Information Processing Deficits in Children with Attention-Deficit/Hyperactivity Disorder, Inattentive Type, and Children with Reading Disability

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Abstract

We examined the information processing capabilities of children diagnosed with the inattentive subtype of attention-deficit/hyperactivity disorder (ADHD) who had been characterized as having a sluggish cognitive tempo. Children referred for school-related problems (n = 81) and nonreferred community controls (n = 149) participated. Of the referred children, 24 met criteria for ADHD, 42 met criteria for reading disability (RD), and 9 of these were comorbid for RD and ADHD. Children with ADHD differed from those without ADHD on a visual search task but not on an auditory processing task; the reverse was true for children with RD. Decomposition of the visual search task into component operations demonstrated that children in the ADHD group had a slow processing rate that was not attributable to inattention. The children with ADHD were not globally poor at information processing or inattentive, but they demonstrated diminished speed of visual processing.

Although the nosologic systems for diagnosing attention-deficit/hyperactivity disorder (ADHD) have continued to evolve with each new edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; American Psychiatric Association, 2000), a recurring theme is the existence of two basic symptom clusters, one consisting of hyperactivity and impulsivity and the other of inattention. Both DSM-III and DSM-IV-TR specify a subtype of the disorder in which motor hyperactivity is not a prominent symptom. In DSM-III, this subtype was referred to as ADHD without hyperactivity (ADHD/WO; American Psychiatric Association, 1980). Although no such subtype was specified in DSM-III-R, it was revived in the DSM-IV-TR. This subtype is now referred to as ADHD—predominantly inattentive type (ADHD/IA). The DSM-III and DSM-IV-TR definitions for this subtype are similar but not identical; impulsive symptoms are not included among the DSM-IV-TR symptoms. Thus, the DSM-IV-TR distinguishes three subtypes of ADHD: predominantly inattentive, predominantly hyperactive-impulsive, and combined.

There is considerable debate about the proper classification of these subtypes. On the one hand, there is the view that these subtypes represent variants of a single underlying disorder. Faraone, Biederman, and Friedman (2000), for example, reported that the prevalence of both subtypes is increased in families with an affected child. On the other hand, there is the view that these subtypes are distinct syndromes, not properly viewed within the framework of a single disorder.

One common finding is the increased prevalence of academic problems among children with the ADHD/IA subtype (Baumgaertel, Wolraich, & Dietrich, 1995; Faraone, Biederman, Weber, & Russell, 1998; Hudziak et al., 1998; Marshall, Schafer, O'Donnell, Elliott, & Handwerk, 1999; McBurnett et al., 1999; Warner-Rogers, Taylor, Taylor, & Sandberg, 2000; Wolraich, Hannah, Baumgaertel, & Feurer, 1998). This association raises the same question that was posed for the DSM-III ADHD/WO subtype—that is, whether the ADHD/IA subtype might be more properly understood within the rubric of learning disabilities rather than as a variant of ADHD (Barkley, 1990; Barkley, DuPaul, & McMurtry, 1990; Barkley, Grodzinsky, & DuPaul, 1992; Goodyear & Hynd, 1992).

Studies based on the DSM-III criteria have indicated that in comparison to controls and to children with hyperactive symptoms, many individuals with inattentive symptoms could also be described as having a sluggish cognitive...
tempo. This characterization has been based on teacher questionnaires (Lahey & Carlson, 1991; Lahey, Schaugency, Framc, & Strauss, 1985; Lahey, Schaugency, Hynd, Carlson, & Nieves, 1987), visual search tasks (Sergeant & Scholten, 1985), and performance on the Wechsler Intelligence Scale for Children–Revised (WISC-R; Wechsler, 1974) Coding subtest (Barkley et al., 1990). This sluggish cognitive tempo descriptor has also been applied to the DSM-IV-TR inattentive subtype, which McBurnett, Piffner, and Frick (2001) argued may itself be dichotomous, with inattentive symptoms and sluggish cognitive tempo forming distinct behavioral clusters. Questionnaire items reflective of the sluggish cognitive tempo descriptor include “Daydreams a lot” and “Often is sluggish or drowsy.”

The present study is based on a heterogeneous group of children referred for diagnosis of learning problems, all of whom participated in a multidisciplinary research program in which neuropsychological performance, information processing, and neurophysiological function were evaluated. The centerpiece of this multidisciplinary research program was a computer-based battery that evaluated children’s performance on four measures of low-level information processing—rapid auditory processing (Waber et al., 2001), paced finger tapping (Waber et al., 2000), motor sequence learning (Waber et al., 2001), and visual filtering (Weller, Harris et al., 2000).

