et al., 2007) using the ANT-I.

Method

Participants

A total of 90 children aged from 6 to 12 years participated in this study. Children were required to have an estimated IQ equal to or greater than 80, normal or corrected-to-normal vision, and no known neurological, mood, or autism spectrum disorders. All participants were treated in a manner consistent with the Canadian Psychological Association's (2001) ethical guidelines. This study received ethical approval from the appropriate research ethics boards. No monetary compensation was offered. Children with ADHD were recruited from two small clinics specializing in the assessment and diagnosis of childhood attention and learning disorders. Attempts were made to contact all children assessed at the clinics who met the study's inclusion criteria. Identical diagnostic procedures were used at both clinics. Children must have been rated by a trained psychologist as reaching *DSM-IV-TR* (APA, 2000) criteria for ADHD in more than one context as assessed by semistructured diagnostic interviews with parents (Parent Interview for Child Symptoms; Ickowicz et al., 2006) and the child's classroom teacher (a modified version of the CAPABLE—Teacher Telephone Interview, C-TTI; Hum, Masellis, Humphries, Schachar, & Tannock, 1999). In addition, T scores more than 65 must have been reached on the Conners' Parent and Teacher Rating Scales–Revised (Conners, 1997).

ADHD group. A total of 26 children with ADHD-C were recruited. One girl was excluded because her overall accuracy rate was below 80%. Of the remaining 25 children, 19 were boys and 6 were girls (mean age = 9.20 years, *SD* = 1.45, range = 6.75-12.33 years). Two children with ADHD-C also had oppositional-defiant disorder, one had an anxiety disorder, one had a learning disability (LD), and one had an LD and an anxiety disorder. A total of 22 children with ADHD-I were recruited. Two boys were excluded because their overall accuracy rates were below 80%. The remaining sample consisted of 20 children (12 boys, 8 girls, mean age = 9.58 years, *SD* = 1.29, range = 7.83-12.08 years). Eight children with ADHD-I were also diagnosed with a comorbid LD.

At the time of the study, 30 (67%) children with ADHD were taking stimulant medication. A total of 27 children were off their medication for 42 or more hours ($M = 62.99$, $SD = 36.37$, range = 42-218 hr). Three children taking short-acting Ritalin had a 24-hr washout period ($M = 25.33$, $SD = 1.53$, range = 24-27 hr). There were no significant differences in the proportion of children taking each type of stimulant medication by ADHD subtype. A total of 12 children with ADHD-C and 5 children with ADHD-I were taking Concerta, $\chi^2(1, N = 45) = 2.50$, $p = .11$; 4 children with ADHD-C and 3 children with ADHD-I were taking Ritalin, $\chi^2(1, N = 45) = 0.01$, $p = .93$; 3 children with ADHD-C and 1 child with ADHD-I were taking Dexedrine, $\chi^2(1, N = 45) = 0.67$, $p = .41$; and 1 child with ADHD-C was taking Ritalin SR, $\chi^2(1, N = 45) = 0.82$, $p = .37$.

TD group. A total of 45 children (31 boys, 14 girls, mean age = 9.41 years, *SD* = 1.29, range = 7.08-12.42 years), who were individually matched to children in the ADHD group on gender and age (within 6 months), were recruited from elementary schools located within the same geographical area as was served by the clinics. Classroom teachers at participating schools were asked to identify approximately 8 "average" students in their classes who did not have any attentional or learning difficulties. Parents of children identified by their teachers were then invited to participate; T scores on the Conners' Parent Rating Scale–Revised—Long Form (CPRS-R-LF) were required to be below 65. According to parental report on the demographics questionnaire, two TD children had previously been diagnosed with anxiety disorders. None of the children in the TD group was taking psychoactive medication.

