Assessing Attentional Systems in Children with Attention Deficit Hyperactivity Disorder

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Abstract

The aim of this study was to evaluate the efficiency and interactions of attentional systems in children with Attention Deficit Hyperactivity Disorder (ADHD) by considering the effects of reinforcement and auditory warning on each component of attention. Thirty-six drug-naïve children (18 children with ADHD/18 typically developing children) performed two revised versions of the Attentional Network Test, which assess the efficiency of alerting, orienting, and executive systems. In feedback trials, children received feedback about their accuracy, whereas in the no-feedback trials, feedback was not given. In both conditions, children with ADHD performed more slowly than did typically developing children. They also showed impairments in the ability to disengage attention and in executive functioning, which improved when alertness was increased by administering the auditory warning. The performance of the attentional networks appeared to be modulated by the absence or the presence of reinforcement. We suggest that the observed executive system deficit in children with ADHD could depend on their low level of arousal rather than being an independent disorder.

Keywords: Attention Deficit Hyperactivity Disorder (ADHD); Alerting; Attentional orienting; Executive function; Feedback, Attentional Network Test

Introduction

Attention Deficit Hyperactivity Disorder

Attention Deficit Hyperactivity Disorder (ADHD) is the most common neurodevelopmental disorder in children (Goldman, Genel, Bezman, & Slanetz, 1998; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007), and it is characterized by inattentiveness, over-activity and impulsiveness (APA, 2000). Inattention is the most commonly studied symptom of ADHD, but it is not clearly defined. Although the diagnosis of ADHD implies attentional deficits, attention is not formally defined in cognitive terms by the diagnostic criteria of the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV). It is not clear which specific attentional ability is reduced in ADHD. In the absence of this information, it is difficult to understand the core attentional deficit of ADHD and to implement a specific attention rehabilitation treatment for ADHD patients.

Attentional Systems

Neuropsychologists consider attention to be a multidimensional ability (Corbetta, Pathel, & Shulman, 2008; Fan, Flombaum, & McCandliss, 2003; Posner & Petersen, 1990; Raz, 2004; Thiel, Zilles, & Fink, 2004) that can be thought of as an organic system (Posner & Fan, 2008). According to the model by Posner and Petersen (1990), attention involves
three specialized neural networks and neuromodulators that serve different attentional functions: (1) alerting—defined as achieving (phasic alerting) and maintaining (tonic alertness or vigilance) a general state of activation of the cognitive system, (2) orienting—defined as selectively allocating the attentional focus to a potentially relevant area of the visual field, and (3) executive control—defined as the ability to control our own behavior to achieve intended goals and resolve conflict among alternative responses.

To independently test the efficiency of the three networks by means of a single task, Fan, McCandliss, Sommer, Raz, and Posner (2002) have created the Attention Network Test (ANT). The ANT combines the Covert Orienting Task (Posner, 1980) and the Flanker Task (Eriksen & Eriksen, 1974), allowing the concomitant assessment of the efficiency of each attentional system, as well as their interactions.

**Why Use the ANT to Assess Attention Deficits?**

The distributed model of attention (Posner & Petersen, 1990) and the ANT (Fan et al., 2002, 2009) are appealing for the study of ADHD disorder for several reasons. First, the study of each of the three attentional systems is potentially relevant to understanding the core mechanism of attention dysfunctions in children with ADHD. As previously mentioned, the primary symptoms of ADHD involve inattention, but this disorder is not defined in terms of specific cognitive deficits. This task will not only enable us to indicate the specific attentional impaired systems in ADHD, but also allow us to understand how they interact and influence each other. Second, there is a well-defined correspondence between behavioral measurements and neural networks of attentional processes in this model. The model developed by Posner and Peterson allows for the identification of the neuroanatomical networks that are involved in ADHD attentional disorders, whereas the ANT provides the outcome measures for the efficiency of the networks performing alerting, orienting, and executive (conflict resolution) functions of attention (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005). Third, ANT allows us to evaluate the interaction among these attentional systems (Callejas, Lupianez, Funes, & Tudela, 2005; Callejas, Lupianez, & Tudela, 2004; Fan et al., 2009; Fuentes & Campoy, 2008; Martella et al., 2011) and to show how they influence each other.

**Attention Deficits in ADHD**

Previous studies have reported deficits in tonic (Bellgrove, Hawi, Kirley, Gill, & Robertson, 2005; Johnson et al., 2007) and phasic alertness (O’Connell, Bellgrove, Dockree, & Robertson, 2006) in children with ADHD. A meta-analysis on studies evaluating orienting by means of covert visuospatial attention tasks in ADHD (Huang-Pollock & Nigg, 2003) concluded that ADHD is not characterized by significant visual orienting dysfunctions. However, several studies (e.g., Jonkman, Kenner, & Verbaten, 1999; Jonkman, Van Melis, Kenner, & Markus, 2007; Lansberger, Kenemans, & Van Engeland, 2007; Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007; Ridderinkhof, Scheres, Oosterlaan, & Sergeant, 2005; Shalev & Tsal, 2003) have reported impairments in executive control in children with ADHD.

These findings were obtained by assessing each attentional system independently. As a result, they fail to address what happens when all three attentional systems work together or how these systems interact.

