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Impaired conflict resolution and alerting in children with ADHD: evidence from the Attention Network Task (ANT)

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Background: An important theory of attention suggests that there are three separate networks that execute discrete cognitive functions. The 'alerting' network acquires and maintains an alert state, the 'orienting' network selects information from sensory input and the 'conflict' network resolves conflict that arises between potential responses. This theory holds promise for dissociating discrete patterns of cognitive impairment in disorders where attentional deficits may often be subtle, such as in attention deficit hyperactivity disorder (ADHD). **Methods:** The Attentional Network Test (ANT), a behavioural assay of the functional integrity of attention networks, was used to examine the performance of 73 children with ADHD and 73 controls. **Results:** Performance on the ANT clearly differentiated the children with and without ADHD in terms of mean and standard deviation (SD) of reaction time (RT), the number of incorrect responses made and the number of omission errors made. The ADHD group demonstrated deficits in the conflict network in terms of slower RT and a higher number of incorrect responses. The ADHD group showed deficits in the alerting network in terms of the number of omission errors made. There was no demonstration of a deficit in the orienting network in ADHD on this task. **Conclusions:** The children with ADHD demonstrated deficits in the alerting and conflict attention networks but normal functioning of the orienting network. **Keywords:** ADD/ADHD, Attention Network Task, attention, behavioural genetics, child development, executive function. **Abbreviations:** ADHD: attention deficit hyperactivity disorder; ANT: Attention Network Task; RT: response time.

Although inattention is one of the three cardinal symptoms of attention deficit hyperactivity disorder (ADHD), there has been a general failure within the literature to define an objective pattern of attention deficit in ADHD (Huang-Pollock & Nigg, 2003). Fan and colleagues recently developed the Attention Network Test (ANT) to assay the integrity of separable neural systems for alertness, spatial orienting and executive control of attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT holds promise for dissociating discrete patterns of cognitive impairment in disorders where attentional deficits may often be subtle. Here we sought to delineate a profile of attention deficit in a large sample of children with and without ADHD using the ANT.

Posner and colleagues advanced an influential theory of attention in which discrete cognitive processes are supported by independent attentional networks (Posner & Peterson, 1990; Posner & Rothbart, 2006). The *alerting* network is hypothesised to acquire and maintain an alert state. The *orienting* network selects information from sensory input for further processing. The *conflict* network resolves the conflict that arises between competing stimuli. These networks are theorised to be both anatomically and functionally segregated. The alerting network is thought to rely upon the frontal and parietal lobes, with tonic levels of alertness driven by noradrenergic input from the locus coeruleus (Posner & Peterson, 1990; Posner, Sheese, Odludas, & Tang, 2006). The orienting network is composed of the superior parietal lobe, the temporoparietal junction, the frontal eye fields, the pulvinar and the superior colliculus (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Posner & Peterson, 1990; Posner et al., 2006); acetylcholine is hypothesised to be the dominant neuromodulator of this network (Posner & Rothbart, 2006). The conflict network is thought to comprise the lateral prefrontal cortex, the anterior cingulate and the basal ganglia (Botvinick, Cohen, & Carter, 2004; Posner et al., 2006), with patterns of activity that are predominantly modulated by dopamine (Posner & Rothbart, 2006).

The ANT is a two-choice reaction time (RT) task developed to independently and reliably test the efficiency of the three networks within an integrated paradigm (Fan et al., 2002). Response times are facilitated via the provision of cues that provide valid

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spatial information regarding the location of an upcoming target (*testing orienting*), or cues that are alerting but spatially non-informative (*testing alerting*). Centrally presented arrowheads (left or right pointing) are flanked by arrowheads that point in either the same (congruent) or opposite (incongruent) direction from the target stimulus, thus challenging the *conflict network*. Functional MRI studies of the ANT have confirmed these behavioural dissociations by demonstrating that the neural areas described above are active during the different elements of the task (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005).

Recent studies of the ANT in children and adults with ADHD have proven inconsistent. No deficits in the alerting, orienting or conflict networks were shown in a group of 30 family-physician-diagnosed adults with ADHD (Oberlin, Alford, & Marrocco, 2005) and 16 children with combined-type ADHD and 26 children with inattentive-type ADHD (J. Booth, Carlson, & Tucker, 2007). Konrad and colleagues studied children with and without ADHD on a modified ANT in an fMRI design[1] (Konrad, Neufang, Hanisch, Fink, & Herpertz-Dahlmann, 2006). No behavioural group difference was found for the alerting or re-orienting networks but the ADHD group demonstrated a behavioural deficit in the conflict network. The fMRI results suggested hypo-activation of specific brain regions by the ADHD group on the alerting and conflict contrasts and deviant areas of activation on the re-orienting and conflict contrasts. Neural compensation for deficient fronto-striatal activity may have occurred to explain the lack of a behavioural deficit in the re-orienting index (Konrad et al., 2006).

