Performance on a neurocognitive measure of alerting differentiates ADHD combined and inattentive subtypes: A preliminary report

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Abstract

The performance of 16 attention-deficit hyperactivity disorder (ADHD)/C, 26 ADHD/IA, and 24 control children was compared using a computer reaction time task designed to measure the effects of Posner’s orienting, conflict and alerting attentional systems. No group differences in orienting or conflict were found. In contrast, children with ADHD/IA showed stronger alerting effects than those with ADHD/C, as indicated by relatively greater performance benefits following a warning cue. Although neither ADHD group differed significantly from controls on alerting, effect size comparisons indicated that children with ADHD/IA showed a somewhat larger ($d = .57$) and children with ADHD/C a somewhat smaller ($d = .44$) alerting effect relative to control children. The results are among the first to document unique patterns of attentional capacity for ADHD subtypes.

Keywords: Attention-deficit hyperactivity disorder; Inattentive subtype; Alerting; Child ANT; Attention

Attention-deficit hyperactivity disorder (ADHD) is a heterogeneous disorder currently defined by clinical history and behavioral report of impairment. Three subtypes have been identified in the Diagnostic and Statistical Manual (DSM)-IV (American Psychiatric Association, 1994) according to their constituent symptom profiles of inattention and/or hyperactivity/impulsivity. Research has focused primarily on the combined subtype (ADHD/C) with impairment in both symptom domains. The inattentive subtype (ADHD/IA), with primary symptoms in the inattention domain without clinically significant hyperactivity/impulsivity, has been far less studied. Reviews of the associated features of the ADHD/C and ADHD/IA subtypes have suggested that the groups show distinctive patterns of age of onset, sex ratios, comorbidity, and academic and social impairment (Milich, Balentine, & Lynam, 2001). Furthermore, compelling, though preliminary, evidence for distinct attention deficits in the DSM-IV subtypes comes from earlier research on attention-deficit disorders conducted with children diagnosed using DSM-III (American Psychiatric Association, 1980) criteria. This work suggested that the cognitive performance of “nonhyperactive” groups was characterized by features of slow information processing, drowsiness, sluggishness, low levels of alertness, and mild problems with memory/orientation (Barkley, Du Paul, & McMurray, 1990; Lahey, Schaubhency, Frame, & Strauss, 1984; McBurnett, Lahey, & Pfiffner, 1993), whereas the performance of those with “hyperactivity” was characterized by distractibility,
difficulty concentrating, sloppiness, and disorganization (Carlson & Mann, 2000; Lahey, Carlson, & Frick, 1997). These findings have led to the suggestion that ADHD/IA represents the expression of unique cognitive deficits (Barkley, 1997; Milich et al., 2001) however, data documenting such differences at the neurocognitive level remain lacking. The hyperactive only subtype (ADHD/HI), which was newly introduced in DSM-IV, is less prevalent and has generated far less research than the other two subtypes and is not included in this study because of the belief that it may represent a developmentally early manifestation of the ADHD/C subtype (Barkley, 1996) and thus not constitute a unique diagnostic category.

Attempts to identify a core deficit in ADHD are complicated by the existence of multiple neural networks of attention associated with various cognitive processes and clinical manifestations. Hyperactivity and the executive control of behavior in ADHD has been predominantly linked to frontal lobe functioning, whereas inattention in ADHD has been linked to the frontal lobes as well as to right parietal and midline subcortical regions involved in the regulation of attention and arousal (Swanson, Posner, et al., 1998), but these relationships have not been established in the subtypes. However, of the few studies that have investigated neurocognitive functioning in the subtypes, most have used standard neuropsychological tests that can have poor sensitivity to the unique impairments associated with many childhood disorders (Pennington, Bennetto, McAleer, & Roberts, 1996).