Preliminary analyses indicated that mean estimated IQ did not vary among the three groups, $F(2, 87) = 1.01$, $p = .37$. Racial/ethnicity of the sample was primarily Caucasian (97%), and this did not vary according to group, $\chi^2(4, N = 90) = 6.32$, $p = .18$. The first language of all participants was English. Socioeconomic status of the sample was estimated by parental report of household gross annual income rated in *Cdn*$10,000 increments on a 7-point scale (from 1 = *up to Cdn$20,000 per year* to 7 = *more than Cdn$70,000 per year*). The median income of the study sample was 6 (i.e., *Cdn$60,001 to Cdn$70,000*), and this did not significantly differ among groups, $\chi^2(12, N = 84) = 23.16$, $p = .19$. As expected, children with ADHD-C and ADHD-I displayed significantly higher T scores than the TD group on the CPRS-R-LF (see Table 1).

Measures

Attention Network Test–Interaction (ANT-I; Callejas et al., 2004). The ANT-I was programmed to run on E-Prime (Version 1.1; Psychology Software Tools Inc., 2002) and was presented on a laptop computer. To measure executive attention, 50% of trials were Flanker trials and 50% were Simon trials. On Flanker trials, the target array consisted of a set of five black arrows pointing either to the left or to the right and presented horizontally above or below fixation. The central arrow was considered the target. On congruent trials, the five arrows pointed in the same direction. On incongruent trials, the central arrow pointed in the opposite direction of the flanking arrows.

On Simon trials, the target stimulus was a single black arrow pointing either left or right that was presented on either the left or the right side of fixation. A congruent trial was one where the direction of the arrow was congruent with its spatial location (e.g., a left-pointing arrow presented on the left side of fixation). An incongruent trial was one where the arrow pointed in the opposite direction of its spatial location (e.g., a right-pointing arrow presented on the left side of fixation).

For both Flanker and Simon trials, the instruction was to indicate which way the target arrow was pointing by pressing the corresponding key on the keyboard. For left-pointing targets, the "c" key was pressed, and for right-pointing targets, the "m" key was pressed. Alerting had two levels (tone and no tone). It was measured by comparing RT on trials with a 2,000-Hz, 50-ms tone that preceded the target stimuli (on 50% of trials) relative to trials that did not include this tone. The tone was presented bilaterally through stereo headphones. The orienting variable had three levels (no cue, valid cue, and invalid cue). On two thirds of the trials, an asterisk cue appeared on the computer screen for 50 ms before the appearance of the target. A valid cue was one that was presented in

Table 1. Descriptive Statistics for the Study Sample

	ADHD-C[a]		ADHD-I[b]		TD[c]					
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2	Contrast[d]
Age (months)	110.36	17.4	114.95	12.05	112.89	15.43	0.51	.60		
Age (years)	9.20	1.45	9.58	1.00	9.41	1.29	0.51	.60		
WISC-IV Est. IQ	99.00	9.77	97.8	12.85	101.6	10.37	1.01	.37		
CPRS Opp	63.00	15.98	59.05	4.19	46.42	6.31	19.02	<.001	.30	TD < ADHD-C, ADHD-I
CPRS Cog Prob/In	67.68	10.29	70.45	9.84	46.02	6.78	80.61	<.001	.65	TD < ADHD-C, ADHD-I
CPRS Hyper-Imp	70.52	15.4	61.45	18.12	48.04	6.58	26.95	<.001	.38	TD < ADHD-I < ADHD-C
CPRS ADHD index	69.72	10.28	69.65	8.83	44.86	6.23	105.34	<.001	.71	TD < ADHD-C, ADHD-I

ADHD-C = ADHD combined type; ADHD-I = ADHD predominately inattentive type; TD = typically developing; WISC-IV = Wechsler Intelligence Scale for Children (4th ed.); IQ scores were estimated from the vocabulary and block design subtests; CPRS = Conners' Parent Rating Scale–Revised (Long Form), scores reported from this measure are *t* scores; Opp = Oppositional; Cog Prob/In = cognitive problems/inattention scale; Hyper-Imp = hyperactive-impulsive scale.
[a] *N* = 25
[b] *N* = 20
[c] *N* = 45
[d] Post hoc analyses were conducted using Tukey LSD.

the same location as the upcoming target stimuli. An invalid cue was one that was presented in the opposite location. Orienting ability was measured by comparing RT on trials with an invalid cue relative to trials with a valid cue. The background was gray, and all visual stimuli were black.