In an earlier study (Weller, Bernstein, Bellinger, & Waber, 2000), based on this group of children, we described the neuropsychological profiles of the children who met DSM-IV-TR criteria for ADHD/IA and compared them with the children who had reading disability (RD), both, or neither sets of symptoms. Given the speculation that ADHD/IA may be best understood within the spectrum of learning disabilities, this comparison allowed us to investigate the extent to which children with ADHD/IA resembled children with RD, the most common of the learning disabilities (Shaywitz, Fletcher, & Shaywitz, 1995). Similar contrasts have been commonly used in clinical studies of children with ADHD (see Aylward, Verbalst, & Bell, 1990; Barkley et al., 1990; Dykman, Ackerman, & Oigesby, 1979; Purvis & Tannock, 1997, Reader, Harris, Schuerholz, & Denckla, 1994; Richards, Samuels, Turnure, & Ysseldyke, 1990; Robbins, 1992).

A double dissociation pattern emerged, wherein groups of children could be differentiated by their different patterns of performance on contrasting measures. Children with RD were, not surprisingly, distinguishable by their poor performance on written language measures, but not on measures of processing speed. Conversely, children with ADHD/IA were distinguishable by their poor performance on processing speed measures, particularly Coding and Symbol Search (Wechsler, 1991), but not on written language measures. This result, which is consistent with the earlier sluggish cognitive tempo descriptions, was interpreted as suggesting that a specific deficit in processing speed might be contributing to the behavioral problems that bring children with ADHD/IA to clinical attention.

In the present study, we replicated our earlier study examining the processing speed capabilities of children with ADHD/IA. This time, however, we examined computer-based measures of information processing. The primary measure was the Visual Filtering task (Weller, Harris et al., 2000), a visual search task that allows the speed of visual search to be decomposed into component processes. To evaluate whether diminished processing speed is specifically associated with ADHD/IA or whether these children have general performance problems, we again implemented a double dissociation design. As a contrast task, we selected an auditory processing measure that has been consistently associated with reading impairment (Reed, 1989; Tallal, 1980; Waber et al., 2001). In the context of the double dissociation design, we predicted that children with ADHD/IA would perform more poorly than children without ADHD/IA on the visual task but not on the auditory task, and vice versa for children with RD.

Visual search tasks examine the speed with which participants are able to find target items within various types of visual displays. Visual search tasks are sensitive to the fundamental properties of the human visual system that enable a target to effortlessly "pop out" (i.e., the visual field is processed in parallel) when it is placed among distractors of one type but that demand systematic examination of each item in turn (i.e., serially) if the same target appears among other types of distractors (Triesman & Gormican, 1988). These two search operations, parallel and serial, can be differentiated operationally by measuring changes in response times when varying the number of distractors. When the time to find the target changes minimally as distractors are added, it is inferred that the field is processed in parallel. If, however, there is a marked increase in search time as distractors are added, it is assumed that items are examined individually, and a serial search is inferred (Cheal & Lyon, 1992).

A number of theories have been offered to explain these findings, including feature integration theory (Triesman & Gormican, 1988) and similarity theory (Duncan & Humphreys, 1989). Wolfe, Cave, and Franzel (1989) have proposed a model of guided visual search in which the initial stage of the search is directed by preattentive parallel processes. If the target is not located, a serial examination of the stimuli is initiated, guided by information gleaned from the parallel stage. Wolfe (1998) has argued that this combination of early parallel and late serial mechanisms, rather than a strict dichotomy between the two, best explains the range of findings (i.e., performances on some visual search tasks do not fall cleanly within serial or parallel processing models) reported in the visual search literature. Search time differences observed between groups
could theoretically reflect inefficient integration of parallel and serial operations, a deficit in one particular operation, or a more generalized slowness in processing speed that would affect both parallel and serial search operations. To distinguish between these possibilities, we examined a range of visual search operations, from simple reaction time through parallel and serial search.

