Controlled Visuomotor Preparation Deficits in Attention-Deficit/Hyperactivity Disorder

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To the best of the authors’ knowledge, there are no published reports on visuomotor preparation in ADHD. This is unfortunate, because research suggests that ADHD is an output-related deficit, and suboptimal execution of tasks may be the result of incomplete visuomotor preparation. The authors compared 19 children with ADHD with 124 healthy and 120 pathological controls in terms of their performance (speed, speed variability, and accuracy) on the finger precuing test, a test measuring (automatic and controlled) visuomotor preparation. The data implied that children with ADHD have an impaired ability to engage in effortful, controlled visuomotor preparation activities. Fast, automatic response preparation was not affected by ADHD. In addition, children with ADHD showed more variability in overall test performance than other children. No group differences were found in response accuracy.

Attention-deficit/hyperactivity disorder (ADHD), one of the most prevalent developmental disorders (Barkley, 1998; Biederman, 1998; Kroes et al., 2001), has been studied extensively in relation to performance on a wide variety of information processing tasks (for a comprehensive review, see Douglas, 1999). Evidence has been found for an output-related processing dysfunction in ADHD, especially of motor execution processes (e.g., Börger & Van der Meere, 2000; Leth-Steensen, King Elbaz, & Douglas, 2000; Van der Meere, Van Baal, & Sergeant, 1989). In contrast, only a few investigators have assessed the preparation of motor behavior in relation to ADHD, which is unfortunate, because preparation precedes motor execution, and faulty or incomplete preparation may lead to suboptimal execution of movements (Hallet, 2000). Therefore, we examined visuomotor preparation in ADHD in detail in the present study.

Preparation of motor behavior has often been studied by use of spatial precuing paradigms (e.g., Adam, Backes, et al., 2003; Adam et al., 1998; Deiber, Ibáñez, Sadato, & Hallett, 1996; Rosenbergbaum, 1983). This paradigm is based on a central motor control model, which assumes that a plan of the intended neuromotor actions must be programmed before one actually executes the actions. This plan, or central motor control model, consists of a set of instructions that specify the various movement parameters. In a typical spatial precuing experiment, advanced instructions are given to the subjects by means of a precue regarding the spatial location of a to-be-presented stimulus to which the subject has to react (i.e., the target stimulus). This so-called precue, or preparatory signal, shown before the target stimulus is shown, can be presented to the subject in a number of ways (e.g., a centrally presented, symbolic precue such as an arrow, or a locally presented, spatial precue such as a marker or flash of light). In addition, it provides information about one or several movement parameters, for instance, which hand to use, direction of movement, or distance.

To measure the effect of the presentation of a precue, one can compare the performance on a precuing condition with a neutral condition in which no precue or instruction is given. It is found that effective motor preparation by a precue will lead to shorter reaction times and greater accuracy, compared with the neutral condi-
tion in both adults and children. In theory, the precue is believed to direct visual attention to the probable location of the target stimulus and thereby enhances processing by allowing resources to be allocated to both the most relevant source of information as well as to the selection and preparation of one or several possible categories of motor action (Adam et al., 1998; Eriksen, 1990; Koski, Paus, Hoyle, & Petrides, 1999; Posner, 1994). Neuroimaging studies including normal subjects and patients with frontal lobe lesions suggest that several brain structures, for example, the frontal cortex and structures of the basal ganglia (such as the putamen), underlie the ability to benefit from precue information (e.g., Adam, Backes, et al., 2003; Koski et al., 1999).

Because ADHD has often been associated with a dysfunctioning of the frontal-striatal areas of the brain (e.g., Barkley, 1998; Oades, 1998; Sagvolden & Sergeant, 1998) and defined as a deficit in the covert attention system, which allows attention to be allocated to and manipulated within certain regions of visual space (McDonals, Bennett, Chambers, & Castello, 1999; Perchet, Revol, Fournet, Mauguiere, & Garcia-Larrea, 2001; Swanson et al., 1991), it seems plausible to assume that ADHD symptomatology affects the effectiveness of visuomotor preparation, including the ability to use cues effectively (Hypothesis 1).

To study visuomotor preparation, one can manipulate a number of factors that affect reaction time in the spatial precuing paradigm. The first factor worth mentioning here is the preparation interval, which can be defined as the time elapsed between the appearance of the precue and the target stimulus. In previous studies, researchers found that, when prolonging the duration of the preparation interval from short (e.g., 100 ms) to long (e.g., 2,000 ms), performances take the form of a U-shaped curve (e.g., Bertelson, 1967; Bertelson & Tisseyr, 1969; Posner & Boies, 1971) in which the fastest reaction times (i.e., after the optimal preparation interval) are found with a preparation interval of about 500 ms duration (Posner & Boies, 1971). By manipulating the duration of the preparation interval, one can test the subject’s (healthy controls and subjects with ADHD) ability to process the precue in more detail. With relatively short preparation intervals (e.g., 100 ms), preparation is believed to proceed relatively automatically (generally fast and relatively unconscious), whereas with longer intervals (e.g., 1,000 ms), the subject can process the cued information more consciously, that is, in a slower, effortful, and attention-demanding manner, and keep the information active in mind over a longer period of time (Fodor, 1983; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). In ADHD, both automatic and controlled information processing have been investigated, but results are still inconsistent. Several authors have shown that children with ADHD perform less well than controls in situations demanding automatic or more controlled processing strategies (Ackerman, Anhalt, Holcomb, & Dykman, 1986; Borcherding et al., 1988; Hazell et al., 1999), whereas other authors have not (Van der Meere & Sergeant, 1988). The inclusion of short and longer preparation intervals, as measures of either automatic or controlled processing, will help to enlarge the present knowledge concerning this subject. We hypothesize that children with ADHD perform significantly worse on both types of information processing (automatic vs. controlled) than do healthy control subjects (Hypothesis 2).