Trials proceeded as follows: First, a central fixation cross was presented for a variable duration ranging from 400 ms to 1,600 ms. Next, the 50-ms tone was presented (on 50% of the trials). After a stimulus onset asynchrony of 400 ms, an asterisk was presented (on 66% of the trials). After 50 ms of this event, the Flanker or Simon stimuli appeared and remained on the screen until a key was pressed or 3,000 ms had elapsed. There were 24 practice trials and 2 experimental blocks of 96 trials each. Time to complete the task was 16 min (not including a 5-min break between blocks).

Research on the reliability of the ANT-I has only begun to emerge recently. Lawrence, Eskes, and Klein (2009) calculated the reliability of the three networks of the ANT-I in nonclinical adult (n = 8) and child (n = 1) samples. They reported that the overall estimate of reliability for the executive attention network was .66 for adults and .43 for children, reliability for the alerting network was .39 for adults and .16 for children, and reliability for the orienting network was .29 for adults and –.11 for children.

Conners' Parent Rating Scale–Revised—Long Form (CPRS-R-LF; Conners, 1997). This questionnaire is frequently used to measure behaviors associated with ADHD. The CPRS-R-LF has good reliability (e.g., internal consistencies of .73 to .96, test–retest reliabilities of .47 to .85) and adequate validity (Sattler, 2002).

Wechsler Intelligence Scale for Children (4th ed., WISC-IV; Wechsler, 2003). The vocabulary and block design subtests were used as a screening measure of intelligence. The vocabulary and block design short form was selected for consistency with other research on this topic (e.g., Booth et al., 2007; Vaidya et al., 2005). It has a strong correlation with the WISC-IV FSIQ (r = .92) and adequate test–retest reliability (r = .87; Sattler, 2008).

Procedure

Children were seen individually in a quiet room. Children with ADHD were seen on weekends at the clinic at which they were originally assessed, and TD children were seen at school during regular school hours. All children first completed the ANT-I. An examiner sat next to each child for the duration of the ANT-I to help ensure consistent attention to the task. The only feedback provided to children while completing the ANT-I was to remind them not to talk and to keep their attention on the computer screen. Next, all children in the TD group and children with ADHD who had been assessed at one of the clinics more than 24 months in the past were given the vocabulary and block design subtests. Children with ADHD who were assessed at the clinic within the 24-month period before this study did not complete these subtests as their initial assessments at the clinic were still considered to be valid (e.g., Canivez & Watkins, 1998). Children chose one small prize after the ANT-I and another at the end of the session. Each session lasted approximately 1 hr.

Results

Two separate analyses were conducted. In the first, the independent variables (IVs) were as follows: group (ADHD vs. TD), alerting trial type (tone vs. no tone), orienting trial type (invalid vs. no cue vs. valid cue), congruency trial type (incongruent vs. congruent), and executive task type (Flanker vs. Simon). A 2 (group) × 2 (alerting) × 3 (orienting) × 2 (congruency) × 2 (executive task type) mixed ANOVA was conducted with repeated measures on the four ANT variables.[1] The dependent variables (DVs) were mean RT and accuracy (proportion correct). In the second analysis, ADHD subtype (ADHD-C vs. ADHD-I) was used in place of group as the IV. The control group was not included in the second set of analyses.[2] Data analyses were conducted in R (R Development Core Team, 2007). RT measures were calculated using only accurate response trials and no outlier rejection procedures were performed.[3] Graphs were created for all effects of interest. Given the goals and scope of this study, three-way or higher interactions will not be discussed.[4]

Comparison Between ADHD and TD Groups

The main effect of group was significant for RT, indicating that the overall mean response latencies of children with ADHD were longer than those of the TD group, $F(1, 88) = 3.91$, $p = .05$, $\eta^2 = .04$, Similarly, a significant main effect of group was found for accuracy, $F(1, 88) = 17.25$, $p < .001$, $\eta^2 = .16$. Children with ADHD were significantly less accurate than TD children overall.