The Visual Filtering task was selected from our information processing battery to be the focus of the present study because visual search tasks have previously been used as indicators of information processing speed (Bisanz & Resnick, 1978; Kail, 1988; Keating, Keniston, Manis, & Bobbitt, 1980) and because the standardized tests from our earlier study (Weiler, Bernstein, et al., 2000) that were most sensitive to ADHD/IA (i.e., Coding and Symbol Search) were primarily visual in nature and similarly associated with output speed. Children with heterogeneous learning impairments have been differentiated from children without learning impairments by their slow speed of performance on this particular task (Weiler, Harris, et al., 2000).

Because good readers can be differentiated from individuals with RD using tests that specifically stress the auditory system (de Weerd, 1988; Mody, Studdert-Kennedy, & Brady, 1997; Reed, 1989; Tallal, 1980), we selected the Rapid Auditory Processing (RAP) task from our battery as the contrast task for the double dissociation. This task entails tone discrimination; children listen to two pairs presented at decreasing intervals and indicate whether the tones are of the same or of different pitches. Performance scores on this task (Waber et al., 2001) and auditory evoked potentials to the same stimuli (Duffy, McAnulty, Wolff, & Waber, 1999) differentiate good from poor readers.

We hypothesized that children with ADHD/IA would show a specific deficit in processing speed, but that they would not be globally inattentive. We predicted that children with ADHD/IA would perform more slowly than children without ADHD/IA on the Visual Filtering task but would not differ on the RAP task; the reverse was predicted for children with RD.

Method

Participants

All children between the ages of 7 years 6 months and 11 years 11 months presenting at a pediatric hospital for the evaluation of school-related problems (learning impairment; LI) or attending a public school system in the metropolitan Boston area (no learning impairment; NLI) were considered potential candidates for participation in a multidisciplinary research program on information processing in children with learning problems. Children meeting the criteria for either the combined or the hyperactive-impulsive subtypes of ADHD were excluded from the study because of concerns that they might not be able to comply with the lengthy test battery; thus, they were not available for comparison purposes. Children who met the criteria for ADHD/IA were purposely included, however, so that their information processing profiles could be contrasted with those of children with other learning problems.

For the LI group, children were excluded if they met the criteria for either the combined or the hyperactive-impulsive types of ADHD as identified by parent and teacher versions of the Diagnostic Rating Scale (DRS), a DSM-IV-TR-based ADHD questionnaire (Weiler, Bellinger, Marmor, Rancier, & Waber, 1999; Weiler, Bellinger, et al., 2000). Children were also excluded if they obtained a Full Scale IQ (FSIQ) score on the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991) below 80; had evidence by history or examination of neurological impairment; were taking psychoactive medication (e.g., Ritalin, Cylert, Adderall); had a significant emotional or behavioral disturbance, as indicated by the Behavioral Symptom Index of the Behavioral Assessment System for Children—Parent Version (BASC; Reynolds & Kamphaus, 1992); or did not use English as their primary language.

Two hundred three eligible children consented to participate in the research program. Teacher DRS forms could not be obtained for 33 children (16%). One additional child could not be included because data from the Visual Filtering task were lost due to a computer malfunction. Participants for the present study were selected from the remaining cohort of 179 children for whom complete data sets were available.

For the NLI community comparison group, exclusionary criteria were the same as for the LI group, with the following modifications: IQ was determined based on the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990); neurological impairment was evaluated based on medical history obtained from a parent questionnaire; and no child had a formal Individualized Education Program (IEP). The BASC score was not obtained for this sample, but it was assumed that most children with a significant emotional or behavioral disorder would have been receiving services through an IEP. One hundred ninety-nine children met the criteria and participated.

Design

In a preliminary analysis, the children in the clinical groups were compared to children in the control group to characterize their performance on the experimental tasks relative to normative expectations. In the primary analysis, the performances of the clinical groups were contrasted against one another to test the double-dissociation hypothesis.

To contrast the performance of children with the inattentive form of attention-deficit/hyperactivity disorder (ADHD/IA) against that of children who did not have ADHD/IA, participants were selected from the LI group ($n = 179$) who exhibited either high or low levels of DSM-IV-TR inatt-
tention symptoms based on questionnaire data. These two groups of children were then further subdivided by their reading skills. Children from the NLI group who exhibited adequate single-word decoding skills and low levels of inattention symptoms were selected to form the control group.

Children who met the criteria for ADHD/IA were classified as ADHD. These were children for whom parents and teachers both reported (using the DRS) that six or more DSM-IV-TR diagnostic criteria for ADHD/IA had occurred frequently for the last 6 months. To eliminate children who might have been marginal cases of ADHD–combined type, children with elevated scores for hyperactivity (i.e., a sum of 11 or greater for parent and teacher DRS scores, combined, for a diagnosis) were excluded ($n = 5$). The resulting ADHD group comprised 24 children (13% of the cohort).