Next to the manipulation of the preparation interval, a second factor influential on precuing is the type of precue (the so-called preparation condition), which can lead to a pattern of differential precuing benefits. In a number of ways, the precue can be manipulated. For instance, in the precuing task we used in this study, three different types of cues can be differentiated. In short, the test is assessed in the following way: In a predictable, temporal order of appearance, three horizontal rows of stimuli are projected on a computer screen. First, a warning signal appears on the screen, including four identical plus signs on a horizontal row (Step 1). These four plus signs refer to four fingers of the subject (two fingers on each hand). Next, a precue is presented to the subject (Step 2). This precue consists of two or four plus signs and provides information about which hands or fingers to use for responding. Two plus signs indicate that one of two fingers will be used to make the response (two-choice reaction task), and four plus signs indicate that one of four fingers will be used (four-choice reaction task). Within this task, there are three types of cues possible. The hand-cued condition specifies two fingers on the same hand; the finger-cued condition specifies the same finger on different hands; and the neither-cued condition specifies different fingers on different hands. Finally, the null-cued condition is included as a control condition, because it leaves the basic, four-choice reaction task unaltered and hence allows no specific motor preparation. After a variable latency, the target stimulus is presented on the screen (Step 3), in response to which the subject has to press the corresponding key as quickly as possible. After a response is given, the entire sequence of the three steps is repeated. On the basis of earlier conducted studies (for a review, see Reeve & Proctor, 1990), it can be concluded that a pattern of differential precuing benefits is usually found when including different precues, in the sense that reaction times (RTs) differ between these cues. For instance, healthy adults were found to perform fastest on the finger precuing test (FPT) hand-cued condition and slowest on the neither-cued condition, with the finger-cued condition being intermediate (Adam et al., 1998). In the present study, we made no hypotheses regarding the relation between ADHD and the complexity of cues.

In sum, we examined visuomotor preparation in ADHD in more detail in this study by use of a spatial precuing paradigm. In addition to the above-mentioned variables, such as preparation interval and preparation condition, a number of additional factors were taken into consideration. First, we compared children with ADHD not only with healthy children but also with a group of children with psychopathology in general (i.e., children who fulfilled the criteria for at least one child psychiatric syndrome that was not ADHD) in order to determine the specificity of ADHD-related findings, because children with ADHD are at risk of developing other psychiatric disorders (Barkley, 1998). Second, Olivier and Rival (2002) found by use of a priming paradigm that 6-year-old children were able to use a prime to prepare their motor response. However, as the preparation interval was prolonged, the young children tended to gradually lose the advantage gained with the presentation of the prime. Only children older than 8 years of age were able to maintain a movement prepared in memory and to synchronize their above-mentioned optimal preparation level throughout all preparation intervals independent of their duration. Therefore, the child has to be at least 8 years old for one to reliably measure all aspects related to spatial precuing. However, several authors have stated that the period between the ages of 5 and 7 years is critical for cognitive development, including the development of visuomotor and motor control, which are
important functions for successful visuomotor preparation and execution (as described in Bernstein, 1989; Ferrel-Chapus, Hay, Olivier, Bard, & Fleury, 2002; Riva, Nichelli, & Devoti, 2000). A dysfunctioning caused by the expression of ADHD during this early period of development may thereby lead to disruptions in cognitive functioning that can only be assessed reliably later in life. Because our goal in this study was to examine the relation between ADHD and visuomotor preparation and, subsequently, the influence of variable preparation conditions and preparation intervals on this relation, we decided to relate the presence of possible psychopathology when the child was approximately 5–7 years of age (i.e., a relevant stage in cognitive development) to cognitive functioning when the child was 9–10 years old (i.e., at a time when most children are able to perform a spatial precuing task).

Method

This report is based on data collected within a research program entitled Study of Attention Disorders Maastricht (SAM), which has a longitudinal, population-based design. The SAM study consists of four separate phases (for a detailed description of the study, see Kalff et al., 2001; Kroes et al., 2001). For the present article, only three phases are relevant and discussed here.