**Assessment of Attentional Systems in ADHD by means of the ANT**

Studies using the original ANT (Fan et al., 2002) or a version of the ANT designed for assessments in children (Rueda et al., 2004) have reported inconsistent results for children and adults with ADHD (Table 1).

The first study using the ANT evaluated adults with ADHD by comparing primarily inattentive (ADHD/I) and combined inattentive/hyperactive (ADHD/C) participants with controls (Oberlin, Alford, & Marrocco, 2005). The results showed that orienting, alerting, and conflict effects in both subtypes were not significantly different from controls. However, ADHD/C but not ADHD/I participants had slower reaction times (RTs) to no spatial cues. These negative findings can be explained by some limitations of the study. The first, emphasized by the authors, relates to the ADHD diagnosis, which was based on retrospective information and confirmed using the DSM-IV scale. More importantly, these results could be secondary to some experimental parameters employed by the original version of the ANT (Fan et al., 2002). In fact, the original ANT does not allow for the separate estimation of the orienting and alerting systems (i.e., the same visual cues were used to assess both systems; Callejas et al., 2004, 2005; Fuentes & Campoy, 2008). Furthermore, it included only valid trials, which allows for the estimation of the attentional benefits but not of the costs due to the reorienting process, an effect that can only be assessed by introducing invalid cues (Posner, 1980). Other studies (Adolfsdottir, Sorensen, & Lundervold, 2008; Booth, Carlson, & Tucker, 2007) using the child-oriented version of the ANT (characterized by the same experimental features as the original ANT; Rueda et al., 2004) also found no impairment in the attentional systems in children with ADHD.
Table 1. All the studies that have used the ANT in order to compare attentional systems in children with ADHD and TDC

<table>
<thead>
<tr>
<th>Authors</th>
<th>ANT typo/logy</th>
<th>Participants</th>
<th>ADHD medication</th>
<th>Participants’ age</th>
<th>Differences between children with ADHD and TDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Accuracy</td>
</tr>
<tr>
<td>Oberlin and colleagues</td>
<td>Revised OV</td>
<td>30 ADHD†, 33 Controls</td>
<td>25 off medication (M) 14 on M‡</td>
<td>18–30 y</td>
<td>TDC = ADHD</td>
</tr>
<tr>
<td>(2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Konrad and colleagues</td>
<td>Lateralized</td>
<td>16 ADHD, 16 TDC</td>
<td>No</td>
<td>8–12 y</td>
<td>TDC &gt; ADHD</td>
</tr>
<tr>
<td>(2006)</td>
<td>ANT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Booth and colleagues</td>
<td>CV</td>
<td>42 ADHD, 24 TDC</td>
<td>13 No, 29 No for 18 h or more</td>
<td>7–13 y</td>
<td>TDC &gt; ADHD</td>
</tr>
<tr>
<td>(2007)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lampe and colleagues</td>
<td>OV</td>
<td>22 ADHD, 20 ADHD + BPD, 21 BPD, 20 Controls</td>
<td>No for 4 weeks or more</td>
<td>18–45 y</td>
<td>—</td>
</tr>
<tr>
<td>(2007)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Adólfsdóttir and colleagues</td>
<td>CV</td>
<td>45 ADHD, 121 TDC</td>
<td>9 No, 36 Yes</td>
<td>7.9–11.9 y</td>
<td>TDC &gt; ADHD</td>
</tr>
<tr>
<td>(2008)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johnson and colleagues</td>
<td>OV</td>
<td>73 ADHD, 73 TDC</td>
<td>No for 24 h or more</td>
<td>Mean = 12.9 y</td>
<td>TDC &gt; ADHD</td>
</tr>
<tr>
<td>(2008)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gupta and Kar</td>
<td>CV</td>
<td>120 ADHD, 120 TDC</td>
<td>—</td>
<td>6–9 y</td>
<td>TDC &lt; ADHD</td>
</tr>
<tr>
<td>(2009)</td>
<td>Revised OV</td>
<td>26 ADHD-C, 22-ADHD-I, 45 TDC</td>
<td>42 Yes, 27 No for 42 h or more</td>
<td>6–12 y</td>
<td>—</td>
</tr>
<tr>
<td>Mullane and colleagues</td>
<td>Revised later-</td>
<td>15 Low ADHD (LA) scores, 21 High ADHD (HA) scores§</td>
<td>—</td>
<td>18–33 y</td>
<td>LA = HA</td>
</tr>
<tr>
<td>(2010)</td>
<td>alized ANT†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poynter and colleagues</td>
<td>Revised later-</td>
<td>15 Low ADHD (LA) scores, 21 High ADHD (HA) scores§</td>
<td>—</td>
<td>18–33 y</td>
<td>LA = HA</td>
</tr>
<tr>
<td>(2010)</td>
<td>alized ANT†</td>
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</table>

Notes: ANT = Attention Network Test; ADHD = Attention Deficit Hyperactivity Disorder; RT = reaction time; TDC = typically developing children; BPD = borderline personality disorder; OV = original version of the ANT (Fan et al., 2002); CV = children version of the ANT (Rueda et al., 2004); LA = low ADHD scores; HA = high ADHD scores; Y = years; Alerting effect = RT warning present trials – RT warning absent trials; Orienting effect = RT valid trials – RT Invalid trials; Conflict effect = RT incongruent trials – RT congruent trials.