The aim of the current study was to test the exact nature of attentional deficits associated with ADHD in a large sample of children with and without ADHD. Heritability data has been presented for the ANT [conflict network $h^2_F = .89$, $h^2_H = .62$; alerting network $h^2_F = .18$, $h^2_H = .14$; orienting network $h^2_F = -.59$, $h^2_H = -.49$] (Fan, Wu, Fossella, & Posner, 2001) and performance indices on this task have been advanced as potential endophenotypes (Posner, Rothbart, & Sheese, 2007). Given that attention deficits in ADHD may be of modest effect size (Huang-Pollock & Nigg, 2003) it is important to first characterise the profile of neurocognitive impairment in ADHD in appropriately powered studies.

In this study we also analysed errors of omission; these errors provide an alternative and potentially quite sensitive measure of the alerting index, since children with ADHD would be expected to make more errors of omission in the no-cue, relative to the more alerting double-cue, condition.

Based on previous behavioural, anatomical and functional imaging evidence, it was predicted that the ADHD group would show deficits in 1) the alerting network, as measured by a longer mean RT and greater omission errors, 2) the conflict network, as measured by a longer mean RT and greater number of incorrect responses, but 3) would not show a deficit in the orienting network on any measures.

Methods and materials

Participants

Seventy-three children with ADHD and 73 control children participated in the study (see Table 1). The mean ages of the two groups did not significantly differ; however, there was a significant difference in IQ, as measured using four subtests (picture completion, vocabulary, information, block design) of the Wechsler Intelligence Scale for Children (WISC; Wechsler, 1992), [$F(1,144) = 21.309$, $p < .001$].

Exclusion criteria for participation in the study included known neurological conditions or pervasive developmental disorders, serious head injuries and below average intelligence (below 70 on the WISC). Control children were also excluded if they had first-degree relatives with ADHD. Handedness was measured using the Edinburgh Handedness Inventory (Oldfield, 1971).

The participants with ADHD were referred by consultant psychiatrists. All participants with ADHD met DSM-IV diagnosis for ADHD, as determined by semi-structured interviews by psychiatrists using the parent form of the Child and Adolescent Psychiatric Assessment (CAPA; Angold et al., 1995) or the Parental Account of Childhood Symptom (PACS; Taylor, Schachar, Thorley, & Wieselberg, 1986). All parents of the ADHD group completed the Conners' Parent Rating Scale – Revised: Short Version (CPRS-R:S; Conners, 1997) and all had ADHD Index T-scores 65 or above.

Table 1 Information on the ADHD and Control children

Group	ADHD	Control
Number	73	73
Age (mean, SD)	12.7 (2.3)	13.1 (1.9)
IQ (mean, SD)	97.2 (13.2)*	107.2 (13.0)
Left-handers	12	4
Male/female	63/10	65/8
DMS-IV Combined Type/ Hyperactive-Impulsive/ Inattentive subtype ADHD[1]	61 72/10	
Comorbid diagnosis of oppositional defiant disorder	30	
Comorbid diagnosis of conduct disorder	8	
Conners' ADHD Index (mean, SD)	76.6 (6.9)*	44.6 (4.7)

ADHD = Attention Deficit Hyperactivity Disorder; IQ = intelligence quotient; * = Significant difference between ADHD and controls. [1]The results of the analysis with the ADHD combined subtype alone (n = 61) remained exactly as per the results with the entire group.

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[1] The major modification involved the inclusion of invalid cues on 20% of all spatially cued trials.

Any stimulant medication was withdrawn for at least 24 hours prior to testing.

The control children were recruited from Dublin schools. Parents of control children completed the CPRS-R:S at the time of testing and all had ADHD Index T-scores less than 60. After complete description of the study to the participants, written informed consent was obtained from parents of all children and the experimental work was conducted under the approval of local ethical committees in accordance with the Declaration of Helsinki.

Apparatus and procedure

All participants performed the ANT as described in Fan et al. (2002). Stimuli were presented using E-Prime on a laptop computer (see Figure 1). Using an external computer mouse, participants pressed the left and right mouse buttons, with their thumbs, corresponding to either a leftward or rightward pointing central arrow target. During the task a fixation cross, lasting between 400 and 1600ms (randomised), was replaced by one of four warning cue types (100ms) that provided increasing levels of information about the forthcoming target. The target (left or right pointing middle arrow) was flanked by 4 arrows pointing in the same (congruent; 1/3 trials) or opposite (incongruent; 1/3 trials) direction. In the final third of trials the target arrow was flanked by dashed lines that formed the neutral condition. Trials were pseudo-randomly presented. A practice block of 24 trials, with feedback on accuracy and speed of response, was followed by three experimental blocks, with no feedback, of 96 trials per block (4 cue conditions × 3 flanker types). Participants rested between blocks. Each block lasted approximately 5 minutes.