The no attention deficit (No AD) group included children for whom parents and teachers both reported that three or fewer DSM-IV-TR criteria for ADHD/IA occurred frequently in the prior 6 months. This group comprised 57 children (32% of the cohort).

These two groups of children were further classified as adequate or poor decoders based on scores from the Basic Reading subtest of the Wechsler Individual Achievement Test (WIAT; Psychological Corp., 1992). Children who met either a regression–discrepancy definition (Reynolds, 1984) using the WISC-III FSIQ, or a low achievement definition, with a Basic Reading score below 90 (Fletcher et al., 1994; Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996; Shankweiler et al., 1995; Shaywitz, Fletcher, Holahan, et al., 1995) were classified as RD; all others were classified as no reading–decoding deficit (No RD). Forty-two children met the criteria for RD, half of them on the basis of the low achievement definition. Table 1 illustrates the distribution of the four groups by age, gender, IQ, socioeconomic status, and scores on the classifying variables.

The same procedure was used to identify from the community sample ($N = 199$) a group of children without ADHD or RD symptoms. Children were excluded if the parent or teacher DRS was incomplete ($n = 11$); if they met the criteria for RD ($n = 9$); if they obtained marginally high ADHD hyperactive–impulsive scores ($n = 4$); or if their ADHD ratings did not meet the full criteria for No AD ($n = 26$). The remaining 149 children (75% of the cohort) constituted the control group.

### Measures

**IQ, Reading, and Math Skills.** General cognitive ability was estimated by the Matrices subtest of the K-BIT (Kaufman & Kaufman, 1990). The K-BIT IQ composite score was not used because this score is partially derived from a subtest that requires spelling (i.e., Definitions), which could unfairly

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**TABLE 1**

Demographic Characteristics of Experimental and Control Groups

<table>
<thead>
<tr>
<th>Measure</th>
<th>ADHD/No RD</th>
<th>ADHD/RD</th>
<th>No AD/No RD</th>
<th>No AD/RD</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>$n$</td>
<td>15</td>
<td>9</td>
<td>24</td>
<td>33</td>
<td>149</td>
</tr>
<tr>
<td>Gender (% boys)</td>
<td>87.5</td>
<td>88.9</td>
<td>58.3</td>
<td>63.6</td>
<td>42.3</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.7</td>
<td>1.3</td>
<td>9.5</td>
<td>1.2</td>
<td>9.6</td>
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<tr>
<td>ADHD-P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention</td>
<td>7.25</td>
<td>1.13</td>
<td>7.44</td>
<td>1.13</td>
<td>1.29</td>
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<tr>
<td>Hyperactivity–Impulsivity</td>
<td>2.00</td>
<td>1.67</td>
<td>1.22</td>
<td>1.09</td>
<td>0.63</td>
</tr>
<tr>
<td>ADHD-T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention</td>
<td>7.50</td>
<td>1.15</td>
<td>7.22</td>
<td>1.09</td>
<td>1.33</td>
</tr>
<tr>
<td>Hyperactivity–Impulsivity</td>
<td>2.81</td>
<td>2.69</td>
<td>2.78</td>
<td>2.17</td>
<td>0.38</td>
</tr>
<tr>
<td>K-BIT Matrices</td>
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<td></td>
</tr>
<tr>
<td>Basic Reading</td>
<td>102.0</td>
<td>8.4</td>
<td>99.2</td>
<td>8.1</td>
<td>104.1</td>
</tr>
<tr>
<td>Numerical Operations</td>
<td>110.4</td>
<td>7.0</td>
<td>86.1</td>
<td>4.3</td>
<td>102.5</td>
</tr>
<tr>
<td>SES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Father’s occupation</td>
<td>5.7</td>
<td>2.5</td>
<td>5.9</td>
<td>2.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Father’s highest grade</td>
<td>15.1</td>
<td>3.0</td>
<td>14.8</td>
<td>2.0</td>
<td>15.5</td>
</tr>
<tr>
<td>Mother’s occupation</td>
<td>5.5</td>
<td>1.8</td>
<td>6.6</td>
<td>1.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Mother’s highest grade</td>
<td>14.0</td>
<td>2.4</td>
<td>15.1</td>
<td>2.2</td>
<td>15.2</td>
</tr>
</tbody>
</table>