Particularly lacking in this area are data documenting neurocognitive differences between the subtypes. Studies assessing the subtypes on neurocognitive measures typically find one or both subtypes to differ from controls but rarely report differences between subtypes. Using a battery of neuropsychological measures, both Houghton, Douglas, and West (1999) and Chhabildas, Pennington, and Willcutt (2001) found a nearly identical profile of deficits in ADHD/C and ADHD/IA groups. Similarly, in a sample of girls, Hinshaw, Carte, Sami, Treuting, and Zupan (2002) found similar deficits in the ADHD/C and IA subtypes in executive functioning (EF), motor, and linguistic performance, but with the ADHD/C group showing a greater magnitude of deficits. In direct comparisons between subtypes, differences emerged on only 2 of 10 measures, suggesting greater EF impairment for the ADHD/C versus the IA group. Nigg, Blaskey, Huang-Pollock, and Rappley (2002) compared the subtypes on a battery of neuropsychological measures and showed poorer performance for the ADHD/IA relative to the ADHD/C group on simple output speed; and, among boys, greater deficits in behavioral inhibition in the ADHD/C relative to the IA group. However, other measures did not differentiate the subtypes suggesting a similar pattern of deficits in measures of processing speed (e.g., Stroop naming) and planning. It is noteworthy that across these studies mean performance scores on neurocognitive measures for ADHD groups typically fall in the same direction, though sometimes only the most discrepant of the two ADHD groups show a statistically significance difference from comparison controls. Thus, these findings do not provide strong evidence that the subtypes differ qualitatively on some cognitive deficit, but rather that they differ in degree of impairment.

Multiple components of attention associated with unique neural systems have been described in the literature (e.g., Posner & Petersen, 1990). Hence, it is not surprising that many different neuroanatomical regions have been implicated in the origins of ADHD. This discrimination of attention as a multifaceted construct (both cognitively and anatomically) comes to the forefront when considering research involving ADHD subtypes, or ADHD groups of mixed type, that may not share a unique attention deficit. Specifically, recent efforts to identify the neurocognitive correlates of the subtypes have relied almost exclusively on tests of EF that may have limited relevance for the ADHD/IA subtype. With the limited scope and specificity of available testing instruments, however, little has been revealed about the specific attention process deficits that distinguish this group. A conceptually driven paradigm is needed that extends assessment beyond the realm of EF and offers predictions about the mechanisms of inattention in ADHD/IA. If deficits in attention found in the absence of hyperactivity/impulsivity, as in ADHD/IA, are dissociable from the inattention of ADHD/C, separate pathways may explain the neurocognitive origins of the subtypes.

1. **Posner’s model**

According to the model proposed by Posner and Raichle (1994), attentional networks within the brain can be broadly categorized into conflict resolution, orienting, and alerting systems, each with different yet interrelated function. The conflict resolution system involves regions of the pre-frontal cortex and basal ganglia and is responsible for the executive control of attention, an aspect of self-regulation that appears to be deficient in the ADHD/C subtype. Alternatively, the orienting system has anatomical foci in the parietal lobes, parts of the midbrain and thalamus, and is responsible for visual orienting and shifting attention. This system is presumed to facilitate automatic processes associated with visual-spatial processing and the disengaging and reengaging of attention (Posner & Raichle, 1994). The third system
of attention proposed by Posner and Raichle (1994), the alerting system, involves the locus coeruleus nucleus of the midbrain and its connections to the frontal and parietal lobes of the right hemisphere. The integrity of the alerting system plays a critical role in arousal, vigilance, and maintaining readiness to react, and may be particularly sensitive to attentional differences in disordered populations (Posner & Petersen, 1990). Accordingly, Posner and Raichle’s model (1994) of separate yet interconnected networks of attention in the brain provides a theoretical model for examining the attentional correlates of the ADHD subtypes.

2. Rationale for the current study

For the impressive history of research on children with ADHD, very little is known about the cognitive deficits associated with the heterogeneous symptom domains. The diagnostic separation of ADHD/C and ADHD/IA subtypes is based largely on differentiation at the behavioral level. It has been suggested, however, that the distinction between these subtypes lies not only in the degree or absence of hyperactivity, but in the nature of the attention deficit (Milich et al., 2001).