Data analysis and statistics

The dependent variables included the mean and SD of RT, number of incorrect responses (responses made in the opposite direction to the direction of the arrow target) and number of omission errors (failure to make a response). All dependent variables were calculated per participant and per condition. Task factors included Cue Type (no, centre, double, spatial) and Flanker Congruency (congruent, neutral, incongruent). Any RTs that were associated with an incorrect response or were shorter than 100ms were rejected from the RT calculations. The alpha level was set at .05 and Bonferroni adjustments were used for post-hoc comparisons throughout the analyses. IQ was not entered as a covariate in the statistical analyses of the mean and SD of RT as IQ was not statistically independent of Group (see Miller & Chapman (2001) for a detailed discussion of this issue).

ANT main analysis

The mean and SD of RT were analysed in a Group (ADHD vs. Control) by Flanker by Cue three-way mixed-model ANOVA design. When Mauchly's test of sphericity was significant, the Greenhouse–Geisser estimate of the *F* statistic was used. The mean and SD of RT met the requirements for ANOVA. The number of incorrect

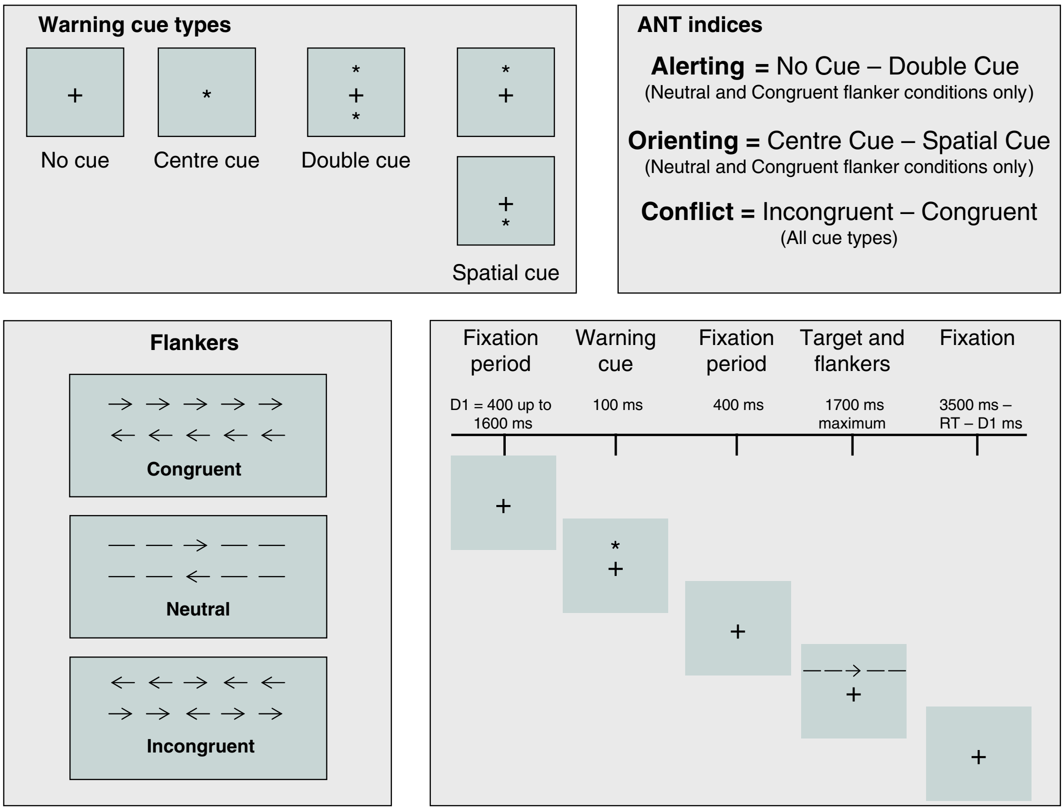

Figure 1 The Attentional Network Task (ANT) parameters, from Fan et al., 2002. One central arrow with four flankers consisted of 3.08° of visual angle. Each arrow or line was separated by .06° of visual angle

responses and omission errors were non-normal in distribution; hence non-parametric one-tailed tests were conducted on focused comparisons.