Note. ADHD = attention-deficit/hyperactivity disorder–inattentive type; No AD = no attention deficit; RD = reading disability; No RD = no reading deficit; K-BIT = Kaufman Brief Intelligence Test; ADHD-P = ADHD Diagnostic Rating Scale, parent version; ADHD-T = ADHD Diagnostic Rating Scale, teacher version; WIAT = Wechsler Individual Achievement Test; SES = socioeconomic status (Hollingshead, 1975).
penalize children in the RD group. Academic skills were evaluated by the Wechsler Individual Achievement Test (WIAT; Psychological Corp., 1992) Basic Reading subtest.

**Visual Filtering.** The Visual Filtering (VF) task includes a visual search task and three additional conditions that decompose the four component operations required to perform the visual search task: Parallel Search, Serial Search, Decision, and Motor Response. Examining the response times for each of these operations alone allows specification of exactly where (if at all) the performances of the groups diverged. For example, by using simple reaction time (SRT) as a covariate, the time needed to initiate a motor response can be removed from the Parallel Search and Serial Search response times.

Figure 1 illustrates the VF task design and shows examples of each stimulus type. For the simple reaction time (SRT) and Go/No-Go tasks, the child is instructed to respond by pressing the right button, as quickly as she or he can, when an X appears on a gray background (100% of the time for SRT; 50% of the time for Go/No-Go). For the remaining tasks (i.e., Choice Reaction Time, Parallel Search, Serial Search), the number and type of distractors are varied, and the child is instructed to press the right button (as quickly as he or she can) if the X is on gray and the left button if the X is on white. A complete description of the stimuli and task design is included in the Appendix.

Each child was given a series of training trials prior to each task (except for the simple reaction time task, which was trained off-line). During the training, the child received auditory feedback for accuracy (bells or crashes). The criterion for moving to the testing phase was a correct response on 10 of 12 consecutive training trials. If the criterion was not reached within 40 trials, the entire test was discontinued.

Stimulus trials were presented in the following sequence: one block of 10 SRT trials; Go/No-Go training; 20 Go/No-Go trials; Choice Reaction Time training; 20 Choice Reaction Time trials; a second block of 10 SRT trials; Visual Search training; and 121 Visual Search trials (i.e., Parallel Search and Serial Search stimuli), which included an initial trial that allowed children to accommodate to the task and was not used in the analysis.

SRT, Go/No-Go, and Choice Reaction Time conditions were each presented as separate blocks of trials. The remaining conditions were presented together in a single block, with the six different types of Parallel Search and Serial Search stimuli evenly interspersed and presented in the same random order for every child. Presentation of the first set of conditions as separate trial blocks allowed the children to be taught the task in a systematic, incremental way. The Parallel Search and Serial Search trials were interspersed to provide for direct comparison of response times among these tasks, to control for potential time-related changes in attention or response bias, and to enhance partici-

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**FIGURE 1.** Stimuli used in the Visual Filtering task. All simple reaction time (SRT) stimuli contain an X on a gray background. For the remaining conditions, stimuli contain an X on either a gray or a white background. For SRT and Go/No-Go, children respond to the X on a gray background with a right button press. For the remaining stimuli, children press the right button if the X is on gray and the left button if the X is on white. See the Appendix for more details.
pants' interest and attention by varying the stimulus type.

Reaction times shorter than 200 ms or longer than 4,000 ms (less than 2% of the trials) were deleted as potentially unreliable. All responses to the SRT and Go/No-Go tasks that occurred within this time frame were included. Median reaction times were computed for each stimulus type to correct for any undue influence of outliers. For the Choice Reaction Time, Parallel Search, and Serial Search trials, the medians were based on correct responses only (92% of trials). For the initial set of VF analyses, the outcome measure was the average reaction time for the four Serial Search conditions.

Rapid Auditory Processing. The Rapid Auditory Processing task (Waber et al., 2001) requires that the child listen to pairs of complex tones and signal by a button press whether the two tones are of the same or of different pitches. The tone pairs varied by their durations (40, 75, or 250 ms) and inter-stimulus intervals (10, 50, or 100 ms). Stimulus characteristics are described in the Appendix. Testing commenced after successful completion of a standardized training phase.