*Including additional visual distractions.

bADHD diagnosis was made by family physician prior to the age of 8.

cNine participants with ADHD did the task both on and off medication.

dIncluding 20% trials with an invalid cue.

eThe ANT included 50% of Flanker Task trials and 50% of Simon Task trials; furthermore, it included 50% of Invalid Trials and 50% of trials with Auditory Tone.

fGreene and colleagues (2008).

gScores on the attention/memory subscale of the Conners’ Adult ADHD Rating scales.
However, Booth and colleagues (2007) found stronger alerting effects in children with ADHD/I than in both children with ADHD/C and control children.

Taken together, these negative findings regarding orienting may support other results that indicate the presence of a preserved orienting network in ADHD (Berger & Posner, 2000; see also Huang-Pollock & Nigg, 2003). However, these results may also be due to the inability to estimate the attentional costs of the reorienting process. The absence of invalid cues might also make the task too easy for an efficient evaluation of the executive system. These experimental features could explain the null results with regard to conflict found by many authors (Adólfsdóttir et al., 2008; Booth et al., 2007; Oberlin et al., 2005). It is notable that Konrad, Neufang, and Hanisch (2006) found a dysfunction in the executive system only when invalid trials (20%) were introduced. Additionally, impairments in conflict resolution were found in children with ADHD when the ANT was made more difficult by introducing additional distractions (Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2010). However, an impaired performance in the executive system of children with ADHD was also detected using the original version (Johnson et al., 2008) and a child-oriented version (Gupta & Kar, 2009) of the ANT. It is not easy to provide a cohesive explanation for these inconsistent findings. One possibility is that the use of ADHD medication could be responsible for many of the inconsistencies. Gupta and Kar (2009) did not report information regarding the drug treatment of the tested children with ADHD, whereas in the work of Johnson and colleagues (2008), any stimulant medication was withdrawn for at least 24 h prior to testing. Among the various studies using the ANT (Table 1), only Konrad and colleagues (2006) included children without a prior history of stimulant treatment. In light of these findings, it is important to emphasize that our participants were drug naïve, and this could highlight the attentional condition in ADHD and partially explain the contrasting results present in the literature.

Nevertheless, drug treatment could not be the only factor affecting these contrasting results. Certainly, other confounding variables should be considered, such as co-morbid disorders, ADHD subtypes, age, and IQ. Finally, although many inconsistent behavioral results have been reported, functional Magnetic Resonance Imaging (fMRI) findings suggest a hypo-activation of specific brain regions in children with ADHD during alerting, conflict, and re-orienting performance (Konrad et al., 2006).

Aims and Hypotheses of this Study

In the current study, we aim to evaluate two revised versions of Rueda’s ANT. In these experiments, we manipulated alertness and motivation. Alertness was manipulated by introducing an auditory tone (warning) in 25% of the trials. To evaluate the orienting system, both spatial and central cues were replaced by peripheral non-predictive cues (50% valid and 50% invalid trials). In Rueda’s version of the ANT, the presence of feedback in every trial does not allow for the evaluation of whether individual attentional systems (specifically the executive system) are affected by motivational aspects. Thus, we manipulated the effect of motivation by introducing feedback in one task (feedback trials), but not in the other (no-feedback trials). The manipulation of feedback could allow us to evaluate the impact of reinforcement on attentional systems in children with ADHD. This issue is very relevant. A recent review (Luman, Oosterlaan, & Sergeant, 2005) indicates that reinforcement contingencies have a positive impact on task performance and levels of motivation in both children with ADHD and typically developing children, and this effect is more prominent in children with ADHD. However, it is important to note that other reports suggest that the performance of both children with ADHD and typically developing children on go/no-go tasks are not enhanced by feedback (e.g., Wodka et al., 2007). The feedback manipulation could explain these inconsistent results.

This study was conducted to test the attentional deficits in children with ADHD and to assess how the attentional systems interact with each other when compared with typically developing children. Based on previous behavioral, anatomical, and functional imaging evidence, we predicted that children with ADHD would show an overall performance impairment (i.e., longer mean RT and poorer accuracy) compared with children with normal development. Specifically, children with ADHD should show a deficit in the alerting network, as reported by longer mean RT, and this effect should be especially prominent under the no-warning condition.

Second, we hypothesized that the auditory warning should speed up RT in all children by increasing phasic alertness (Callejas et al., 2004, 2005), and children with ADHD should benefit more from the alerting effect due to their alertness disorder (O’Connell et al., 2006). It is important to note that this warning manipulation could create a situation where children with ADHD and typically developing children have a similar alerting level. If alerting is solely responsible for the reduced performance in children with ADHD, the presence of a warning should improve the overall ADHD performance, particularly for orienting (Callejas et al., 2004, 2005).

Our third hypothesis deals with the conflict network, as denoted by a longer mean RT in an incongruent flanker condition compared with a congruent flanker condition. Based on the above assumptions, this network should be impaired in children with ADHD, especially in the no-warning condition. In fact, if we argue that the executive dysfunctions in children with ADHD depend on their lowered alertness, then the increase in alerting produced by the warning should improve their executive
performances. In normal adults, an alerting condition interferes with a conflict solution (Fan et al., 2009); thus, typically developing children should be delayed in responding to incongruent flankers in the warning condition.