Alerting network. A significant Group × Trial Type (tone vs. no tone) interaction effect was found for RT, $F(1, 88) = 6.40$, $p = .01$, $\eta^2 = .07$. The reduction in RT on trials with a tone relative to those without a tone was significantly larger for the ADHD group than it was for the TD group. The Group × Trial Type (tone vs. no tone) interaction effect was also significant for accuracy, $F(1, 88) = 8.07$, $p = .006$, $\eta^2 = .08$. The reduction in accuracy on trials with a tone relative to trials without a tone was significantly greater for the ADHD group than it was for the TD group (see Figure 1).[5]

Orienting network. The Group × Trial Type interaction (invalid cue vs. no cue vs. valid cue) effect was not significant for RT, $F(2, 176) = 2.21$, $p = .11$, or accuracy, $F(2, 176) = .03$, $p = .97$ (see Figure 1).

Executive network. A significant Group × Trial Type (congruent vs. incongruent) interaction effect was found for RT, $F(1, 88) = 4.71$, $p = .03$, $\eta^2 = .05$. The increase in RT on incongruent relative to congruent trials was significantly larger for the ADHD group than it was for the TD group. The Group × Trial Type interaction (congruent vs. incongruent) effects was not significant for accuracy, $F(1, 88) = .81$, $p = .37$. In regard to executive task type, the Group × Trial Type (Flanker vs. Simon) interaction effects were not significant for RT, $F(1, 88) = 2.67$, $p = .11$, or accuracy, $F(1, 88) = 2.67$, $p = .11$ (see Figure 1).

Comparison Between ADHD-C and ADHD-I Groups

None of the ADHD Subtype × Trial Type interaction effects was significant for either DV for the alerting, orienting, or executive networks: (a) alerting: RT, $F(1, 43) = 0.13$, $p = .72$; accuracy, $F(1, 43) = 1.77$, $p = .19$; (b) orienting: RT, $F(2, 86) = 0.04$, $p = .96$; accuracy, $F(2, 86) = 0.40$, $p = .67$; and (c) executive: RT, $F(1, 43) = 0.71$, $p = .41$; accuracy, $F(1, 43) = 0.30$, $p = .58$ networks.

Discussion

We conducted an empirical test of Berger and Posner's (2000) hypothesis that children with ADHD would display weaker alerting and executive attention relative to TD children and no difference in orienting attention. As hypothesized, children with ADHD did not differ from TD children in orienting attention. This result is consistent with past reviews (e.g., Huang-Pollock & Nigg, 2003) and previous studies of the ANT with children with ADHD (Booth et al., 2007; Konrad et al., 2006; Penny, 2008). Also, as expected, children with ADHD displayed impairments in alerting (RT and accuracy) and executive attention (RT only) relative to their TD peers.

Alerting attention is responsible for helping children stay optimally alert so that they may respond rapidly to unexpected events (Posner & Rothbart, 2007). Alerting is enhanced by presenting a warning before the to-be-attended-to event/stimulus (Posner & Rothbart, 2007). Our hypothesis that children with ADHD would show weaker alerting than TD children on the ANT-I was supported. When the tone preceded the target, the ADHD group's performance was enhanced to a greater degree than it was for TD children indicating that they were less alert to begin with. Also as predicted, the presence of the warning tone decreased RT but at the expense of accuracy. This effect was present in both groups, but the decrease in accuracy on trials with a tone was considerably larger in the ADHD group. Our results indicate that children with ADHD were less able than the TD group to process information accurately when in a highly alert state.