Training was carried out with tones of 250 ms duration, separated by 400 ms. Children listened to the tone pairs, determined whether the tones were of the same or of different pitches, and received auditory feedback (bells or crashes) as to whether their responses were correct or incorrect. When the child achieved a criterion of 8 out of 10 consecutive correct responses, practice was terminated. A maximum of 40 training trials was given.

In the testing phase, trials (i.e., tone pairs) were given without auditory feedback. Combinations of the three stimulus durations (40, 75, or 250 ms) and three inter-stimulus intervals (ISI: 10, 50, and 100 ms) yielded nine blocks of 10 trials each. The first two trials in each block provided the child with the opportunity to accommodate to the speed of presentation; these trials were not included in the data analysis. The eight test trials included two of each of the four possible pitch combinations (high-high, low-low, high-low, low-high), with the order of presentation randomized for each block. The trial blocks were presented in descending order of ISI within stimulus duration types. All children received the stimuli in the same order.

The outcome measure was the total number of errors across the 72 trials. Some children—four from the clinical sample (three No AD/RD and one ADHD/RD) and nine from the control sample—failed the training phase. Because failure at this phase demonstrated that these children were unable to perform the task, it would have been inappropriate to exclude them from the analysis; therefore, scores were imputed by assigning an age-adjusted score error equal to two standard deviations greater than the mean of all of the children who participated in the larger study (N = 446).

Procedure

The two experimental tasks were administered as part of a fully automated test battery that measured temporal information processing in school-age children. The tasks were presented in the context of an animated space adventure, where each task was an obstacle on a voyage to save a dying planet. The test battery took approximately 90 minutes to administer, not including breaks. The RAP task was administered first, and the VF task was administered last.

Visual Filtering. In this part of the adventure, the children drop supplies to the planet's surface. They are told that if the target (X) is on land (i.e., gray background), they are to drop the supplies (i.e., right button press); if it is not on land (i.e., white background), they are not to drop the supplies (i.e., left button press). For each trial, the computer recorded both the child's response and the response time (RT) from the onset of the stimulus display until the button press. Except for the No-Go trials, where the stimulus remained on the screen for a fixed length of time, all visual stimuli remained on the screen until the child pressed a response button.

Rapid Auditory Processing. In this part of the adventure, an animated character instructs the children to collect supplies (chocolate) from two-headed "chocolate miners." There are two types of chocolate, orange flavored and mint flavored. The child is to collect only the orange-flavored chocolate, which is needed to save the planet. Orange-flavored chocolates are sold by miners whose heads are the same; mint-flavored chocolates are sold by miners with different heads. Because it is dark in the mines, the miners are identified by their voices. Miners with the same voices (tones) sell the good (orange) candy, and miners with different voices sell bad (mint) candy. Images of the chocolate miners appeared on the screen during the narration, and these images were posted over the response buttons to remind the child which button was same and which was different.

Apparatus

Testing was conducted on a Hewlett-Packard Vectra VL 5/133 MT Series 4 computer. Visual stimuli were presented on a Mitsubishi Diamond Scan 15 HX (Model SD5700C) monitor with a 35.6-cm diagonal viewable image. Auditory stimuli were presented via Sony MDR v 600 headphones. Responses were acquired on a custom response box.

Statistical Methods

To identify covariates, demographic data were analyzed using linear regression analysis (PROC GLM; SAS Institute, 1996) for continuous data and chi-square analysis (PROC FREQ; SAS Institute, 1996) for categorical data.

Linear regression was used to analyze the response time and error count data. Repeated measures rather than
MANOVA methods were used to take within-subject correlation into account and to better accommodate the small group sizes. To adjust for departure from normality assumptions, robust estimates of regression coefficients and standard error estimates based on generalized estimating equations (PROC GENMOD; SAS Institute, 1996) were used in all repeated-measures analyses.

The primary outcome variables (treated as repeated measures) were the average median response time for the Serial Search task conditions (VF task) and the total number of errors (RAP task). These variables were entered as age-adjusted z scores, calculated in reference to the entire NJI community population. Preliminary analyses were carried out to determine whether the NJI control group differed from the four LI clinical groups on these tasks. The primary analysis compared performance among the four groups within the LI sample in order to examine the double dissociation. The final set of analyses decomposed the component operations of the visual serial search.