Phase 1 (Months 1–9): Selection of Subjects

During this phase, all caregivers of children who attended the second year of normal kindergarten in the southern part of The Netherlands were asked to give permission for their children’s participation in the SAM study (N = 2,256). In The Netherlands, the second year of kindergarten precedes the first class of elementary school, in which children learn to read and write. The children frequenting second grade are, on average, 5–6 years old. The response rate was 58.4% (n = 1,317). Parallel to inclusion, all children (both parents who gave permission, i.e., responders, and parents who gave no permission, i.e., nonresponders) were examined as part of the routine health examination carried out by the school doctor. By law, school doctors are allowed to use medical information anonymously for epidemiological purposes. Therefore, it was possible to compare two random samples of 200 nonresponders with 200 responders with regard to child characteristics (sex and age), family variables (parental occupation, nationality, and family structure), and environmental variables (living area) collected from the medical records held by the Youth Health Care Organization in the southern part of The Netherlands. This comparison was necessary because of the relatively large percentage of nonresponders; however, no significant differences between the groups were found (for a full description, see Kroes et al., 2001). Next, based on the Dutch version of the Child Behavior Checklist (CBCL; Achenbach & Edelbrock, 1983; Verhulst, Koot, & Van der Ende, 1996), we selected three groups from the responders group for the second stage. Group E (externalizing group; n = 173, i.e., approximately 7.7% of the total sample) consisted of children who scored high either on the CBCL externalizing broad-bent scale (≥90th percentile) or on the CBCL attention problems subscale (≥95th percentile). According to Chen, Faraone, Biederman, and Tsuang (1994), this selected group contains children with a putative risk for the development of ADHD. Next, Group I (internalizing group; n = 59, i.e., approximately 2.6% of the total sample) contained children scoring within a clinical range on the CBCL internalizing scale (≥90th percentile) but who did not fulfill the criteria for Group E membership. Finally, we formed a matched control group (n = 220, i.e., approximately 9.8% of the total sample) consisting of children with low CBCL total problem scores (<90th percentile) who were matched to Groups E and I in terms of age (±2 months), sex, and school (urban vs. rural).

Phase 2 (Months 15–25): Psychiatric Interview

Caregivers of 403 of the originally selected 452 children agreed to a semistructured, psychiatric interview, using the Amsterdam Diagnostic Interview for Children and Adolescents (ADIKA; Kortenburg van der Sluijs, Levita, Manen, & Defares, 1997). This instrument provides information about childhood psychopathology (Diagnostic and Statistical Manual of Mental Disorders [DSM; American Psychiatric Association, 1987, 1994] classifications, including ADHD). Based on the ADIKA results collected in Phase 2, we formed three independent groups: (a) children who in Phase 2 classified as having ADHD (ADHD group), (b) children who in Phase 2 met the criteria for any DSM classification except for ADHD (pathological controls), and (c) healthy controls (controls).

Phase 3 (Months 39–49)

All selected children were again asked to participate in a follow-up investigation. A total of 284 of the 403 children for whom we had ADIKA results in Phase 2 agreed to participate in the follow-up (70.5%). Because of the relatively large dropout of subjects in Phase 3, we tested responders and nonresponders in Phase 3 for group differences in terms of sex, parental occupation, and ADIKA results. Cramer’s V testing revealed no significant differences between responders and nonresponders on these variables (sex: value = .002, p = .965; parental occupation: value = .083, p = .258; ADIKA results: value = .109, p = .901). In Phase 3, we tested all participating children neuropsychologically by means of an extended test protocol, including assessment tools such as the computerized FPT and the paper-and-pencil task block design. Testing took place in a room at the child’s school, and a neuropsychologist or one of three well-trained assistants administered the test battery. The examiner was blind to group membership of the children. Information about variables that could influence outcome, namely, age (during Phase 3), sex, and level of occupational achievement of the caregiver (LOA), was collected. An overview of data collection is presented in Figure 1.

As mentioned above, 284 children completed all phases. For the analyses, however, we excluded the data for 11 children because of a known

![Figure 1](image-url)  
*Figure 1.* A schematic representation of the data collection for this study. ADHD = attention-deficit/hyperactivity disorder; FPT = finger precuing test; LOA = level of occupational achievement of the caregiver.
use of behavior-mediating medication (e.g., methylphenidate or dipiper-
one. Because of this procedure, 5 children with ADHD, 4 children from the pathologic control group, and 2 healthy controls were excluded). In addition, we excluded the data for 10 children because their performance was unreliable (see the FPT description in the Measures section) or because of other problems, such as too-strict timetables or computer defects. We formed three subsamples from the remaining children ($n = 263$), namely (a) a group of children who were classified as having ADHD in Phase 3 (ADHD; $n = 19$, of which 6 children were of the predominantly inattentive type, 4 children were of the predominantly hyperactive-impulsive type, and 9 children were of the combined type), (b) a group of children who were classified with any DSM classification for psychopa-
ology other than ADHD (pathological controls; $n = 120$), and (c) a group of children who did not belong to Groups 1 or 2 (healthy controls; $n = 124$). Group characteristics are summarized in Table 1. In addition, in Table 2, the distribution of psychopathology other than ADHD was pro-
vided for each group (ADHD, psychiatric controls, and normal con-
trols). No children were excluded from the ADHD group and the psychi-
atric control group because of the (co-) occurrence of specified psychopathology.

**Measures**

*The Amsterdam Diagnostic Interview for Children and Adolescents.*

The ADIKA is the Dutch translation of the Diagnostic Interview for Children and Adolescents (DICA; Ezpeleta et al., 1997; Granero Pérez, Ezpeleta Aascanio, Doménach Massons, & De la Osa Chaparro, 1998; Kortenbout van der Sluijs et al., 1997). The ADIKA is a semi-structured psychiatric interview that yields scores for several child psychiatric syn-
dromes according to DSM-III-R guidelines and that was adapted by using the criteria of DSM-IV for diagnosing ADHD (American Psychiatric Association, 1987, 1994). In line with these criteria, children were classified as ADHD if they showed a persistent pattern of inattention and/or hyperactivity-impulsivity that was more frequent and severe than that typically observed in individuals of comparable development (American Psychiatric Association, 1994). Children were included in the pathologic control group if they fulfilled the criteria for at least one child psychiatric syndrome (with the exception of ADHD). Although the Dutch version of the DICA-III-R interview has not been validated, DICA and DICA-III-R have been demonstrated to have high test-retest reliability and moderate correlations with clinical diagnoses (Ezpeleta et al., 1997; Werner, Reich, Herjanic, Jung, & Amado, 1987).