The current study is intended to investigate the cognitive mechanisms underlying inattention in ADHD subtypes. Posner’s model proposing three distinct neural networks of attention provides a theoretically sound model for examining potentially different bases for the attentional problems of the ADHD/C versus ADHD/IA subtypes. It is hypothesized that the conflict resolution component may be most relevant to the former and the alerting component to the latter group. The demonstration of a pattern of differential attentional deficits between the subtypes may have etiological and clinical significance, and would provide further validation and refinement of the DSM-IV distinction.

3. Methods

3.1. Participants

Participants were 66 children between the ages of 7 and 13 years, including 16 who met criteria for ADHD/C, 26 who met criteria for ADHD/IA, and 24 non-diagnosed comparison controls. The participants in this study were part of a larger investigation of neurocognitive functioning in the ADHD/C and ADHD/IA subtypes; only a subset of results is reported here. Children were excluded from participation in the study if they had a history of significant head injury or other neurological disorder; psychosis; or had an estimated full-scale IQ of less than 80. Children taking psychoactive medications, other than stimulants prescribed to treat ADHD symptoms, were also excluded.

Children with ADHD were recruited from patients evaluated at a local Neuropsychological Clinic, who were invited to participate in the study if a clinical diagnosis of ADHD had been made and the available parent and teacher rating data on a DSM-IV diagnostic checklist were consistent with a diagnosis of ADHD. All children were required to meet DSM-IV criteria for onset and duration of symptoms. On a 4-point rating scale, a symptom rated as “quite a bit” or “very much” was considered present; a symptom rated as “not at all” or just a little” was considered absent. In order to maximize subtype differentiation, children classified as ADHD/IA were required to have four or fewer HI symptoms. This cut-off is supported by analyses from Lahey et al. (1994) showing that five HI symptoms best discriminate classification of impaired versus non-impaired cases in this domain and maximizes agreement with clinician judgment. Thirty-four of these children with ADHD (10 ADHD/C and 23 ADHD/IA) met DSM-IV criteria based on both parent and teacher ratings. An additional nine ADHD children (six C and three IA) were included who met criteria by one rater and missed criteria by the other rater by one symptom. Thus, all ADHD children would have met criteria by the “or” algorithm used in the MTA (MTA Cooperative Group, 1999), in which a symptom was counted as “present” if it was endorsed by either parent or teacher.

Control group participants could not have received a diagnosis of ADHD or learning disability (LD), have a history of neurological disorder or obtain estimated IQ of less than 80, and were required to have fewer than four symptoms of IA and HI combined on the DSM-IV ADHD rating scale. The majority of the control group was recruited from responses to a solicitation letter given to and distributed by parents of the clinic-referred children. Fourteen of the control children met rating criteria by both parent and teacher, while four were rated by parent only as teacher forms were not returned. Six additional control children for whom teacher ratings were not available were recruited from participants in another research study; these children all met criteria by parent rating.
3.2. Diagnostic and descriptive measures

Block Design and Vocabulary subtests of the Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991) were administered to obtain an estimate of intellectual functioning (Sattler, 1992). The Wide Range Achievement Test-Revision 3 (WRAT-3; Jastak & Wilkinson, 1993) reading and arithmetic subtests were administered to assess achievement levels.

The DSM-IV diagnostic checklist assesses symptoms of inattention, hyperactivity/impulsivity, and oppositional behavior based on DSM-IV diagnostic criteria for ADHD and Oppositional Defiant Disorder (ODD). Each symptom is rated on a 4-point scale: 0 = not at all, 1 = just a little, 2 = pretty much, and 3 = very much. A symptom was considered “present” if rated as “pretty much” or “very much.”

Demographic and descriptive characteristics of the sample are summarized in Table 1. ANOVA’s and Chi square analyses were used to compare groups on demographic and descriptive variables. Groups did not differ on age [$F (2, 63) = .026, p = .974$] or ethnicity [$\chi^2 (2) = 4.49, p = .106$]. Groups showed a trend to differ on sex [$\chi^2 (2) = 5.86, p = .053$]. Pairwise comparisons revealed that the ADHD/C group has more boys than the control group [$\chi^2 (1) = 5.79, p < .05$]. The groups also showed a trend to differ on IQ [$F (2, 57) = 3.03, p = .056$]. Post hoc Tukey comparison revealed a trend (.052) for the control group to have higher IQ than the ADHD/IA group. Groups differed significantly on WRAT reading [$F (2, 55) = 8.08, p < .01$] and showed a trend to differ on WRAT arithmetic [$F (2, 55) = 2.94, p = .062$]. Post hoc comparisons revealed that the control group had higher reading scores than ADHD/C ($p < .001$) and ADHD/IA ($p < .01$) groups and showed a trend ($p = .061$) to have higher math scores than the ADHD/IA group.