The finding that children with ADHD displayed weaker alerting attention than did TD children suggests that their general level of alertness is lower. Clinically, this information could be shared with parents or educators to help them understand the rationale for treating symptoms of ADHD with stimulant medication or to emphasize that the child's inattentive or hyperactive behavior is an effort to increase his or her alertness and is not intentional (Nigg, 2006). From an educational perspective, increasing alertness during instruction may be accomplished with a variety of strategies such as changing activities more frequently, using high-interest topics, incorporating multimedia or hands-on activities into lessons, or using visually stimulating teaching materials (Nigg, 2006). Our results further underscore the importance of identifying and assisting children with ADHD to maintain an optimally alert state—one that is not too low to result in slow and inconsistent responding and one that is not too high to produce rapid but more error-prone performance (Nigg, 2006).

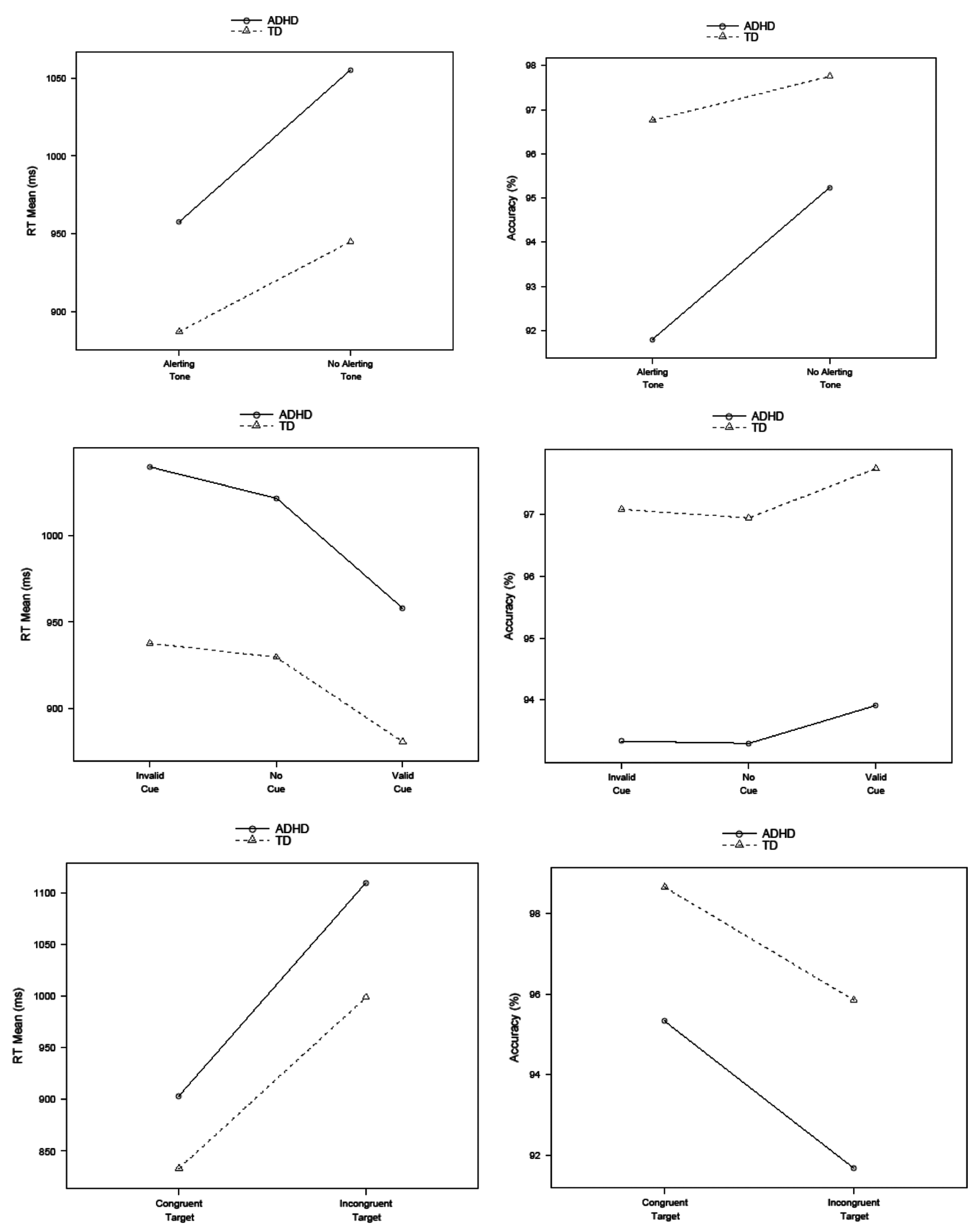

Figure 1. Group × Trial Type interaction effects for reaction time (RT) (ms) and accuracy (percent correct) for the alerting (tone vs. no tone), orienting (invalid vs. no cue vs. valid), and executive (congruent vs. incongruent) networks.

The finding of weaker alerting attention supports the conclusions of Nigg (2006), Berger and Posner (2000), and those of reviews of continuous performance tests (CPT; Corkum & Siegel, 1993; Losier et al., 1996; Nigg, 2006). They are, however, inconsistent with the three previous studies of the ANT, which found no difference in alerting between children with ADHD and TD children. Although Booth et al. (2007) reported a significant difference in alerting between children with ADHD-C and children with ADHD-I, neither group differed from the control group (whose score was intermediate between the two ADHD groups). More important, the ANT versions used in the previous studies used noninformative visual warning cues for the alerting manipulation as opposed to the auditory warning employed on the ANT-I. RTs following auditory warning tones are faster than those following visual warning cues (Fernandez-Duque & Posner, 1997), and auditory cues create larger alerting effects than visual cues (Fernandez-Duque & Posner, 1997; Posner, Nissen, & Klein, 1976). It will be important for future research to replicate our finding of weaker alerting in ADHD on the ANT-I.

The deliberate control of attention is essential for the regulation of behavior and achievement of future goals (Posner & Rothbart, 2007). Our hypothesis that children with ADHD would show less efficient executive attention than TD children was supported. On the ANT-I, executive attention is operationally defined as interference control (i.e., suppression of distracting information or stimuli that activate competing but incorrect responses). Children with ADHD were more vulnerable to the interference and associated additional processing demands during