<table>
<thead>
<tr>
<th>Variable</th>
<th>ADHD (n = 19)</th>
<th>Pathological (n = 120)</th>
<th>Controls (n = 124)</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>9.3</td>
<td>0.4</td>
<td>9.2</td>
<td>0.4</td>
<td>9.1</td>
<td>0.4</td>
<td>0.4</td>
<td>.286</td>
</tr>
<tr>
<td>Sex (boys:girls)</td>
<td>13.6</td>
<td>72.48</td>
<td>11.09</td>
<td>62.62</td>
<td>1.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block design</td>
<td>9.7</td>
<td>4.0</td>
<td>9.6</td>
<td>3.4</td>
<td>10.3</td>
<td>3.5</td>
<td>1.21</td>
<td></td>
</tr>
<tr>
<td>Vocabulary</td>
<td>9.2</td>
<td>2.6</td>
<td>8.8</td>
<td>2.6</td>
<td>8.8</td>
<td>2.9</td>
<td>.796</td>
<td></td>
</tr>
<tr>
<td>LOA</td>
<td>2.9</td>
<td>1.7</td>
<td>3.7</td>
<td>2.0</td>
<td>4.5</td>
<td>1.8</td>
<td>.003</td>
<td></td>
</tr>
<tr>
<td>Hand preference (left:right)</td>
<td>2:17</td>
<td>11:109</td>
<td>13:111</td>
<td>938</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Associations between ordinal and/or interval variables (group membership vs. age, block design scores, vocabulary scores, and level of occupational achievement of the caregiver [LOA]) were calculated by use of Spearman’s rho. In contrast, $\chi^2$ tests (Cramer’s V testing) were used to measure the associations between nominal (sex and hand preference) and ordinal variables (groups). ADHD = attention-deficit/hyperactivity disorder.

**Table 2**

**Distribution of Psychopathology, Other Than Attention-Deficit/Hyperactivity Disorder (ADHD), Found in the Three Groups**

<table>
<thead>
<tr>
<th>Type of comorbidity (no. of cases)</th>
<th>ADHD</th>
<th>Psychiatric</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>No psychopathology</td>
<td>124</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No psychopathology other than ADHD</td>
<td>4</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Anxiety disorders</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Mood disorders and anxiety disorders</td>
<td>3</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Conduct disorders</td>
<td>3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Conduct disorders and anxiety disorders</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Disorders of elimination and anxiety disorders</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Disorders of elimination and mood disorders</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Disorders of elimination, mood disorders, and anxiety disorders</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Disorders of elimination, conduct disorders, and mood disorders</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Disorders of elimination, conduct disorders, and anxiety disorders</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>No. of cases</td>
<td>19</td>
<td>120</td>
<td>124</td>
</tr>
</tbody>
</table>

Block design. A subtest of the Wechsler Intelligence Scale for Children—Revised (WISC–R; Wechsler, 1974; Dutch version by De Bruyn et al., 1986), block design is a construction test in which the subject is presented with nine blocks. Each block has two white sides, two red sides, and two half red, half white sides. The task is to use the blocks to construct copies of designs printed on paper in smaller scale (Lezak, 1995). Performance is highly correlated with general mental ability (Benton, 1984). Reliability and validity are believed to be average to good (Lezak, 1995). The range of standard scores is 1–19 ($M = 10, SD = 3$).

Vocabulary test. We used this subtest of the WISC–R (Wechsler, 1974; Dutch version by De Bruyn et al., 1986) to provide an estimate of general ability (Lezak, 1995). The examiner asked the child to explain the meaning of certain words. The complexity of words increased with each item. The range of standard scores is 1–19 ($M = 10, SD = 3$). Reliability and validity are believed to be average to good (De Bruyn et al., 1986).

Level of occupational achievement of the caregiver. The occupation of the caregivers of the child was originally scored on a 7-point scale, ranging from unskilled (1) to scientific labor (7) (Directoraat-Generaal voor de Arbeidsvoorziening, 1989). Male and female homemakers were coded separately and entered as a separate occupation category (0). When the LOA differed between mother and father, or when data were missing for one caregiver, the highest available score was chosen.

Finger prepping test. This test was originally developed by Miller (1982), and the Dutch version adjusted by Adam et al. (1998) is often used

1 Child psychiatric syndromes included syndromes such as major depression, dysthymia, bipolar syndrome, separation anxiety, phobia, over-
xious disorder, avoidant disorder, oppositional disorder, conduct disor-
der, functional encopresis, functional enuresis, obsessive compulsive dis-
order, posttraumatic stress disorder, and pervasive developmental disorders.
to test visuomotor preparation in adults: The task is to respond as quickly as possible to the appearance of spatially oriented stimuli on a computer screen. The FPT is a four-choice RT task with the index and middle fingers of both hands located on separate keys of the computer keyboard, the buttons ±, ×, >, and ?, respectively. The fingers are placed on the keys before the test starts. In a predictable, temporal order of appearance, three horizontal rows of stimuli are projected on a computer screen (see Figure 2).