**Results**

**Clinical Groups vs. Control Group**

**Demographics.** Demographic variables were analyzed to identify covariates for subsequent analyses. The control group had a higher proportion of girls than the clinical group, \( \chi^2(1, N = 230) = 15.2, p < .001 \), and the children in the control group obtained higher scores on K-BIT Matrices, \( F(1, 226) = 20.52, p < .0001 \). There were no differences in age, parental occupation (Hollingshead, 1975), or years of parental education (\( p > .05 \) for all). Therefore, gender and K-BIT Matrices were entered as covariates in all comparisons between the clinical and control groups.

**Information Processing.** A repeated-measures multiple linear regression analysis was used to examine the differences between the control group and the four clinical groups on the information processing tasks. The regression was modeled as a z score = Group (2) × Task (2) × Gender (2) × K-BIT.

There was no main effect of task, \( \beta = .04, SE = .09, p > .05 \), nor were there any significant interactions. There were main effects of gender, \( \beta = .30, SE = .10, p < .01 \), with boys obtaining better scores than girls, and K-BIT Matrices, \( \beta = .01, SE = .04, p < .0001 \), with children with higher Matrices scores obtaining better scores. There was also a main effect of group membership, \( \beta = .73, SE = .12, p < .0001 \). The control group performed better than the clinical groups taken together.

Planned comparisons were used to contrast the performance of the control group with each of the four clinical groups. The control group obtained scores from .6 to 1.7 standard deviations (SD) better than each of the clinical groups: ADHD/RD, \( \beta = 1.7, SE = .3, p < .0001 \); No AD/RD, \( \beta = .7, SE = .2, p < .0001 \); ADHD/No RD, \( \beta = .7, SE = .2, p < .0001 \); No AD/No RD, \( \beta = .6, SE = .2, p = .001 \). Thus, all of the clinical groups—even the clinical group that did not meet criteria for either ADHD or RD—performed less well than the control group on the information processing tasks.

**Comparisons Among the Clinical Groups**

**Demographics.** There were no main effects or interactions of ADHD group or reading group for K-BIT Matrices, mother’s education, mother’s occupation, father’s education, or father’s occupation. There was, however, a 2-way Reading × ADHD interaction, \( F(1, 76) = 5.2, p < .05 \), for age; children in the ADHD/RD group were younger (\( p < .001 \)) than those in the other groups. Because the scores on the information processing tasks were already age-adjusted, age was not used as a covariate. The ADHD group had a higher proportion of boys than the No AD group, \( \chi^2(1) = 5.4, p < .05 \). Therefore, gender was entered as a covariate.

**Information Processing.** A repeated-measures multiple linear regression analysis was used to examine the effects of ADHD and reading group, with task serving as the repeated measure. The multiple regression was modeled as a z score = Reading (2) × ADHD (2) × Task (2) × Gender (2).

Because there was a significant 3-way Task × ADHD × Reading interaction, \( \chi^2(4) = 12.4, p < .05 \), separate analyses were carried out for the two tasks (see Figure 2).

For the Serial Search task, there was a main effect of ADHD; children with ADHD demonstrated longer response times than No AD group children, \( \beta = .94, SE = .36, p < .01 \). There were no other significant main effects or interactions.

For the RAP task, there was a main effect of reading, \( \beta = .3, SE = .27, p < .05 \); adequate decoders made fewer errors than poor decoders. None of the other main effects or interactions were significant. Thus, the predicted double dissociation was demonstrated.

**Decomposition of Visual Search Performance**

A further goal of this study was to identify which components of the Serial Search task entailed the greatest response time cost for children with ADHD/IA. Performance on the Serial Search task reflects the sum of its component operations, any one or any combination of which could have contributed to the observed differences in RT between children with and without ADHD.

At least four distinct component processing operations can be identified in the Serial Search task. The child must

1. locate the X among the field of distractors (through serial or parallel search operations);
2. determine whether the X is on a gray or white background (Go/No-Go);
3. choose the response (Choice Reaction Time); and
4. perform the motor response (SRT).
Analyses of these components are presented in the reverse of this order, from simplest to most complex. Figure 3 shows response times for the clinical groups.

**Response and Decision.** Response times for the SRT, Go/No-Go, and Choice Reaction Time tasks were entered as the dependent variable, with condition (i.e., SRT, Go/No-Go, and Choice Reaction Time) serving as the repeated measure. Both age and gender were used as covariates because we wished to examine actual (i.e., not standardized) response times. The multiple regression in this case was modeled as RT = Condition × Reading × ADHD × Gender × Age.