To aid in comparing this sample to other research, we report rates of LD and ODD due to their generally high comorbidity with ADHD. Participants were experimentally classified as having a learning disability if they displayed

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Participant demographic and descriptive characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADHD/C, mean (S.D.), $n = 16$</td>
</tr>
<tr>
<td>Age in months</td>
<td>114 (22)</td>
</tr>
<tr>
<td>Sex ratio male</td>
<td>88%</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>94%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>0%</td>
</tr>
<tr>
<td>Asian</td>
<td>6%</td>
</tr>
<tr>
<td>Parent DSM-IV</td>
<td></td>
</tr>
<tr>
<td>Inattention</td>
<td>8.0 (1.3)</td>
</tr>
<tr>
<td>Hyperactivity/impulsivity</td>
<td>6.9 (1.5)</td>
</tr>
<tr>
<td>ODD</td>
<td>3.3 (2.2)</td>
</tr>
<tr>
<td>ADHD/C, mean (S.D.), $n = 16$</td>
<td>ADHD/IA, mean (S.D.), $n = 26$</td>
</tr>
<tr>
<td>Teacher DSM-IV</td>
<td></td>
</tr>
<tr>
<td>Inattention</td>
<td>7.8 (1.2)</td>
</tr>
<tr>
<td>Hyperactivity/impulsivity</td>
<td>7.0 (1.4)</td>
</tr>
<tr>
<td>ODD</td>
<td>3.1 (2.4)</td>
</tr>
<tr>
<td>ADHD/C, mean (S.D.), $n = 16$</td>
<td>ADHD/IA, mean (S.D.), $n = 26$</td>
</tr>
<tr>
<td>WISC IQ (pro-rated)</td>
<td>111 (17)</td>
</tr>
<tr>
<td>ADHD/C, mean (S.D.), $n = 15$</td>
<td>ADHD/IA, mean (S.D.), $n = 25$</td>
</tr>
<tr>
<td>WRAT-3</td>
<td></td>
</tr>
<tr>
<td>Arithmetic</td>
<td>103 (15)</td>
</tr>
<tr>
<td>Reading</td>
<td>98 (12)</td>
</tr>
</tbody>
</table>

Corrected $ns$ are reported for several variables. Complete data were not collected for the six controls who did not participate in the larger study. WRAT math and reading scores were unavailable for two participants.
below average achievement (standardized score of ≤85) and a discrepancy of greater than one standard deviation, i.e., >15 points, between estimated Full Scale IQ on the WISC-III and the WRAT-3 reading or arithmetic subtests. LD was identified in two of the ADHD/C participants (i.e., two reading LDs) and one of the ADHD/IA participants (i.e., one arithmetic LD). To consider the effects of Learning Disabilities on task performance, analyses were run both with and without these children. Excluding these children resulted in the same pattern of findings on all dependent variables, thus they were included in final analyses.

ODD diagnoses were assigned to children who received four or more rating scale symptoms endorsed by either parent or teacher. Nine (56%) of the ADHD/C, five (19%) of the ADHD/IA, and one (4%) of the control children met ODD diagnostic criteria.

3.3. Procedure

Eighty-eight percent of ADHD/C (14/16) and 58% of the ADHD/IA (15/26) children were being treated with stimulant medication. All participants taking stimulant medication followed an 18-h or greater washout period prior to participation. Testing sessions took place at the Austin Neurological Clinic and lasted approximately 3 h. IRB approval was obtained for this research. At the beginning of the session, parents signed consent forms and children signed assent forms. Parents then completed diagnostic, descriptive, and experimental forms. Participants completed several experimental neuropsychological measures, including the Attention Network Test (ANT), during the study session. Families received $40 for their participation in the study, and teachers who returned the forms received $10.