First, a warning signal appears on the screen, including four identical plus signs on a horizontal row (Step 1). Next, a precue (preparation condition) is presented to the subject (Step 2). This precue consists of two or four plus signs and provides information about which hands or fingers to use for responding. Two plus signs indicate that one of two fingers will be used to make the response (two-choice reaction task), and four plus signs indicate that one of four fingers will be used (four-choice reaction task). After a variable latency (termed the preparation interval), the target stimulus is presented on the screen (Step 3), in response to which the subject has to press the corresponding key as quickly as possible. The preparation interval reflects the amount of time available to selectively prepare for the finger responses indicated by the precue before the target stimulus is presented. After a response is given, the entire sequence of the three steps is repeated. Subjects received a block of 80 trials for each preparation interval. Each block was preceded by an extended oral instruction about the different preparation conditions and a practice trial during which the subject was given feedback on his or her test performance. The actual test was started only after the practice trials were completed without mistakes. The order of the cuing conditions within a block of 80 trials was at random and in the initial instruction, emphasis on speed and accuracy was equally strong. In case of error, the trial was rejected but not repeated at random within the remaining trials.

There are four types of preparation conditions (Figure 3). The null-cued condition (see Figure 3A) is included as a control condition, because it leaves the basic, four-choice reaction task unaltered and hence allows no specific motor preparation; the hand-cued condition (Figure 3B) specifies two fingers on the same hand; the finger-cued condition (Figure 3C) specifies the same finger on different hands; and the neither-cued condition (Figure 3D) specifies different fingers on different hands. Finally, the duration of the preparation intervals was manipulated in the FPT: That is, the duration was either short (100 ms) or long (1,000 ms).

Statistics

As a first step, we tried to make an estimation of the missing data on the continuous variable LOA (n = 4) by use of the expectation maximization (EM) algorithm through SPSS missing value analyses (MVA). Because we found a statistically reliable deviation from randomness by use of Little’s MCAR test (p = .048), the cases with missing values on continuous predictors could not be imputed by use of the EM algorithm. Therefore, we chose to estimate these missing values by use of the regression algorithm as defined in SPSS MVA. If the RT of a single trial was shorter than 150 ms (i.e., anticipation) or longer than 3,000 ms (i.e., too long), we excluded it from the calculation of the mean speed and speed variability and did not include it in the analyses of accuracy, because we believed that these extreme low and high RTs were assumed not to be representative of the processes under study; we excluded 6% of all responses for these reasons.

Next, we evaluated FPT performance statistically for differences between groups (ADHD children, pathological controls, and healthy controls). We studied three outcomes: that is, speed (i.e., mean RT of hits), speed variability (i.e., standard deviation of RT of hits), and accuracy (i.e., percentage of errors). For all outcome measures, we performed a 3 × 4 × 2 (Group × Preparation Condition × Preparation Interval) general linear models (GLM) repeated measures analysis for unequal sample sizes. For each of the three analyses, we chose group membership as the between-subjects variable and preparation condition (null-cued, hand-cued, finger-cued, or neither-cued) and preparation interval (100 ms or 1,000 ms) as within-subjects variables. For all analyses, Levene’s test of equality of error variances was not significant. Also, the critical value for rejecting the null hypotheses was defined at p < .05. We conducted post hoc corrections with the least significant difference (LSD) algorithm. In addition, we corrected all analyses for LOA, which was included as a covariate. Preliminary experiments showed that hand preference, sex, vocabulary scores, and block design did not differ across groups and, thus, we did not include them as covariates.

Results

Speed

Figure 4 represents the RT performance for preparation conditions and preparation intervals for all groups. Analysis of the log-transformed reaction times revealed a significant Group × Preparation Condition × Preparation Interval interaction, F(6, 516) = 2.33; p = .031, indicating a differential precuing benefit for short- and long-preparation intervals and for groups. Post hoc analyses indicated that, during the short preparation intervals (100 ms), healthy 9-year-old children benefited from hand cuing in comparison with the uncued condition (p < .001): On average, RTs in the hand-cued condition were 58 ms shorter than they were in the null-cued condition. Also, children performed significantly faster on the hand-cued condition than they did on the finger-cued (p = .004) or neither-cued conditions (p < .001). In contrast, they

Figure 2. Schematic presentation of the steps as shown on the computer.
seemed to have difficulties using the finger-cued or the neither-cued conditions during this short preparation interval; that is, we found no differences in RTs between the finger-, neither-, and null-cued conditions (RT\textsubscript{finger-cued} vs. RT\textsubscript{null-cued}: $p = .349$; RT\textsubscript{neither-cued} vs. RT\textsubscript{null-cued}: $p = .289$; RT\textsubscript{finger-cued} vs. RT\textsubscript{neither-cued}: $p = .075$). When the preparation interval was increased from 100 ms to 1,000 ms, all RTs became significantly longer in healthy controls. In addition, during the long preparation interval, RTs in the hand-cued condition were, on average, again significantly shorter than those in the null-cued condition ($p < .001$); RTs on the hand-cued condition were, on average, 62 ms shorter than those in the null-cued condition. Also, children performed significantly faster on the hand-cued condition than they did on the finger-cued ($p < .001$) or neither-cued conditions ($p < .001$). In contrast with the short preparation interval, the RTs for the finger-cued and neither-cued conditions with the long preparation interval, however, were even longer than those for the null-cued condition (RT\textsubscript{finger-cued} vs. RT\textsubscript{null-cued}: $p < .001$; RT\textsubscript{neither-cued} vs. RT\textsubscript{null-cued}: $p < .001$; RT\textsubscript{finger-cued} vs. RT\textsubscript{neither-cued}: $p = .578$), suggesting that these cues hampered performance. The results of the healthy control group were highly comparable with the FPT performance of pathological control subjects (for a comparison, see Figure 4A and B).