We also hypothesize that children with ADHD should not show a deficit in the orienting network, as observed by previous studies (Huang-Pollock & Nigg, 2003).

Finally, reinforcement contingencies (the presence of feedback) should have a positive impact on task performance and motivation for both children with ADHD and typically developing children, but this effect should be more prominent in children with ADHD (Luman et al., 2005).

In conclusion, this work aims to assess the functioning of attentional systems and their interactions in children with ADHD. To the best of our knowledge, this is the first study designed to clearly delineate the specific attentional deficits in drug-naive children with ADHD and to assess whether motivation and alerting could modulate the efficiency of the other attentional systems in this attentional disorder.

Methods

Participants

Thirty-six children participated in the study: 18 were diagnosed as ADHD (17 men/1 woman [should be noted that the gender ratio does not reflect that typical of ADHD; however, the male/female ratio referring to larger samples of children with ADHD is not necessarily the same when considering such a small group]), and 18 were typically developing children (17 men/1 woman). All children with ADHD were drug-naive patients first admitted to the Day Hospital of the Child Psychiatry Unit of the University of Rome “Tor Vergata.” Children included in this study did not have a prior history of stimulant treatment. A psychopathological evaluation was performed by a team of child psychiatrists by means of the Kiddie Schedule of Affective Disorders (K-SADS; Kaufman, Birmaher, Brent, Rao, & Ryan, 1996), the Conners’ Parent Rating Scale, the Conners’ Teacher Rating Scale (Conners, 1989), the Children Depression Inventory (Kovacs, 1985), and the Multidimensional Anxiety Scale for Children (March, 1997). The inclusion criteria for this study were the diagnosis of ADHD (based on the DSM-IV criteria and confirmed by K-SADS and by both Parents and Teachers Conners scores), no history of mental retardation, brain trauma, neurological diseases, or physical impairment, a lack of co-morbid mental disorders with the exception of oppositional defiant disorder (ODD), and no learning disabilities.

Control group participants were gender- and age-matched with the ADHD group and taken from a wider group of 50 children recruited from two public schools in Rome. The children in the control group had no history of cerebral injury or other neurological or psychiatric disorders.

Table 2. Participant demographic and descriptive characteristics

<table>
<thead>
<tr>
<th></th>
<th>Children with ADHD</th>
<th>Typically developing children</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>10.1 (± 1.7)</td>
<td>10 (± 1.2)</td>
<td>0.11</td>
<td>.74</td>
</tr>
<tr>
<td>PCM- and PSM-correct responses</td>
<td>35.2 (± 8.9)</td>
<td>35.4 (± 4.3)</td>
<td>0.01</td>
<td>.92</td>
</tr>
<tr>
<td>Number of children with ADHD-I</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of children with ADHD-C</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parents Inattention Conners scores</td>
<td>64.6 (± 9.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parents Hyperactivity Conners scores</td>
<td>63.3 (± 10.6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parents ADHD index</td>
<td>64.6 (± 9.4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers Inattention Conners scores</td>
<td>69.4 (± 12.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers Hyperactivity Conners scores</td>
<td>71.7 (± 11.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teachers ADHD index</td>
<td>74.2 (± 13.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD/I: number of inattention symptoms</td>
<td>6.3 (± 1.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD/I: number of hyperactivity symptoms</td>
<td>3.5 (± 0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD/I: number of impulsivity symptoms</td>
<td>1.5 (± 0.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD/C: number of inattention symptoms</td>
<td>4.5 (± 2.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD/C: number of hyperactivity symptoms</td>
<td>4.8 (± 1.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADHD/C: number of impulsivity symptoms</td>
<td>2.5 (± 0.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oppositional defiant disorder</td>
<td>2</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct disorder</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning disabilities</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depression/Anxiety disorders</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: ADHD = Attention Deficit Hyperactivity Disorder; PCM = Progressive Colored Matrices; PSM = Progressive Standard Matrices; ADHD/I = children showing prevalently inattentive symptoms (APA, 2000); ADHD/C = children showing inattentiveness and hyperactivity/impulsiveness symptoms (APA, 2000).
All children age 11 and older had a full-scale IQ that fell above the 75th percentile on the Progressive Colored Matrices (Raven, Court, & Raven, 1990; Raven, Raven, & Court, 1993), and all children age 10.5 or younger had an IQ > 80 on the Progressive Standard Matrices (Raven et al., 1990, 1993). The presence of ADHD in control children was assessed via an independent evaluation by the teacher and one parent who completed a DSM-IV-TR report card (APA, 2000). Any child with a possible indication of ADHD was not considered. The mean age and IQ scores of the two groups did not significantly differ. The demographic data of the sample are reported in Table 2. The procedure used in this study was approved by the Child Psychiatry and Neurology Institute Ethical Committee, and written informed consent was given by all of the parents or legal guardians of the participants included in the study prior to the testing.

**Apparatus**

The stimuli were presented using E-Prime software on a Pentium 4 PC and were displayed on a 21-inch color VGA monitor from a viewing distance of approximately 56 cm (with a headrest). Responses were collected via a mouse, and a headphone was used to administer the acoustic stimuli.