incongruent trials. Moreover, the ADHD group displayed a similar level of impairment on both measures of executive attention included in the ANT-I (i.e., Flanker and Simon trials). Contrary to our expectations and our recent review of Flanker and Simon task performance in children with ADHD (Mullane et al., 2009), the ADHD group was not significantly more adversely affected than the TD group in terms of errors made during incongruent trials. Although children with ADHD were slower to filter out distracting information during incongruent trials, this increase in effortful processing time did not produce an increase in errors.

The finding of weaker executive attention may also have clinical and educational implications. Because children with ADHD have more difficulty differentiating between important and irrelevant (but salient) information, environmental strategies designed to reduce the amount of irrelevant information competing for a child's attention and/or those intended to enhance the salience of important information may help to compensate for this weakness (Nigg, 2006). Some strategies to reduce the demands on executive attention include removing as many external distractions as possible while completing homework, presenting fewer problems or items per page on worksheets, using a highlighter to help children identify the most important details when reading or completing mathematics word problems or making operation signs more salient (e.g., larger) on math worksheets.

Evidence for weaker executive attention in children with ADHD has been found in reviews of the Stroop task (Homack & Riccio, 2004; Lansbergen et al., 2007; Pennington & Ozonoff, 1996) and in our recent review of Flanker and Simon tasks (Mullane et al., 2009). Executive attention in children with ADHD was also found to be impaired relative to TD children in the one other study that employed an adult ANT (Konrad et al., 2006). The present study's results are, however, inconsistent with the two studies that used the child ANT (Booth et al., 2007; Penny, 2008). It is possible that differences between the child ANT and the ANT-I tasks are responsible for the discrepant findings. It is also possible that intelligence had a moderating effect in some of the previous child ANT studies. Although Penny did not report this information, the ADHD group in the study by Booth et al. had an above average mean IQ. Intelligence has been shown to moderate differences in executive task performance, including measures of attention and inhibition (as measured by the Test of Variables of Attention-Revised), even when other theoretically relevant variables were controlled (Mahone et al., 2002). Within the average range of IQ, TD children performed better than children with ADHD on executive tasks; however, in the high-average (110 to 119) and superior (120 or greater) ranges, the two groups did not differ (Mahone et al., 2002). In the present study, as well as the study by Konrad et al., the mean estimated IQ scores for the ADHD and TD groups were closely matched and both were in the average range.