In contrast, the FPT performance of children with ADHD revealed a deviant spatial precuing pattern. To be more specific, on the 100-ms preparation interval, children with ADHD reacted as the control children did, with significantly faster RTs in the hand-cued condition than in the null-cued condition ($p = .005$). Also, children with ADHD tended to perform faster on the hand-cued condition than they did on the finger-cued ($p = .051$) or neither-cued conditions ($p = .066$). During the short preparation interval, we found no differences in RTs between the finger-, neither-, and null-cued conditions (RT\textsubscript{finger-cued} vs. RT\textsubscript{null-cued}: $p = .986$; RT\textsubscript{neither-cued} vs. RT\textsubscript{null-cued}: $p = .348$; RT\textsubscript{finger-cued} vs. RT\textsubscript{neither-cued}: $p = .197$). When the preparation interval was increased from 100 ms to 1,000 ms, the hand-cuing effect was no longer seen in the children with ADHD (RT\textsubscript{hand-cued} vs. RT\textsubscript{null-cued}: $p = .585$; RT\textsubscript{hand-cued} vs. RT\textsubscript{finger-cued}: $p = .468$; RT\textsubscript{hand-cued} vs. RT\textsubscript{neither-cued}: $p = .867$; RT\textsubscript{finger-cued} vs. RT\textsubscript{null-cued}: $p = .943$; RT\textsubscript{neither-cued} vs. RT\textsubscript{null-cued}: $p = .733$; RT\textsubscript{finger-cued} vs. RT\textsubscript{neither-cued}: $p = .754$), whereas it was in the control children. Thus, when faster and more automatic information processing was required (with the 100-ms preparation interval), children with ADHD were able to benefit from hand cuing (and to prepare their response) to a similar extent as were pathological and healthy controls. In contrast, they were not able to benefit from hand cuing when there was sufficient time (preparation interval 1,000 ms) to allow for effortful processing of the information.

**Speed Variability**

With regard to speed variability, we found no significant three-way and two-way interactions, except for Preparation Interval $\times$ Preparation Condition, $F(3, 257) = 3.67; p = .013$ (see supplemental Table 1 on the Web at http://dx.doi.org/10.1037/0894-4105.19.1.66.supp). Post hoc analyses revealed that, in the short preparation condition, variability in speed, averaged over all groups, was significantly higher in the neither-cued condition than it was in all other conditions. Speed variability increased with an increase in preparation intervals, with the variability in speed in the null-cued and hand-cued conditions being significantly lower than it was in the neither-cued and finger-cued conditions. In addition, the GLM repeated measures revealed a significant main effect for group on measures of speed variability, $F(2, 259) = 5.96; p = .003$. Post hoc analyses indicated that children with ADHD (476 ms, $SE = 24.7$) showed a greater variability in speed, calculated over all preparation intervals and preparation conditions, than did the pathological controls (392 ms, $SE = 9.8$; $p = .002$) and the healthy controls (384 ms, $SE = 9.7$; $p = .001$). The pathological and healthy control groups did not differ from each other in terms of speed variability ($p = .550$).

**Accuracy**

With regard to accuracy, no significant three-way and two-way interactions were found among group, preparation interval, and preparation condition, except for Preparation Interval $\times$ Preparation Condition, $F(3, 257) = 17.06; p < .001$ (see supplemental Table 2 on the Web at http://dx.doi.org/10.1037/0894-4105.19.1.66.supp). Post hoc analyses revealed that, in the short preparation condition, accuracy was highest in the hand-cued condition ($M = 2.7$, $SE = 0.3$) and lowest in the finger-cued condition ($M = 4.9$, $SE = 0.4$), with the null-cued ($M = 3.0$, $SE = 0.3$) and neither-cued ($M = 4.8$, $SE = 0.4$) conditions being intermediate. Accuracy in both the hand-cued and null-cued conditions differed significantly from that in the finger-cued and neither-cued conditions. With a long preparation interval (1,000 ms), accuracy was higher in the hand-cued ($M = 3.3$, $SE = 0.3$) and null-cued ($M = 2.0$, $SE = 0.5$) conditions than it was in the finger-cued ($M = 7.4$, $SE = 0.4$) and neither-cued ($M = 6.9$, $SE = 0.5$) conditions. Accuracy in the null-cued condition was also significantly better than it was in the hand-cued condition. We found no
differences in accuracy between the finger-cued and neither-cued conditions. In addition, the GLM repeated measures analyzing accuracy showed no main effect or interactions for group (ADHD vs. pathological controls vs. controls). Over all preparation conditions and intervals averaged, children in all three groups made 4.3%–4.4% inaccurate responses.

Discussion

In this study, children with ADHD were compared in a double controlled design with healthy and pathological controls in terms of their performance (speed, speed variability, and accuracy) on the FPT task and its relation to visuomotor preparation. The results of the study are discussed here in more detail. In addition, the FPT data on healthy control subjects are also discussed thoroughly, because FPT data are available for adult subjects but scarce for children. Previous studies have suggested that information processing time decreases from childhood through adolescence and adulthood (e.g., see Wickens, 1974, for a review as described in Olivier & Bard, 2000). A large percentage of this difference may be due to an age-related improvement in identification and selection of motor responses (e.g., Welsandt, Zupnick, & Meyer, 1973). Therefore, it seems important to study FPT performance in control children as well as in adults.