**Feedback Trials**

**Stimuli.** For an extensive and detailed description of both the stimuli and the procedure, see Rueda and colleagues (2004). Each trial began with the presentation of a central cross (visual angle of 1°). The target was a left- or right-pointing yellow fish (1.6°) presented at the center of the screen. The fish was presented either alone (baseline trials) or flanked on both sides by two yellow fish pointing either in the same direction (congruent trials) or in the opposite direction (incongruent trials). The distance between the fish was 0.21°. The target and flankers subtended 8.84° and were presented at 1° above or below the fixation point over a blue–green background. The cue was an asterisk of 1° presented for 150 ms, and it could be presented at the position of the upcoming target (valid cue condition), in the opposite location (invalid cue condition), or above and below the fixation cross (double cue condition), or it could be absent (no-cue condition). Fig. 1 shows a schematic of the cue and the flanker conditions.

The auditory and visual feedback was an animation showing the target fish blowing bubbles and exclaiming “Woohoo!” when a correct response was given. Incorrect responses were followed by a single tone and no animation of the fish. The auditory warning stimulus was 2000 Hz and lasted 50 ms.

**Procedure.** Subjects were tested individually in a silent and dimly illuminated room. Each trial began with a fixation period of variable duration (400–1600 ms). This was followed by a warning stimulus lasting 50 ms in 25% of the trials. Next, a cue of

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**Fig. 1.** Schematic representation of both flanker and cue conditions. At the top of the figure, the stimulus target is represented by the fish in the central position. It must be emphasized that the figure provides a simplified version of the stimuli; in fact, the same stimuli of Rueda and colleagues (2004) were used in the present experiment.
150 ms was presented. After a fixation period of 450 ms, the target was presented until the participant responded with a limit of 1700 ms. Both the auditory and the visual feedback were given following correct responses, and only the auditory feedback was given following incorrect responses.

The fixation point was at the center of the screen throughout the trial. The sequence of the events for each trial is shown in Fig. 2.

The central fish was flanked by two fish on each side, which were pointing in either the same direction (congruent condition) or the opposite direction (incongruent condition) as the central fish. The difference between these two conditions is thought to be an index of executive control. This so-called “conflict effect” is calculated by subtracting the mean RT of the congruent flanking conditions from the mean RT of incongruent flanking conditions. The two conditions differ only in the information given by the flankers. When the images are congruent, they provide a facilitating effect on the discrimination of the target stimulus, whereas incongruent flankers distract participants. Visual cues are used to separately assess the alerting (improved performance following a double cue) and orienting (an additional benefit when the cue correctly indicates the target location, i.e., a valid vs. invalid cue) attentional functions. The validity effect is calculated by subtracting the mean RT of the valid cue conditions from the mean RT of the invalid conditions. Both invalid and valid cues alert the participant to the forthcoming appearance of the target, but only the valid cue provides spatial information, which allows subjects to orient their attention.
to the appropriate spatial location. Therefore, the RT difference between valid and invalid cues provides a measure of orienting attention (Fan et al., 2002, 2009). In the no-cue or double-cue conditions, attention tends to be diffused across the two potential target locations. Neither of these conditions provided spatial information about the target stimulus position, but the double-cue alerts the participant to the imminent appearance of the target. Therefore, the alerting effect is calculated by subtracting the mean RT of the double-cue conditions from the mean RT of the no-cue conditions. This represents the benefit of alerting on the speed of the response to the target.

After a 24-trial practice block, participants performed two experimental blocks of 240 trials: 24 valid, 24 invalid, 16 double-cue, and 16 no-cue trials for each flanker condition. The entire experiment comprised 480 trials. Children with ADHD executed the task in a silent room in the clinic, and the controls were tested in a room of their own school with the same experimental conditions.

Task. The task was to identify the direction of the centrally presented fish by clicking the right or the left button on the mouse. The instructions given were similar to those used by Rueda and colleagues (2004). Participants were told to pay attention to the central fish and to fixate on the cross in the center of the screen throughout the entire task. They were instructed to respond as quickly and accurately as possible.

The practice block took approximately 3 min, and each block was approximately 25 min. The entire session lasted approximately 60 min. The children could take a break at the end of the practice block and between the experimental blocks.

No-Feedback Trials

The participants, stimuli, and procedure were the same as those described for the feedback trials. The only difference was the absence of feedback. The administration of the two trial blocks was counterbalanced among participants, and they were performed on two different days.

Experimental design. According to a consolidated ANT analysis, only the RTs of correct responses ranging between 200 and 1400 ms were considered (Rueda et al., 2004). Because the RTs in the baseline and congruent flanker conditions did not differ \( (p = .73) \), the RTs from the baseline trials were disregarded for subsequent analyses. A Group (ADHD, Control) × Warning (Present, Absent) × Cue (Valid, Invalid, Double, No-cue) × Flanker (Congruent, Incongruent) mixed-design analysis of variance (ANOVA) was performed on both the mean RTs of the correct responses and mean errors. The warning present/absent conditions were used to evaluate the auditory alertness. Double and no-cue conditions assessed visual alertness. Valid and invalid trials evaluated orienting, and congruent and incongruent flanker trials provided a measure of executive functions.