The children’s version of the ANT (Rueda et al., 2004) is a computer based reaction time (RT) task that measures alerting, orienting and conflict: the cognitive processes associated with Posner’s three networks of attention. In our study, task instructions were presented on the computer screen and explained by the examiner. Children were instructed to visually fixate on a cross located in the center of the computer screen. They were then told a fish would appear either above or below the fixation point and that they were to “feed” that fish by pressing the right or left mouse click with the corresponding thumb in the same direction the fish was pointing. The target appears either alone (neutral) or with four additional fish, two flanking each side. In congruent trials, flanking fish point in the same direction as the target and in incongruent trials, they point in the opposite direction. The child was to ignore flanking fish and respond based solely on the orientation of the center fish. Further, trials were either uncued or preceded by an asterisk to serve as an alerting &/or spatial cue. In the spatial cue condition, one asterisk appears either above or below the central fixation point and predicts the specific location of the upcoming target. In the central cue condition, one asterisk appears at the location of the central fixation point serving as an alerting cue but providing no clue as to the specific location of the target stimuli. In the double cue condition, two asterisks appear, one above and one below the central fixation point, again providing alerting information but no spatial information. Hence, trials consisted of a fixation period, cue or no cue, fixation period, target (i.e., a fish, either alone or flanked) and a final fixation period. After responding, auditory and visual feedback is presented to indicate whether the response is correct or incorrect. Following a correct response, the target fish is displayed blowing bubbles accompanied by a recording of a voice saying “whoohoo.” Incorrect responses are followed by a single tone and no animation of the fish. The task consists of a practice of 24 trials followed by three 5-min test sessions of 48 trials; the trial conditions were counterbalanced across sessions. Total duration for each trial on the ANT is 4500 ms. The first fixation period is variable in duration, from 400 to 1600 ms, preceding the presentation of a spatial cue, and fixed at 200 ms preceding the target in no cue trials. For the cued trials, either one or two asterisks are presented for 200 ms. A 400 ms fixation period marked the cue-target stimulus onset asynchrony. Stimuli are presented until a response is made or for a maximum of 2000 ms.

The three networks of attention are assessed by manipulations of flanker congruency and cue condition. Median reaction time values were obtained for each condition (i.e., median RT per cue condition across the flanker conditions and median RT for each flanker condition across cue conditions). The alerting score was calculated as the difference between the participant’s median RT of double cue trials and the median RT of no cue trials. The orienting score was calculated as the difference between the median RT of the spatial cue trials and the median RT of the center cue, or control, trials. Finally, the conflict score for each participant was calculated as the difference between the median RT of congruent trials and the median RT of incongruent trials. Mean scores across participants were then computed for each network effect. These values were calculated from the reaction time data of correct trials only.
4. Results

4.1. Missing data and outliers for the ANT

Two participants, one ADHD/C and one control, who had very low accuracy rates of below 80%, were excluded from the study. When overall accuracy is low, the probability of chance responding for any given trial is high, and correct responses are less likely to reflect the cognitive processes of interest involved in accurate responding. The two excluded participants were not represented in any of the data in this paper, including demographics.

Outlier analyses were conducted for each of the network scores. Histogram plots of the distribution of data for orienting, alerting, and conflict scores were examined. Extreme infrequent values, delineated by a break in the distribution of data, were considered to be outliers. Three outlier values were identified for the network scores, one for alerting (one ADHD/C) and two for orienting (one ADHD/C and one ADHD/IA); these three data points were excluded from their respective analyses. The alerting outlier was 2.56 standard deviations and the orienting outliers were 3.10 and 2.69 standard deviations away from their respective group means. No outliers for control cases were identified. Children for whom outlier values were found were excluded only from the specific analyses for which the outlier was found, but not from other ANT analyses. Corrected \( n \)s are reported in tables for the performance variables.