Network analyses

Based on the large interaction between Flanker and Cue reported by Fan et al. (2002), we deviated from the original ANT calculation method by removing the incongruent trials from the calculation of the alerting and orienting indices to facilitate an assessment of these domains, independent of conflict processes. Accordingly, the *Alerting* index was calculated by averaging the responses to the congruent and neutral flanker trials together and then subtracting the double-cue from the no-cue conditions. The *Orienting* index was calculated by averaging responses to the congruent and neutral flanker trials and then subtracting the spatial-cue from the centre-cue conditions. In accordance with Fan et al. (2002), the functioning of the *Conflict* network was calculated by subtracting the average of all cue types under the congruent conditions from the average of all cue types from the incongruent conditions. The mean and SD of RT for each of the network calculations were analysed using univariate ANOVA with Group as the between-subjects factor. Any group differences in the number of incorrect responses and omission errors for each of the network calculations were analysed with the Mann–Whitney test (one-tailed).

Results

Mean RT – ANT main analysis

Significant Group and Flanker main effects were further explained by a Group by Flanker interaction, [$F(2,288) = 3.731$, $p < .043$, $\eta_p^2 = .025$] (see Figure 2). Pairwise comparisons suggested that the mean RT of the ADHD group [mean in ms (SD): incongruent 850 (174); congruent 692 (127); neutral 689 (132)] was significantly slower than the control group [incongruent 728 (149); congruent 595 (112); neutral 586 (110)], on all flankers (all $p < .001$). For both groups, the mean RT for the incongruent flanker condition was significantly slower than for the congruent ($p < .001$) and neutral ($p < .001$) conditions. There was no significant difference between the congruent and neutral flanker conditions for the ADHD group ($p > .999$). The interaction may have been driven by the significantly quicker response of the control children in the neutral flanker condition compared with the congruent flanker condition ($p < .032$). Please also note the larger difference between the incongruent and congruent flanker mean RTs for the ADHD group compared with the control group, which is examined in the Conflict Index calculation below.

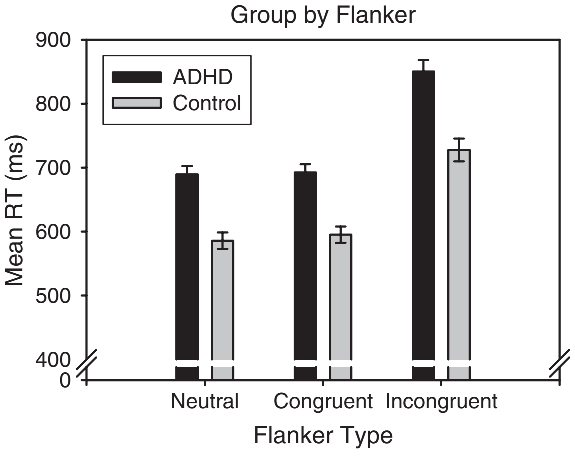

Figure 2 Mean reaction time (RT) (in ms, with standard error bars) of the attention deficit hyperactivity disorder (ADHD) and Control groups in response to each flanker type on the Attentional Network Task (ANT)

A Cue main effect was further explained by a Cue by Flanker interaction, [$F(6,864) = 5.429$, $p < .001$, $\eta_p^2 = .036$]. For each flanker type, the mean RT of each cue type differed significantly (all ps $< .010$) (see Figure 3). The mean RTs for the neutral and congruent flankers, for each cue type, were significantly faster than the mean RTs for the incongruent flanker type (all $p < .001$). There was no significant difference in mean RT between the neutral and congruent flankers for the no- ($p > .999$), double- ($p > .841$) and spatial-cue ($p > .772$) conditions. The interaction was driven by the trend towards a significant difference in mean RT for the centre-cue type between the neutral (mean 647 ms, SD 134) and congruent (mean 658 ms, SD 133) flanker types ($p > .077$). There was no interaction between Cue and Group.

Mean RT – Alerting, Orienting and Conflict Indices

The results of the index calculations are presented in Table 2. There was no significant difference between the two groups in mean RT for the Alerting and Orienting indices. The ADHD group was slower to respond to incongruent configurations, as indicated by a significantly higher *conflict* index relative to the control children (Cohen's $d = .38$ medium effect

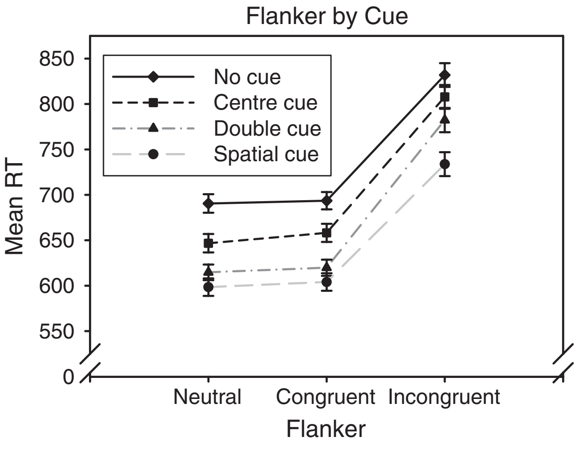

Figure 3 Mean RT of all participants in response to each cue and flanker type on the ANT

size). This result suggests that children with ADHD have greater difficulty than controls in resolving the conflict engendered by the incongruent stimulus configuration.