To estimate the efficiency of each attentional system, thus enabling us to compare the results of this study with previous studies using the ANT (Callejas et al., 2004, 2005; Fan et al., 2002; Fuentes & Campoy, 2008), and to assess the effect of auditory alertness on the other two networks (orienting and executive), separate Group × Warning ANOVAs were performed on the “orienting effect” (RT invalid-cue − RT valid-cue) and the “conflict effect” (RT incongruent trials – RT congruent trials). The orienting effect provides a measure of the orienting system, and the conflict effect is a measure of the executive control system.

Post hoc comparisons were conducted using either the least significant difference test (repeated measures) or the Duncan test (mixed measures).

An \( \alpha \)-value of 0.01 was used to establish statistical significance for all analyses.

Results

Feedback Trials

Reaction time analysis. Table 3 shows the mean RT (± SD) for each experimental condition. All main effects were significant (Table 4), with children with ADHD showing slower RTs compared with typically developing children. Children with ADHD had faster RT when the tone was present than when it was absent. The “Cue” effect revealed no difference between valid and invalid trials, but both conditions yielded faster RTs than the double-cue \( (p < .01) \) and no-cue \( (p < .0001) \) trials. RTs in the double-cue trials were faster than RTs in the no-cue trials \( (p < .00001) \). Finally, the incongruent trials yielded slower RTs compared with the congruent trials.

A “Group × Warning” interaction—\( F(1,34) = 10.84, p < .01, \) partial \( \eta^2 = 0.24 \) (Fig. 3)—demonstrated a slower RT in the absent warning condition (mean RT = 688.28 ms) than in the present warning condition (mean RT = 645.91 ms; \( p < .0001 \))
for children with ADHD only. For the control group, the absent (mean RT = 545.08 ms) and the present (mean RT = 540.26 ms) warning conditions were not different \((p = .55)\). None of the other interactions were significant \((F < 3)\).

To evaluate the orienting effect specifically, a “Group × Warning × Cue × Flanker” ANOVA was performed that included only the valid and the invalid trials as spatial cues. This analysis confirmed significant effects for Group—\(F(1,34) = 12.24, p < .001\), partial \(\eta^2 = 0.26\); Warning—\(F(1,34) = 19.31, p < .0001\), partial \(\eta^2 = 0.36\); Flanker—\(F(1,34) = 70.22, p < .000001\), partial \(\eta^2 = 0.67\); and Group × Warning—\(F(1,34) = 8.66, p < .01\), partial \(\eta^2 = 0.20\)—interactions. The Cue and all the other interactions were not significant \((F < 2)\).

The ANOVAs performed on the orienting and conflict effects did not reveal any significant effects or interactions \((F < 3)\).

### Accuracy analysis.

The effect of the Group—\(F(1,34) = 4.36, p < .05\), partial \(\eta^2 = 0.11\)—revealed a higher percentage of uncorrected responses in the children with ADHD \((mean = 8.51)\) when compared with typically developing children \((mean = 3.31)\), but this difference was only marginally significant. A significant Flanker effect—\(F(1,34) = 28.16, p < .00001\), partial \(\eta^2 = 0.45\)—revealed that there were less incorrect responses in the congruent \((mean = 4.28)\) than in the incongruent trials \((mean = 7.53)\). All other effects or interactions were not significant \((F < 2)\).

### No-Feedback Trials

#### Reaction time analysis.

Table 3 reports the means (±SD) for each experimental condition. All main effects were significant (Table 4), and children with ADHD showed slower RTs than controls and faster RTs when the tone was present than when it is not.

#### Accuracy analysis.

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was absent. The Cue effect revealed no difference between valid and invalid trials, but these trials were faster than both the double-cue ($p < .01$) and the no-cue ($p < .0001$) trials. The double-cue and the no-cue trials were also significantly different ($p < .0001$). Furthermore, the Flanker effect showed faster RTs in the congruent trials than in the incongruent trials. The Group $\times$ Warning $\times$ Flanker interaction—$F(1,34) = 4.29$, $p < .05$, partial $\eta^2 = 0.11$ (Fig. 4)—revealed that the presence of the warning reduced RT in children with ADHD only when they responded to incongruent flanker trials ($p < .001$). The Cue $\times$ Flanker interaction—$F(3,102) = 2.56$, $p = .06$, partial $\eta^2 = 0.07$—and all other interactions were not significant ($F < 2$).

When considering only valid and invalid trials, the results confirmed the effects observed for Group—$F(1,34) = 18.29$, $p < .0001$, partial $\eta^2 = 0.35$; Warning—$F(1,34) = 11.09$, $p < .01$, partial $\eta^2 = 0.25$; Flanker—$F(1,34) = 24.05$, $p < .0001$, partial $\eta^2 = 0.41$; and Group $\times$ Cue $\times$ Flanker—$F(1,34) = 4.96$, $p < .05$, partial $\eta^2 = 0.13$ (Fig. 5)—interactions. This analysis revealed that children with ADHD had slower RTs in the valid trials (mean RT = 637.51 ms) than in the invalid trials (mean RT = 606.50 ms; $p < .01$) in the congruent flanker condition only. The Cue effect ($F < 1$), the Cue $\times$ Flanker interaction, $F(1,34) = 3.93$, $p = .06$, partial $\eta^2 = 0.10$, and all the other interactions ($F < 3$) were not significant.