4.2. Consideration of IQ, reading, and sex effects

To assess effects of IQ, reading, and sex, these variables were correlated with the five task DVs; accuracy, reaction time, orienting, alerting and conflict. IQ did not correlate with any of the DVs. Reading correlated significantly with reaction time \((r = -0.373, p < .01)\) and nearly significantly \((r = 0.235, p = .08)\) with accuracy, but when reading was used as a covariate in these analyses the pattern of results remained unchanged. Sex showed a trend to correlate with conflict \((p = .062)\). Analyses for boys only were conducted but not reported here. The pattern of results was consistent with those of the entire group. The low \( n \) of ADHD/C girls precluded the separate analysis of girls only.

4.3. Group performance on the ANT

A MANOVA examining cue type, flanker type, and group showed significant main effects for group \([F(2, 64) = 8.52, p < .001]\), flanker type \([F(2, 63) = 120.92, p < .001]\), and cue type \([F(3, 62) = 65.074, p < .001]\). There was a trend for a three-way interaction between group, flanker type, and cue type \([F(12, 118) = 1.67, p = .08]\). There were no significant two-way interactions between group, flanker type, or cue type.

Group performance on the each of the dependent measures was examined with univariate ANOVAs. To assess the magnitude of group differences, effect sizes \((d)\) were calculated for selected comparisons. Performance scores for the three groups are reported in Table 2.

A main effect for group was found for accuracy \([F(2, 63) = 9.42, p < .001]\). Post hoc comparisons revealed that the control group was more accurate than the ADHD/C \((p < .001, d = 1.42)\) and ADHD/IA \((p < .05, d = .73)\) groups. Pairwise comparisons also revealed a trend \((p = .092, d = .63)\) for the ADHD/IA group to be more accurate than the ADHD/C group. A main effect for group was found for overall reaction time, calculated based on correct responses only, \([F(2, 63) = 8.27, p < .01]\) with post hoc comparisons showing that the control group was significantly faster than the ADHD/C \((p < .01, d = 1.22)\) and ADHD/IA \((p < .01, d = 1.01)\) groups. Univariate ANOVAs for orienting \([F(2, 61) = .22, p = .807]\) and conflict \([F(2, 63) = .00, p = .996]\) did not yield significant group differences. Groups differed

Table 2

<table>
<thead>
<tr>
<th></th>
<th>ADHD/C, mean (S.D.)</th>
<th>ADHD/IA, mean (S.D.)</th>
<th>Control, mean (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orienting (ms)</td>
<td>52.90 (35.45)</td>
<td>43.33 (50.22)</td>
<td>45.60 (45.18)</td>
</tr>
<tr>
<td>Alerting (ms)</td>
<td>46.32 (60.14)</td>
<td>101.89 (57.62)</td>
<td>70.85 (50.43)</td>
</tr>
<tr>
<td>Conflict (ms)</td>
<td>63.98 (61.88)</td>
<td>62.80 (42.70)</td>
<td>62.70 (34.22)</td>
</tr>
<tr>
<td>Overall reaction time (ms)</td>
<td>830.34 (110.70)</td>
<td>821.32 (130.64)</td>
<td>709.29 (85.51)</td>
</tr>
<tr>
<td>Accuracy percent</td>
<td>91.02 (4.41)</td>
<td>93.78 (4.35)</td>
<td>96.67 (3.52)</td>
</tr>
</tbody>
</table>
Table 3
Correlations among teacher symptom scores and overall reaction time and accuracy on the Attention Network Test

<table>
<thead>
<tr>
<th>DSM-IV HI</th>
<th>Overall RT</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSM-IV IA</td>
<td>.450***</td>
<td>.397**</td>
</tr>
<tr>
<td>DSM-IV HI</td>
<td>.205</td>
<td></td>
</tr>
<tr>
<td>Overall RT</td>
<td></td>
<td>−.575***</td>
</tr>
</tbody>
</table>

* Correlation (two-tailed) significant at the .05 level.
** Correlation (two-tailed) significant at the .01 level.
*** Correlation (two-tailed) significant at the .001.

significantly on alerting \[F(2, 62) = 5.02, p < .05\] with post hoc Tukey comparisons revealing that the ADHD/IA group showed a significantly greater alerting effect than the ADHD/C group \((p < .01; d = .94)\).