SD of RT – ANT main analysis

Significant Group and Flanker main effects were further explained by a Flanker by Group interaction [$F(2,288) = 4.524$, $p < .012$, $\eta_p^2 = .030$]. Pairwise comparisons suggested that the response time of the ADHD group was significantly more variable [mean in ms (SD): incongruent 206 (76); congruent 192 (71); neutral 201 (76)] than that of the control group [incongruent 172 (69); congruent 151 (74); neutral 147 (73)], on all flankers (all $p < .001$). For both the ADHD ($p < .012$) and control ($p < .001$) groups, the SD of RT for the incongruent flanker condition was significantly greater compared with the congruent flanker. For both the ADHD ($p > .139$) and control ($p > .999$) groups, there was no difference in SD of RT between the congruent and neutral flanker conditions. The interaction was driven by the significantly less variable response of the control children in the neutral flanker condition compared with the incongruent flanker condition ($p < .001$): the ADHD group ($p > .647$) failed to demonstrate this reduction in variability in the presence of the neutral flanker.

A significant Cue main effect was found [$F(3,432) = 15.214$, $p < .001$, $\eta_p^2 = .096$], but no significant interactions concerning Cue were found. The SD of RT for the no-cue condition [191 (75)] was significantly more variable than for the centre- [179 (77)] ($p < .003$), double- [169 (74)] ($p < .001$) and spatial-cue [173 (78)] ($p < .001$) conditions. The SD of RT for the centre cue was significantly more variable compared with the double cue ($p < .028$) but did not differ significantly from the spatial cue ($p > .700$]. There was no significant difference in SD of RT between the double and spatial cues ($p > .999$).

SD of RT – Alerting, Orienting and Conflict Indices

There was no significant Group difference in SD of RT for any of the indices (see Table 2).

Incorrect responses – ANT main analysis

Given the significant Group by Flanker interactions for the Mean and SD of RT measures, a focused Group comparison for each Flanker type was conducted for incorrect responses and analysed using the Mann–Whitney test (see Figure 4). For each Flanker type, the ADHD group made significantly more incorrect responses than the Control group. The ADHD group [median (inter-quartile range): congruent 7.0 (8.5), incongruent 18 (17.5), neutral 8.0 (8.0)] made significantly more incorrect responses than the control group [congruent 5.0 (5.0), incongruent 12 (11.5), neutral 5.0 (6.0)] in the

Table 2 Alerting, Orienting and Conflict Index results

	Alerting[1]		Orienting[2]		Conflict[3]	
	ADHD	Control	ADHD	Control	ADHD	Control
Mean RT (in ms)	Mean 77 (SD 56)	Mean 66 (SD 40)	Mean 58 (SD 46)	Mean 53 (SD 37)	Mean 158 (SD 78)	Mean 133 (SD 55)
Statistic	Not significant. [F(1,144) = 1.660, $p > 0.200$, np2 = 0.011]		Not significant. [F(1, 1 44) = 0.434, $p > 0.511$, rp2 = 0.004]		Significant. [F(1,144) = 5.123, $p < 0.025$, np2 = 0.034]	
SD of RT	Mean 19 (SD 50)	Mean 29 (SD 40)	Mean 13 (SD 49)	Mean -1 (SD 39)	Mean 14 (SD 44)	Mean 21 (SD 39)
Statistic	Not significant. [F(1,144) = 1.626, $p > 0.204$, rp2 = 0.011]		Not significant. [F(1, 1 44) = 3.543, $p < 0.062$, rp2 = 0.024]		Not significant. [F(1,144) = 1.013, $p > 0.316$, rp2 = 0.007]	
Incorrect responses	Median 0.0 (IQR1.5)	Median 0.0 (IQR1.0)	Median 0.0 (IQR1.5)	Median 0.0 (IQR1.5)	Median 3.3 (IQR2.6)	Median 1.8 (IQR2.3)
Statistic	Not significant. [U = 2375, $p > 0.126$, r = –0.09]		Not significant. [11 = 2521, $p > 0.286$, r = –0.05]		Significant. [U = 1965, $p < 0.003$, r = –0.23]	
Omission errors	Median 0.0 (IQR1.5)	Median 0.0 (IQR1.0)	Median 0.0 (IQR1.0)	Median 0.0 (IQR1.0)	Median 0.3 (SD1.3)	Median 0.0 (SD0.8)
Statistic	Significant. [U = 2084, $p < 0.010$, r = –0.19]		Not significant. [U = 2554, $p > 0.329$, r = –0.04]		Not significant. [U = 2457, $p < 0.207$, r = –0.07]	

ADHD = Attention Deficit Hyperactivity Disorder; SD = standard deviation; IQR = inter-quartile range; [1]Alerting Index = Average of neutral and congruent data in the No cue condition - Average of neutral and congruent data in the Double cue condition; [2]Orienting Index = Average of neutral and congruent data in the Centre cue condition - Average of neutral and congruent data in the Spatial cue condition; [3]Conflict Index = Average of all cue data in the Incongruent condition -Average of all cue data in the Congruent condition.