A commonly cited drawback to EF models of ADHD is the relative complexity of the tasks typically used to measure executive processes (e.g., Tower of Hanoi, Wisconsin Card Sorting Test; Pennington & Ozonoff, 1996). An advantage of the ANT-I over traditional neuropsychological EF measures is that it offers a more stringent, theory-driven definition of executive control that has been shown to measure the hypothesized function it is intended to measure (e.g., Fan et al., 2005). This increases the likelihood that the executive control process under investigation has been isolated. However, it will be important for future research to examine whether executive attention on the ANT-I is related to performance on more complex EF tasks and "real-world" situations requiring this ability (e.g., Lawrence et al., 2004).

Another goal of this study was to compare the attentional capabilities of children with ADHD-C and children with ADHD-I on the ANT-I to determine whether children with ADHD-I would display weaker alerting (as in Booth et al., 2007). Contrary to our expectations, the alerting abilities of children with ADHD-I and ADHD-C were similar. In fact, no subtype-related differences were found on any of the three attention networks. Although some have argued that children with ADHD-I display a different pattern of neurocognitive deficits (e.g., Barkley, 1997; Carlson & Mann, 2002), so far, the research has not provided strong support for this intuitively appealing hypothesis (Nigg, 2006). At the broader behavioral level, important ADHD subtype–related differences such as varying rates of comorbid psychological disorders have been found (Carlson, Shin, & Booth, 1999; Weiss, Worling, & Wasdell, 2003). In contrast, at more specific levels of measurement (e.g., genetics, neuroanatomical, neurocognitive), children with ADHD-I generally do not differ from those with ADHD-C (e.g., Baeyens, Roeyers, & Vande Walle, 2006). Although there have been some isolated reports of ADHD subtype–related neurocognitive differences (e.g., Lockwood et al., 2001), it has been argued that the most parsimonious conclusion is that children with ADHD-I and ADHD-C differ from TD children but do not usually differ from each other (Nigg, 2006). Our results support this latter interpretation.

Others have suggested that the *DSM-IV-TR* definition of ADHD-I is inadequate and that it includes children who are "subthreshold" for ADHD-C as well as a subset of children with solely inattentive symptoms (McBurnett, Pfiffner, & Frick, 2001). It has been hypothesized that this purely inattentive group represents a separate disorder with a distinct cognitive profile characterized by sluggishness and frequent daydreaming. This symptom profile is known as sluggish cognitive tempo (SCT; Carlson & Mann, 2002; McBurnett et al., 2001; Penny, 2008). In the present study, ADHD-I was defined according to the *DSM-IV* to ensure the greatest generalizability of the findings; therefore, children could have had as many as five hyperactive-impulsive symptoms. In contrast, Booth et al. (2007) noted that their ADHD-I group had an atypically low number of hyperactive-impulsive symptoms (M parent = 0.5, M teacher = 1.0). Thus, it may be that a subset of children with ADHD-I *without* hyperactive-impulsive symptoms do, in fact, display weaker alerting attention than children with ADHD-C. It would be beneficial for future studies of the ANT-I to include a comprehensive measure of SCT such as the one recently developed by Penny (2008) to more closely examine the relationship of this symptom cluster to performance on the ANT-I.

It is important to consider the limitations of this study. Although the ANT-I allows for stringent measurement of attentional processes, this increase in measurement rigor is associated with a reduction in ecological validity. Little is known about the extent to which deficits on laboratory tests of executive control translate to impairment in children's daily functioning (Lawrence et al., 2004). Executive attention has, however, been identified as critical for regulating emotions as well as for the development of explicit learning in TD children (Posner & Rothbart, 2007). It will be interesting for future research to explore these relationships in children with ADHD.