There was no significant effect or interaction for the orienting effect ($F < 2$).
With regard to the conflict effect, the Group × Warning interaction—\(F(1,34) = 4.29, p < .05\), partial \(\eta^2 = 0.11\) (Fig. 6)—revealed that children with ADHD had greater conflict than control in the absent warning condition (mean = 63.18) than in the present warning condition (mean = 31.24, \(p < .05\); Fig. 6).

Accuracy analysis. An effect of Cue—\(F(3,102) = 3.08, p < .05\), partial \(\eta^2 = 0.08\)—revealed a lower percentage of errors in the no-cue trials (mean = 8.56) than in all the other trial conditions (mean valid = 10.75, mean invalid = 10.14, mean double-cue = 10.26, \(p < .05\)), but this difference was only marginally significant. The Flanker effect—\(F(1,34) = 45.75, p < .0000001\), partial \(\eta^2 = 0.57\)—revealed more correct responses in the congruent (mean = 8.06) than in the incongruent trials (mean = 11.80). All of the other effects and interactions were not significant (\(F < 3\)).

Discussion

Attentional Systems in ADHD

The slower functioning and poorer performance of children with ADHD confirm the presence of relevant attentional deficits. Our results are consistent with the hypo-arousal hypothesis (Andreou et al., 2007; Johnson et al., 2007; Konrad et al., 2006). Nevertheless, the alerting property of the warning itself is effective for children with ADHD. In fact, the auditory warning specifically increases alertness (i.e., speeds up RT) in children with ADHD, but not in controls. Such results support the effectiveness of increasing alertness to contrast the sustained attention deficit of children with ADHD (Adólfsdóttir et al., 2008; Booth et al., 2007; Johnson et al., 2008).
However, it is remarkable that the increase in alertness induced by the presence of the warning was effective only when a feedback was present. In other words, this difference cannot be attributed to a general increase in alertness produced by the feedback. In fact, a statistical analysis performed to directly compare the two experiments (not reported) did not reveal any difference in RTs between the experiments or a Group × Experiment interaction ($F < 1$). We might conclude that the alerting effect of the auditory warning in children with ADHD is modulated by the presence of the feedback. In fact, a Group by Warning interaction was observed in the feedback trials only (Fig. 3). The role of reinforcement has been widely reviewed by comparing 1,181 children with ADHD and typically developing children (Luman et al., 2005). The authors concluded that reward and response cost have a positive effect on the task performance of both children with ADHD and typically developing children, but they also highlighted that the observed improvement was more prominent in children with ADHD than in typically developing children. Our results seem to be consistent with these conclusions, but our findings also indicated that reinforcement interacts with the alerting system. In fact, reinforcement increases alertness in children with ADHD when it is present, and it affects the other two attentional systems (orienting and executive), which are similar to normally developing children. This modulation of alertness by reinforcements could explain some inconsistent results present in literature (Luman et al., 2005; Wodka et al., 2007).

In the no-feedback trials, the warning improves RT in children with ADHD when they respond to incongruent flanker trials (Fig. 4). It should be noted that children with ADHD need only half the time to resolve an attentional conflict in the presence of the warning (present warning condition: $RT_{\text{incongruent}} - RT_{\text{congruent}} = 31.24$ ms) when compared with its absence (absent warning condition: $RT_{\text{incongruent}} - RT_{\text{congruent}} = 63.18$ ms; Fig. 6). This difference is specifically due to the capacity of the warning to reduce the RT in the incongruent condition. This result is of interest for at least two reasons. On the one hand, it suggests that an increase in alertness is able to help children with ADHD resolve attentional conflicts. On the other hand, it indicates that the warning is effective only for incongruent trials. This could suggest that children with ADHD do not have a general deficit in the executive system itself, but an executive deficit specifically related to the low level of alertness. We could argue that the executive impairment found in ADHD can directly depend on the low level of alertness, instead of being an autonomous deficit. Children with ADHD could have an alertness impairment that worsens their performance during a particularly difficult task (incongruent trials). This hypothesis also appears to be supported by the absence of a Group × Flanker interaction ($F < 1$). Alternatively, we can assume that the executive system in ADHD is preserved at high levels of alertness and impaired at low level of alertness. In fact, according to Sergeant’s hypothesis (Sergeant, 2000, 2005), the executive deficits of ADHD could, at least in part, be explained in terms of an energetic dysfunction.

These results could also explain some of the inconsistent results obtained for executive deficits in children with ADHD. It is important to highlight that all studies evaluating attentional systems using the ANT have not independently manipulated alertness (they have not introduced an auditory warning). Many methodological differences among these studies (Table 1) could have produced uncontrolled variations in alertness, which could partially explain some of these incoherent results.

Attentional conflict resolution in typically developing children tended to take more time in the presence of the warning (48.47 ms) than in the absence of the warning (41.07 ms; Fig. 6). This result is consistent with data observed in adults showing that an increase in alertness induces an interfering effect in conflict solution (Fan et al., 2009).