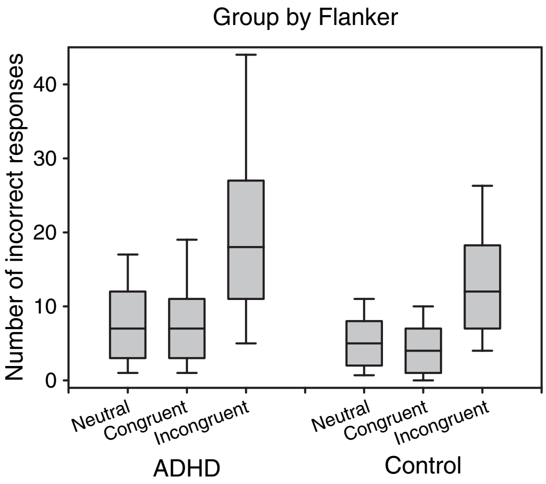

Figure 4 A box plot of number of incorrect responses made by the ADHD and Control groups in response to each flanker type of the ANT. The median is illustrated as the line bisecting the box. The top and bottom of the box represent the 75th and 25th percentiles respectively. The extended lines represent the 90th and 10th percentiles

presence of the congruent [U = 1912, $p < .001$, $r = -.24$], the incongruent [U = 1833, $p < .001$, $r = -.27$] and the neutral flankers [U = 1920, $p < .002$, $r = -.24$].

Any difference in the number of incorrect responses made between the three flanker types was analysed using Friedman's ANOVA, for each group separately. For both the ADHD [χ^2 (2) = 83.317, $p < .001$] and control groups [χ^2 (2) = 74.898, $p < .001$] there was a significant difference in the number of incorrect responses made between the three flanker conditions. Wilcoxon's signed-rank test with the Bonferroni adjustment for Type I error was used for post-hoc comparisons. For the ADHD group, significantly fewer incorrect responses were made in the congruent [T = 36, $p < .001$, $r = -.84$] and neutral [T = 57, $p < .001$, $r = -.83$] conditions compared with the incongruent condition. There was no significant difference in the number of incorrect responses made between the congruent and neutral conditions [T = 764, $p > .096$, $r = -.15$]. For the Control group, significantly less incorrect responses were made in the congruent [T = 40, $p < .001$, $r = -.82$] and neutral [T = 45, $p < .001$, $r = -.81$] conditions compared with the incongruent condition. Significantly more incorrect responses were made in the neutral condition compared with the congruent condition [T = 638, $p < .008$, $r = -.28$]. The ADHD group was less able to utilise the provision of the congruent cues to aid the response decision, compared with the control group.

Incorrect responses – Alerting, Orienting and Conflict Indices

There was no significant difference between the two groups for the Alerting and Orienting indices (see Table 2). The ADHD group, however, made significantly more incorrect errors in the presence of the incongruent compared with the congruent flankers than the control group, as indicated by the significantly higher *conflict* index ($r = -.23$ small to medium effect size).

Omission errors – ANT main analysis

Subsequent to inspecting the data, a focused Group comparison for each Cue type was conducted and analysed using the Mann–Whitney test (see Figure 5). The more alerting the cue type, the fewer omission errors the ADHD group appeared to make. The ADHD group [median (inter-quartile range): no cue 5.0 (6.5); centre cue 4.0 (6.0)] made significantly more omission errors than the Control group [no cue 2.0 (4.0); centre cue 2.0 (4.5)] in both the no- [U = 1979, $p < .003$, $r = -.22$] and centre-cue [U = 1943, $p < .002$, $r = -.24$] conditions. For the more alerting Cue types, the difference between the ADHD and control groups was not as apparent. There was no significant difference between the number of omission errors made by the ADHD [3.0 (4.0)] compared with the Control group [3.0 (4.5)] for the double-cue [U = 2523, $p < .288$, $r = -.05$] condition. The ADHD group [(4.0 (5.0)] made significantly more omission errors in the spatial-cue [U = 2227, $p < .042$ (one-tailed), $r = -.14$] condition than the control group [(3.0 (5.5)], although this was not a strong finding.