**FPT Performance in ADHD**

Because ADHD has often been associated with a dysfunctioning of the frontal-striatal areas of the brain (e.g., Barkley, 1998; Oades, 1998; Sagvolden & Sergeant, 1998) and defined as a deficit in the covert attention system, which allows attention to be allocated to and manipulated within certain regions of visual space (McDonalds et al., 1999; Perchet et al., 2001; Swanson et al., 1991), we hypothesized that ADHD symptomatology affects visuomotor preparation, including the ability to use cues effectively. To be more specific, we hypothesized that children with ADHD perform significantly worse when asked to prepare for a motor action either consciously or automatically. In addition, we studied whether different cues (in terms of unimanual or bimanual) resulted in differential precuing benefits and whether these benefits were different for children with ADHD than they were for control subjects. On the basis of earlier studies conducted on adults (Adam, Backes, et al., 2003; Reeve & Proctor, 1990), we hypothesized that a pattern of differential precuing benefits could be found in children when including different precues. Here, RTs are assumed to be longest for the uncued condition and shortest for the unimanual cued condition, with the RTs for the bimanual cued condition being intermediate. In the present study, we made no hypotheses regarding the differences in performance between ADHD children and control subjects.

In this study, we found that preparation interval and preparation condition had a different effect on test performance in the children with ADHD, on one hand, and the children in the two control groups, on the other. Whereas children from the control groups were able to benefit from hand cuing compared with null cuing irrespective of the preparation interval, children with ADHD were able to benefit from hand cuing only when processing was fast and rather automatic (i.e., with a preparation interval of 100 ms) and not when processing was more conscious (i.e., with a preparation interval of 500 ms).
The results indicate that fast, automatic response preparation is not affected by ADHD, whereas attention-demanding or controlled response preparation is. There is increasing evidence that at least two independent neural circuits are engaged in attention-demanding visuomotor preparation, namely, the posterior attention system and the anterior attention system (Brown, 1996; Posner & Petersen, 1990; Shallice, 1988). The main function of the posterior system is to direct, focus, and manipulate attention on a specific location within visual space in the absence of eye movements (i.e., selection-for-perception) and involves mainly the parietal cortex and the superior colliculus of the brain. The anterior attention system is primarily related to the selection and preparation of one or several possible categories of motor action (i.e., selection-for-action) and seems to involve mainly the frontal lobe structures, including the motor cortex. Several authors have hypothesized that ADHD is associated with a deficit in the anterior attention system and more specifically with control processes involved in motor responses, mainly in the presetting or preparation stage (McDonalds et al., 1999; Perchet et al., 2001; Swanson et al., 1991). Although our results suggest that there is a deficit in the controlled preparation of a motor action in ADHD, we cannot say, on the basis of the FPT data, whether the anterior or the posterior attention system is affected. This is because the successful processing of cuing information in the FPT is a function of both perceptual processes concerned with cue identification and a set of processing operations concerned with planning or programming of relevant motor output (Adam, Hommel, & Umiltà, 2003; Adam et al., 1998; Rosenbaum, 1980). Therefore, more research is needed to understand why children with ADHD tend to perform significantly less well than controls on tasks measuring controlled visuomotor preparation.

Another mechanism that may be taken into consideration when studying automatic and controlled visuomotor preparation is the passive–active discussion often seen in motor response literature. Although a number of authors (e.g., Bertelson, 1967; Bertelson & Tisseya, 1969; Posner & Boies, 1971) assume that motor preparation is, in general, a passive process, others such as Woodrow (1914) suggest that motor preparation is more an active process used by the subject to synchronize the optimal motor preparation with the occurrence of the target stimulus. If this last theory is true, RTs were reduced by the pre-cue independent of the preparation interval. The study of Börger and Van der Meere (2000) shows, for instance, that the differences between children with ADHD and controls on motor activation and effort allocation were found only with a slow presentation rate (that is, 6 s) on a go/no-go test. No differences were found with a fast presentation rate (that is, 2 s).

The authors explained these results in terms of an inability to synchronize motor execution to external visual stimulation. Although inefficient attention allocation may also result in longer RTs on the FPT, it is believed that this inefficiency cannot be the only explanation for the results found in the present study, because the presentation rate during the controlled visuomotor preparation task included in the study is relatively fast (i.e., 1 s). However, more research in this area is still needed.

Also, we found group differences (ADHD, pathological controls, and healthy controls) in the present study in terms of variability in speed. Children with ADHD showed a greater variability in speed over all preparation conditions and intervals than did the children in the control groups. The pathological control group did not deviate from the healthy controls. By including this control group, we were able to conclude that this increased variability in speed is specific for ADHD. In line with this finding, Douglas (1999) stated that the high degree of variability in ADHD performance on many cognitive tasks seems to signify a pervasive manifestation of regulatory problems involving the inconsistent allocation of effort.

Finally, we found in this study that although the children with ADHD performed differently than the control groups in terms of speed and speed variability, accuracy was comparable within all groups. This last finding is in line with the findings of Börger and Van der Meere (2000), who found comparable results on a go/no-go task.