We did not observe faster RT in the orienting system when the spatial cue was valid compared with when it was invalid. Valid and invalid cues produced attentional benefits in both groups of children. Spatial cues improved alertness, but they have not been able to induce the orienting of attention (valid and invalid cues did not result in different RT). This result is inconsistent with other findings reporting slower RTs when children with ADHD responded to a valid or an invalid cue than to either neutral or no-cue conditions (Dhar, Been, Mindera, & Althaus, 2008; Huang-Pollock, Nigg, & Halperin, 2006; McDonald, Bennett, Chambers, & Castiello, 1999; for a review see Huang-Pollock & Nigg, 2003). However, our data are consistent with Pearson, Yaffee, Loveland, and Norton (1995), who attributed this effect to a decreased flexibility in children with ADHD in orienting attention on a diffuse area of the visual space. In agreement with Huang-Pollock and Nigg (2003), we conclude that children with ADHD could have difficulty in voluntarily spreading their attention across a large area of space (as required by double- or no-cue conditions) while awaiting the target to optimize the detection of a target at any location. The results of our study indicate that this difficulty is also present in typically developing children. We did not observe a validity effect (faster RTs in the valid compared with the invalid trials) in either children with ADHD or typically developing children. This result can be attributed to the type of stimulus onset asynchrony (SOA) used. In fact, Rueda’s SOA of 600 ms might induce a facilitation in some children, but an inhibition of return (IOR; slower RTs in valid trials compared with invalid trials) in others (Posner & Cohen, 1984). In accordance with this hypothesis, approximately half of the children showed faster RT when the cue was valid rather than invalid (validity effect), whereas the other half displayed an opposite pattern (IOR effect). Nevertheless, when children with ADHD responded to congruent flankers, an IOR effect was observed, suggesting an impairment in disengaging attention. This result confirms previous observations in children with ADHD performing a Covert Orienting task (Swanson et al., 1991; Wood, Maruff, Levy, Farrow, & Hay, 1999), and it seems to highlight
a difficulty in the endogenous method of orienting (for a review, see Huang-Pollock & Nigg, 2003). Endogenous orienting refers to a voluntary allocation of attentional resources to a spatial location, whereas exogenous orienting is considered reflexive and automatic (Jonides, 1981). It is well known that similar neural networks may mediate endogenous orienting and IOR (Mayer, Dorflinger, Rao, & Seidenbergd, 2004). Our results suggest that children with ADHD can have impairments in the voluntary allocation of visuospatial attention, as shown by their difficulty in disengaging attention from an invalid location, whereas automatic orienting to exogenous cues seems to be intact. It is not clear why this IOR effect is observed only in the congruent flanker condition.

The analysis of accuracy confirms a poorer performance in children with ADHD than in typically developing children. It also reveals a significant impairment when incongruent rather than congruent flankers are presented, highlighting a no trade-off accuracy effect. It is important to note that the percentage of errors was not high, but this could be due to the appealing graphic characteristics of the task.

Clinical Implications of Results

The results of this study seem to suggest that a balanced program that includes positive and negative reinforcements and simultaneously produces an increase in auditory alertness may be effective in improving the attention of children with ADHD. Further experiments are needed to decouple the clinical subtypes of ADHD and to determine the effectiveness of different programs of reinforcement. For example, is the random administration of reinforcement equally as effective as a continuous one? Which frequency of reinforcement is more effective? This could be investigated by realizing and assessing a behavioral reinforcement program aimed to promote an increase in alertness. Such a program should involve both parents and teachers.

It might be interesting to examine whether and to what extent a similar program is able to improve all attentional systems or alertness only in children with ADHD.

Conclusions

The two revised versions of ANT appear to effectively assess the efficiency of the three attentional systems, as all main effects were significant. They also highlight impairments in each attentional system for children with ADHD, albeit to a different degree. Alertness appears to be particularly impaired. However, deficits are also observed in the orienting and executive systems. All of the attentional networks seem to be modulated by feedback. In fact, in the feedback trials, no significant difference between ADHD and typically developing children was observed for the orienting or executive networks.

The improved performance in children with ADHD in the warning present condition suggests the effectiveness of increasing alertness in order to counteract the sustained attention deficit of children with ADHD.

Our results also confirm the utility of the ANT in evaluating all the attentional systems and their interactions at the same time. In fact, some specific deficits in children with ADHD with regard to conflict solution and orienting are evident only when analyzing the interactions among the attentional systems.

To the best of our knowledge, this is the first study to simultaneously assess the efficiency and interactions among the attentional systems in children with ADHD by independently manipulating the orienting, alerting, and executive systems. It is also important to note that our participants were drug-naïve children with no major co-morbid disorders except ODD. It should be also noted that only one other study has included drug-naïve children (Konrad et al., 2006). That study recorded the concomitant activation of the neural networks. However, from a behavioral point of view, it also introduced a bias by collecting the RT of children in an unusual condition (during the execution of an fMRI).

Our strong selection criteria for children with ADHD allow us to hypothesize that the observed results may effectively reflect the actual framework of attention in ADHD. On the other hand, this selection is also the source of the primary weakness in our study: the small number of participants. Future studies will address this limitation.

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Conflict of Interest

None declared.
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