There were different rates of comorbidity between our ADHD-C and ADHD-I groups, and it was not possible to match individually TD children to those with ADHD on comorbid disorders. A common criticism in the literature is the failure to control for the potential effect of comorbid disorders on the neurocognitive functioning of children with ADHD (Tannock, 2002). Without controlling this variable or excluding all children with ADHD who are also diagnosed with a comorbid disorder, it cannot be concluded that the impairment in the cognitive function under investigation is specific to ADHD. An investigation of the *specificity* of these impairments to ADHD, however, was not the focus of the present study. Given the high rates of comorbidity observed in this population (e.g., Wilens et al., 2002); it is more likely than not for a child with ADHD to be diagnosed with more than one disorder. We chose to include children with ADHD who were also diagnosed with comorbid disorders to increase the generalizability of our results. Nevertheless, it will be important for future studies to address the issue of specificity of the alerting and executive attention deficits reported here by including appropriate clinical control group(s) (e.g., children with LD or ODD but *without* ADHD).

In summary, the results of the present study add to the growing body of literature that has found the attention network theory to be a useful cognitive model for conceptualizing the attentional difficulties of children with ADHD. Consistent with the predictions of Berger and Posner (2000), children with ADHD displayed weaker alerting and executive attention and intact orienting attention relative to their TD peers. Contrary to our expectations, children with ADHD-I did not display weaker alerting than did children with ADHD-C. This adds to the growing literature that has not found neurocognitive differences between ADHD subtypes as defined by the *DSM-IV*. Given the results of this study as well as the findings in previous research, there does appear to be an "attention deficit" in ADHD. This deficit is not a general attention deficit; rather, it is specific to the processes of alerting and executive attention. Consequently, strategies designed to enhance alerting and executive attention should be considered when developing programs for children with ADHD to increase their success in academic, behavioral, and social domains.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interests with respect to their authorship or the publication of this article.

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Notes

1. Before performing each ANOVA, Mauchly's test was used to check for violations of sphericity. Although these tests revealed

occasional violations, subsequent Greenhouse–Geiser and Huynh–Feldt corrected results never diverged in significance from the uncorrected ANOVA. To conserve space, only the results of the uncorrected ANOVA are reported in the following section.

2. The reason for this analytic strategy was because a preliminary mixed ANOVA with three levels of the IV group (ADHD-C vs. ADHD-I vs. TD) revealed that the main effect of group was not significant for RT ($p = .13$). The main effects of group were, however, significant for accuracy. Post hoc tests indicated that the two ADHD groups significantly differed from the TD group but did not differ from each other. For RT, the trend was similar but it did not reach significance (i.e., ADHD-C vs. TD, $p = .06$; ADHD-I vs. TD, $p = .25$; ADHD-C vs. ADHD-I, $p = .60$). Thus, it was determined to be appropriate to collapse the two ADHD groups into one to increase power to detect differences in the comparison with the TD group and to eliminate the control group from the analysis of ADHD subtypes.
3. We did not apply traditional outlier rejection procedures for two reasons. First, for RT research generally, Ulrich and Miller (1994) have shown that such data manipulations may obscure true effects and/or introduce false effects. Second, the results of Leth-Steensen, King Elbaz, and Douglas (2000) suggest that the performance of individuals with ADHD on RT tasks may be best characterized only by occasional slowing. Thus, more strongly skewed RT distributions may be expected in children with this disorder. Traditional outlier rejection on the basis of assumptions of normality would, therefore, remove these potentially important differences.
4. It should be noted that only two higher-order interaction effects involving group were significant: Specifically, the Group × Congruency Trial Type × Executive Task Type × Alerting Trial Type was significant for RT, $F(1, 88) = 5.62$, $p = .02$, and the Group × Congruency Trial Type × Orienting Trial Type for accuracy, $F(2, 176) = 3.09$, $p = .048$.
5. The tabulated data can be obtained by writing to the corresponding author (J. Mullane).

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