**FPT Performance in Control Subjects**

As mentioned in the first paragraph of the Discussion section, special attention is given here to the FPT performance in healthy children. In terms of preparation conditions, we found that, for the control subjects, only the hand-cued condition led to an improvement in performance (in speed and speed variability; however, no improvements were found for accuracy) averaged over both preparation intervals. Performance on bimanual two-choice response tasks (as for the finger-cued and neither-cued conditions) did not improve in comparison with that in the null-cued condition. These results are in contrast to studies of FPT performance in adults. For instance, Adam et al. (1998) found that young and middle-aged adults can benefit from preparation (in terms of speed) in all FPT cuing conditions (hand-, finger-, and neither-cued). The combination of results in children and adults seems to point toward a developmental trend in a programming of the three spatial parameters (hand-, finger-, and neither-cued) in which the hand-cued parameters are programmed before the finger- and neither-cued parameters. It is interesting to note that Adam, Backes, et al. (2003) found a specific anatomic substrate to underlie visuomotor preparation, including the frontal lobes (middle frontal gyrus, premotor, and supplementary motor cortex), parietal cortex (inferior and superior parietal lobule and intraparietal sulcus), and basal ganglia (caudate nucleus and putamen), but that they found differences in brain activity when comparing the different cuing conditions. Compared with the finger- or neither-cued conditions, the hand-cued task was associated with more activity in the basal ganglia and less activity in the parietal cortex. The authors explained this difference in activity in the basal ganglia in terms of the inhibitory capacity of this area of the brain, in which it appears to be easier to inhibit the (pre)motor cortex of one hemisphere (as in the unimanual hand-cued condition) than it is to inhibit two irrelevant responses represented in two hemispheres (as in the bimanual, finger-, and neither-cued conditions). The decrease in parietal cortex activity was explained in the context of spatial grouping and Gestalt principles (Adam, Hommel, & Umiltà, 2003). The visual cue for preparation of the fingers on one hand represents a neutral, strong perceptual subgroup that is established quickly and automatically. In contrast, the less natural and more complex cues for the finger-cued and neither-cued conditions involve the fingers of both hands (and hence both hemispheres) and require more complex processing to create a subgroup, which is reflected by the increased activity detected by fMRI. It is possible that consciously processed higher-order functions (such...
as fine-tuned spatial discrimination—inhibition and controlled attention orienting) develop later and are more sensitive to aging than the more reflexive information processes, which may explain the similarity in performance between young children and adults.

In terms of preparation intervals, we found that speed and speed variability increased and accuracy decreased over all preparation conditions (the null-cued condition) as the preparation interval increased (from 100 ms to 1,000 ms). This indicates that, in 9-year-olds, FPT performance is adversely affected when the interval during which children can anticipate on a future action becomes longer. With the short preparation interval, children seemed to react fairly automatically to cued stimuli, whereas with the longer preparation interval, children acted more consciously and had more time to bring controlled processing resources to bear on the cues. Support for this distinction between automatic and controlled processing comes from the results for the more complex finger-cued and neither-cued conditions. It would appear that the processing involved in these cued conditions is too difficult for 9-year-old children. It is interesting to note that when processing was automatic (100-ms condition interval), no differences in performance were found between the null-cued condition and the finger-cued and neither-cued conditions.

When studying the interaction of preparation intervals and preparation conditions in healthy control subjects, we found the following results. During the short preparation intervals (100 ms), healthy 9-year-old children benefited from hand cuing in comparison with the uncued condition. In contrast, they seemed to have difficulties using the finger-cued or neither-cued conditions during this short preparation interval; that is, we found no differences in RTs between the finger-, neither-, and null-cued conditions. During the controlled visuomotor preparation, however, results were comparable with the short preparation in terms of performance on the hand-cued condition. With the long preparation interval, the RTs for the finger-cued and neither-cued conditions were, however, even longer than those for the null-cued condition, suggesting that these cues hampered performance. It may well be that, in contrast to adults, the bimanual cue is too difficult to process for 9–10-year-old children (independent of the level of consciousness). More research in this matter is still needed.

**Limitations of the Study Design**

The FPT is an appropriate instrument with which to study visuomotor preparation, because the preparation intervals and preparation conditions can be changed spatially, and because the compatible nature of the cues reduces the complexity of the cue-decoding processes, thereby allowing the use of relatively short preparation intervals. Short preparation intervals have the advantage of diminishing the possibility of involving other processes such as working memory (an aspect of cognition often related to ADHD) or mental imagery; moreover, the motor action (namely, pressing a key) is identical for all preparation conditions.

Despite our use of this instrument, our study had a number of limitations. For one, we assessed the diagnostic classifications solely on the basis of the outcome of a semistructured interview conducted with help of the caregiver(s) of the child. Cross-informant reports, such as teacher reports, were not included. Therefore, it is possible that the number of children with externalizing behavior was overestimated, although Barkley (1998) reported that there was 90% overlap between parent reports and teacher reports. In addition, no information was included about the level of impairment within the ADHD group. Also, the ADHD group was relatively diverse, because there was no restriction regarding all subtypes of ADHD (predominantly inattentive type, predominantly hyperactive–impulsive type, and the combined type) and comorbidity in this group. This may have influenced the performance on the FPT test. The same is true for the pathological control group. More research including predefined, homogeneous ADHD groups and specified psychiatric control groups (e.g., children with depression or conduct disorder) is, therefore, necessary.

**Conclusion**

This study showed a deficit in controlled visuomotor preparation, as operationalized by the FPT paradigm, in children suffering from ADHD compared with both healthy and pathological control subjects. These data contribute to knowledge about the specificity of cognitive deficits in ADHD.

**References**


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