4.4. Relationships among symptom scores, accuracy, and reaction time

Table 3 shows correlations among the teacher rated diagnostic indices of HI and IA, overall reaction time and accuracy. Both IA and HI symptoms showed significant negative correlations with ANT accuracy, and higher IA scores were also related to slower reaction times. Not surprisingly, significant negative correlations were found between overall RT and accuracy.

5. Discussion

Group comparisons on the ANT did not reveal significant differences in the efficiency of the orienting or conflict attention networks. In contrast, as hypothesized, the alerting effect was sensitive to group membership. The ADHD/IA group showed a stronger alerting effect than the ADHD/C group, as indicated by a greater difference in response latency between the double cue and no cue conditions. Thus, when the cue appears on the computer screen to warn of the upcoming target, children with ADHD/IA speed their performance to a greater degree than do children with ADHD/C relative to their respective baseline performance when no cue is provided. Although ADHD/IA group and the ADHD/C group showed large effects \((d = .94)\) to differ from each other on this variable, they did not differ significantly from the control children, whose mean scores fell between those of the ADHD/C and ADHD/IA groups. Effect size comparisons on alerting showed that, relative to controls, the ADHD/IA group benefited somewhat more \((d = .57)\) and the ADHD/C group benefited somewhat less \((d = .44)\) from the warning cues. In interpreting the difference in the alerting response between the ADHD/C and ADHD/IA groups, it is important to consider the potential effect of baseline reaction time. Children with ADHD have been shown in the past to have slower processing speed relative to controls (Willcutt & Carlson, 2005) and our data are certainly consistent with this. One may hypothesize that subjects with slower initial reaction times may have more potential for improvement with an alerting cue and hence artificially skew the data on this task. However, both the ADHD/C and ADHD/IA groups had slower uncued reaction times relative to controls and this slowing was of a similar magnitude. Despite this similarity of baseline reaction time, the IA group showed significant benefit from the alerting cue while the C group showed only a marginal change; one that was less than the control group despite a potential ceiling on the size of the alerting effect in the controls due to a faster initial reaction time. This suggests that the slow initial reaction time in the ADHD subtypes may be the result of different neurocognitive (dys)function. Hence, some of the confusion in the literature regarding the neurocognitive underpinnings of ADHD likely arises from the false assumption that the overt behaviors characterizing ADHD represent unitary neurocognitive constructs/processes.

5.1. Alerting

The alerting system has been associated with frontal and parietal regions of the right hemisphere and the mechanisms of the alerting effect are presumed to lie in the subcortical noradrenergic system arising in the locus coeruleus (Posner & Petersen, 1990). The norepinephrine (NE) system arising in the locus coeruleus is thought to be involved in regulating the alert state (Posner & Petersen, 1990), and disrupting activity of the noradrenergic systems involved in arousal
can reduce the effectiveness of alerting produced by a warning signal (Fan, McCandliss, Sommer, Raz, & Posner, 2002). While our findings cannot be definitively interpreted as reflecting “damage” to a specific neurotransmitter “system,” the muted alerting effect in the ADHD/C group is certainly consistent with this model. But whatever the cause, these findings raise the possibility that the two ADHD subtypes have unique pathophysiology. Furthermore; alerting effects are diffuse, due to the broad distribution of axons innervating large areas of the cerebral cortex. The breadth of modulation of this system may have some bearing on our findings of group differences in the efficiency of this attention network.

The demonstration of a divergent pattern of neurocognitive performance between ADHD subtypes is among the first in the literature. Studies that report subtype differences on neurocognitive measures have typically found one subtype to differ from controls but have not found ADHD subtypes to differ significantly from each other. Performance means for ADHD groups usually fall in same direction, with the most extreme ADHD group showing a greater effect to differ from comparison controls. Probably the most striking finding of significant subtype differences on neurocognitive measures has been demonstrated by studies showing that the combined type performed worse than the inattentive type on measures of inhibition (Nigg et al., 2002). However, such findings do not provide evidence that the subtypes differ qualitatively on some cognitive deficit, but rather that they differ in degree of impairment. In contrast, the current study suggests that ADHD/IA and ADHD/C are associated with unique attentional correlates associated with the alerting system.