Any difference in the number of omission errors made between the four cue conditions was analysed using Friedman's ANOVA, for each group separately. There was a significant difference in the number of omission errors made over the four cue types for the ADHD [χ^2 (3) = 13.199, $p < .004$], but not for the control group [χ^2 (3) = 5.255, $p > .154$]. Wilcoxon's

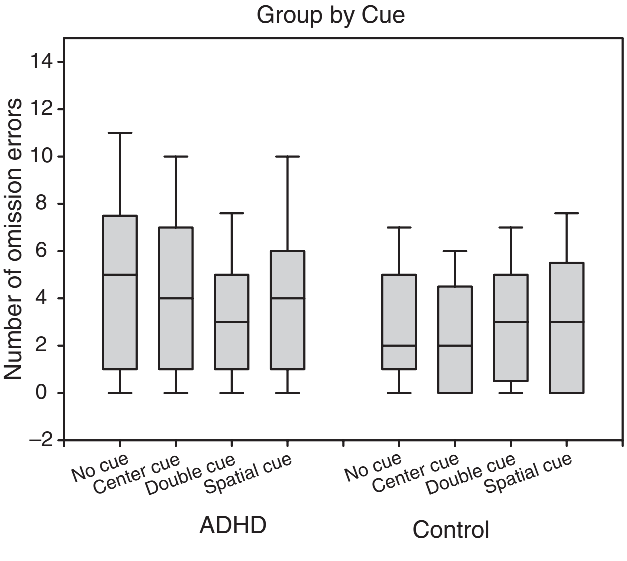

Figure 5 A box plot of number of omission errors made by the ADHD and Control groups in response to each cue type of the ANT

signed-rank test with the Bonferroni adjustment for Type I error was used for post-hoc comparisons. For the ADHD group, significantly less omission errors were made in the double compared with the no- [T = 372, $p < .001$, $r = -.46$] and centre-cue [T = 487, $p < .001$, $r = -.37$] conditions. In addition, there was a strong trend for a significant difference between the spatial- and double-cue conditions [T = 546, $p < .012$, $r = -.37$]; this failed to reach the Bonferroni-adjusted alpha level of .008. The no-centre cue [T = 590, $p < .093$, $r = -.16$], no-spatial cue [T = 595, $p < .032$, $r = -.22$] and centre-spatial cue [T = 644, $p < .146$, $r = -.12$] comparisons were not significant. This result demonstrates that the double-cue can rescue the attention deficit of the ADHD children, presumably via a phasic increase in alertness.

Omission errors – Alerting, Orienting and Conflict Indices

There was a significant difference between the two groups for the Alerting index (see Table 2). The difference in the number of omission errors made in the no- compared with the double-cue condition was significantly greater for the ADHD than for the control group, as indicated by the significantly higher *alerting* index ($r = -.19$ small effect size). There was no Group significant difference for the orienting and conflict indices.

Discussion

Performance on the ANT differentiated children with and without ADHD. The ADHD group demonstrated poor functioning of the conflict network: this group was slower and more error prone when resolving the conflict engendered by incongruent flanker stimuli. This group showed deficits in the alerting network, as evidenced by the elevated omission error rate in the no-cue condition. The provision of the more alerting cues, the double cue in particular, resulted in a relative decrease in omission errors made by the ADHD group; this did not occur with the control children. There was no evidence, however, of a deficit in the orienting network in ADHD as measured by the ANT. These results from the ANT suggest that children with ADHD have deficits in the alerting and conflict networks but intact spatial orienting on this task.

Tasks that engender response conflict, such as the Eriksen Flanker Task, reliably activate a network of brain areas including the anterior cingulate and right dorsolateral prefrontal cortex (DLPFC) – the *conflict network* (see (Bush, Valera, & Seidman, 2005) for a review). The slower and less accurate performance of the ADHD group on incongruent trials of the ANT may reflect dysfunction within this conflict system or indeed dysfunction in a more general action monitoring system (Roelofs, van Turennout, & Coles, 2006). Although the broader literature on interference control in Stroop-type tasks in ADHD is equivocal with respect to whether deficits in inhibiting the incongruent stimuli are evident or not (van Mourik, Oosterlaan, & Sergeant, 2005), some previous behavioural studies have shown poor performance of children with ADHD on flanker interference tasks (Jonkman et al., 1999; Scheres et al., 2004). Previous imaging studies have demonstrated reduced size and functional activation of the anterior cingulate and the DLPFC in children and adults with ADHD, compared with controls (see Seidman, Valera, & Makris, 2005; van Veen & Carter, 2002, for reviews). The slower and less accurate performance of the ADHD group on the ANT in this study suggests dysfunctional activity of the conflict network.

The ANT provides a measure of the putative *alerting* network. Posner and colleagues (Posner & Peterson, 1990) reported that patients with frontal lesions were slow to initiate responses when a target stimulus was not preceded by a warning cue, relative to when this cue was present. These findings indicate a problem with the 'tonic' or internal aspects of alertness but an intact ability to use cues to 'phasically' improve performance. Tonic levels of alertness are thought to be modulated by noradrenaline and difficulties with alertness might arise due to deficient fronto-parietal control over the locus coeruleus (see Halperin & Schulz, 2006, for review). The number of omission errors made by the ADHD group was significantly reduced in the presence of the double- compared with the no- and centre-cue conditions, suggesting that attention in ADHD can be phasically activated. These data may also be consistent with current theories of ADHD which emphasise a problem of arousal regulation (Andreou et al., 2007; Johnson et al., 2007; Wiersema, van der Meere, Roeyers, Van Coster, & Baeyens, 2006): children with ADHD may find it more difficult to regulate their arousal in the absence of an alerting cue than when this is present. For the no- and centre-cue conditions, the ADHD group made significantly greater omission errors than the controls. The spatial-cue condition comprises a single cue above or below fixation and therefore is less alerting than the double-cue condition, which cues attention simultaneously above and below fixation. The children with ADHD made fewer omission errors in the spatial-cue condition: error rates fell between the highly alerting double-cue condition and the less alerting no- and centre- cue conditions. The reduction in omission errors in the presence of the double cue, combined with a heightened error rate in the no-cue condition, resulted in a significantly higher *alerting index* for the ADHD group, compared with the control group. Control children, on the other hand, showed little difference in their omission error rates as a function of cue type. These data may indicate that children with ADHD have a basic problem with alertness. This behavioural profile in ADHD implies dysfunction within the fronto-parietal-thalamic network, which is required to maintain sensitivity to incoming stimuli (Posner et al., 2006). Structural and functional deficits in both prefrontal and parietal cortex have been reported in ADHD (R. Booth et al., 2005; Silk et al., 2005) and there is evidence of cortical hypo-arousal in ADHD (Lazzaro et al., 1999; Lou, Henriksen, Bruhn, Borner, & Neilsen, 1989; Rowe et al., 2005). As in this current study, Konrad and colleagues found no behavioural effect of ADHD on the alerting network using mean RT as the behavioural measure. They did report, however, hyper-activation in the vicinity of the locus coeruleus and hypo-activation in the right anterior cingulate cortex, potentially consistent with noradrenergic dysregulation in ADHD (Konrad et al., 2006). The RT measure may be less sensitive than errors of omission to dysfunction within the alerting network.

For the *orienting* network, no group difference was found on any of the dependent measures; this replicates studies by other researchers using the ANT (J. Booth, Carlson, & Tucker, 2007; Konrad et al., 2006; Oberlin, Alford, & Marrocco, 2005) and other covert visuo-spatial attention tasks (see Huang-Pollock & Nigg, 2003, for a review). Konrad and colleagues found increased activation in the fronto-striatal circuitry in children with ADHD during re-orienting, suggesting that alternative areas may have compensated for potential dysfunction (Konrad et al., 2006). Other neuropsychological and neurophysiological studies have shown impaired attentional orienting in ADHD (e.g., Brandeis et al., 2002). It should also be noted, however, that the ANT does not include invalidly cued trials that are required to assess the re-orienting of attention. Some studies have noted deficits in this process in ADHD (e.g., Swanson et al., 1991).

With a relatively large sample size, the effect sizes found in this study for group differences in the conflict (mean RT Cohen's $d = .38$, incorrect responses $r = -.23$) and the alerting (omission errors $r = -.19$) network indices were small to medium. This suggests that the attentional deficits of the ADHD group are modest, in keeping with previous reports (Huang-Pollock & Nigg, 2003). Nevertheless, given the well-elaborated cognitive-neuroanatomical models of attention, the results of the present study provide important insights into the potential neural substrates of cognitive deficit in ADHD. Although the ADHD group was significantly more variable than the control group in terms of the SD of RT measure, this measure provided poor sensitivity to the ANT manipulations, especially that of the cue. This may suggest that variability is a sensitive marker of general cognitive dysfunction in ADHD, potentially linked to underlying arousal, but is less sensitive to dysfunction within discrete cognitive systems.

In summary, the performance of this large group of children with and without ADHD on the ANT provides evidence of deficits within the alerting and conflict networks in ADHD, but intact orienting. The heightened level of omission errors in the no- and centre-cue conditions in the ADHD group, but rescue of this impairment in the double- and spatial-cue conditions, suggests a basic problem of intrinsic alertness that can be remediated by phasic alerts.

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