5.2. Conflict and orienting

Our hypotheses for group differences in conflict and orienting were not supported. Failure to find group differences is the most surprising for conflict, which is designed to be a measure of executive functioning. Executive functions represent a broad domain and different tasks of executive functions tap various and overlapping abilities. While there is evidence for a deficit of executive functions in ADHD/C, some executive measures are sensitive to ADHD dysfunction whereas others are not. The most consistent findings have been reported for tests of motor/cognitive inhibition such as measured by continuous performance tests and the Stop Task (Chhabildas et al., 2001). Even the narrow spectrum of conflict tasks produce different patterns of brain activation although they are considered to assess the same cognitive construct; the flanker task activates an area of the anterior cingulate which is distinct from but overlaps activation produced by other conflict tasks (Fan et al., 2002). Relatively, in their study examining the development of attentional networks in children, Rueda et al. (2004) presented an unexpected finding that although children’s conflict scores on the ANT decreased between the ages of 4 and 8, suggesting improved efficiency of the network, their scores differed little beyond age 7 on into adulthood. This is inconsistent with the notion that an executive network of attention continues to improve until adulthood (Rueda et al., 2004). Perhaps conflict as measured by the ANT flanker task, is not as sensitive to impairment in ADHD as other tasks of executive functioning. Alternatively, the lack of a conflict effect may be related to sample characteristics. That is, the relatively high average IQs of our clinical sample (ADHD/C = 114; ADHD/IA = 116) may reflect lower levels of EF dysfunction than is typically found for children with ADHD. A sample with a more representative range of IQ might find the hypothesized group differences in conflict. This assertion might also explain the lack of a relation between IQ and conflict.

It is noted by Posner and colleagues that there is little empirical support for the involvement of the orienting network in ADHD pathology. It is not clear that the neural pathways involved in orienting contribute to the impairment of attention observed in this population (Berger & Posner, 2000). Our study does test the efficiency of the orienting network in ADHD and provides no additional evidence to suggest that the attention deficit in either ADHD subtype is due to or can be detected by impaired orienting to visual spatial cues.

5.3. Limitations

In interpreting the findings, several caveats must be noted along with a consideration of study limitations. First, the low statistical power limits the strength of conclusions that can be drawn from these data. The sample size allowed sufficient statistical power to detect at least large effects, as demonstrated in the ADHD/IA subtype showing a significantly greater alerting effect than the ADHD/C subtype on the ANT. Differences between control and ADHD groups, however, were nonsignificant, though effect size comparisons suggested that the ADHD/IA group showed a somewhat greater ($d = .57$) and the ADHD/C group a somewhat smaller ($d = −.44$) alerting effect than controls. This pattern
raises the possibility that a larger sample would have provided the power to detect statistically significant differences allowing for more definitive conclusions about impairment.

A potentially important sample characteristic that likely influenced results is the very low prevalence of hyperactivity/impulsivity symptoms in the ADHD/IA group (teacher = 1.0, parent = .5 mean HI symptoms). This is a relatively unique sample in that the ADHD/IA group is a truly “nonhyperactive” group. Thus, the ADHD/IA group is not representative of DSM-IV criteria, which allows up to five HI symptoms to be present for inclusion in this subtype. The low HI symptoms of this group may have contributed to the significant findings differentiating ADHD/IA from ADHD/C on the cognitive/attentional process of alerting. While this sample characteristic may limit the generalizability of our findings, it also raises an intriguing issue regarding DSM-IV diagnostic criteria. Since our results demonstrate attentional differences in at least one network, alerting, when a “nonhyperactive” inattentive group is examined, subtype differentiation may be optimized if researchers begin using more stringent diagnostic criteria than the clinical guidelines of the DSM-IV.

5.4. Clinical implications

Some clinical implications of these findings are noteworthy. If the alerting difference is upheld in future research, it suggests possibilities for designing maximally beneficial educational interventions which can be subtype specific. For example, the use of cues as a teaching aid might be particularly powerful for children with ADHD/IA. The delineation of different mechanisms of attentional impairment may also help lead the search for pharmacologically specific treatments, particularly as agents with more specific mechanisms of action become available.

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