There was a main effect of condition, \( \chi^2(2) = 33.3, p < .0001 \); median RTs for the SRT were 619 ms faster (\( SE = 126, p < .0001 \)) than Go/No-Go RTs, which were, in turn, 451 ms faster (\( SE = 143, p < .01 \)) than choice reaction times. There were no other significant main effects or interactions. Thus, the observed group differences in the Serial Search task could not be attributed to the response or decision demands of the task.

**Parallel Search.** Parallel search processes could have contributed to the group differences observed for serial search. To test this, the three Parallel Search conditions (P1, P2, P3; see the Appendix) were entered as repeated measures, again with age and gender used as covariates. This multiple regression was modeled as RT = Condition × Reading × ADHD × Gender × Age.

There was no main effect of condition, \( \chi^2(2) = 3.9, p > .05 \), as would be expected for parallel search stimuli in which the addition of visual information does not change the time to find the target. There was also no main effect for reading, \( \beta = 20, SE = 45.6, p > .05 \), nor were there significant interactions. Children with ADHD, however, responded 124 ms more slowly than children without ADHD (\( SE = 56.9, p < .05 \)). Thus, parallel search processes were implicated in the slow rate of serial search observed for children in the ADHD group.

**Slope of the Serial Search Function.** We next examined serial search independent of other component operations. Least squares regression lines were fitted to each child’s RTs across the four Serial Search conditions. The slope of these lines reflects the increase in RT as the number of distractors is increased. Children who are more affected by the additional distractors will have proportionally greater increases in their RTs and, thus, steeper slopes. Because all of the response and decision operations are included in each of the constituent Serial Search tasks, and the P/S Parallel Search condition serves as the baseline for this computation, this regression line represents the unique effect of the serial search process. The slope variable was adjusted for age using a z score transformation, and the regression was modeled as Slope = Reading \( (2) \) × ADHD \( (2) \) × Gender \( (2) \).

There was a significant main effect of ADHD; children with ADHD had steeper Serial Search functions than children without ADHD, \( \beta = 1.0, SE = .46, p < .05 \). There was no main effect of reading, \( \beta = .30, SE = .33, p > .05 \), nor were the interactions significant. Thus, children with ADHD had slower Serial Search rates in addition to and independent of the difference in their speed of Parallel Search.

**RT Changes Over Time.** One obvious concern in drawing inferences about ADHD from the visual search task is that poor performance could reflect a child’s difficulty with sustained attention. To examine this possibility, we calculated the median RT and the number of errors for each quarter (i.e., consecutive block of 30 stimuli) of the task. If children were experiencing difficulty sustaining attention, they might be expected to respond more slowly
and/or commit more errors as the task progressed. For this analysis, RT and errors were the dependent variables; ADHD, reading, gender, and age were the between-subjects factors; and quarter was the repeated measure. This multiple regression was modeled as RT (or errors) = Quarter (4) × ADHD (2) × Reading (2) × Gender (2) × Age.

There were significant main effects for ADHD; RT: $\beta = 18.15$, $SE = 7.67$, $p < .05$; errors: $\beta = 11.3$, $SE = 5.5$, $p < .05$. Children with ADHD committed more errors than children without AD (12 vs. 8 errors over 120 trials). There was no effect of quarter; RT: $\chi^2(3) = 3.04$, $p > .05$; errors: $\chi^2(3) = 4.03$, $p > .05$; nor were there ADHD × Quarter interactions; RT: $\chi^2(3) = 1.66$, $p > .05$; errors: $\chi^2(3) = 1.28$, $p > .05$. Thus, there was no evidence that RT or error rates changed systematically over the course of the test for either group, suggesting that on this task, children with ADHD did not have difficulty sustaining attention over time.

**RAP Response Time**

Because the number of errors was the primary outcome measure of interest for the RAP test, children were not instructed to respond as quickly as possible for this task. Nevertheless, RT is systematically related to the stimulus characteristics of this task (Waber et al., 2001). For the sake of completeness, therefore, we evaluated the RAP task using RT as the outcome variable. RT was age adjusted using a z-score transformation and modeled as RAP RT = Reading (2) × ADHD (2) × Gender (2). There were no significant main effects of reading, $\beta = .27$, $SE = .29$, $p > .05$; ADHD, $\beta = .30$, $SE = .35$, $p > .05$; or gender, $\beta = .06$, $SE = .32$, $p > .05$; nor were the interactions significant.

**Discussion**

Consistent with the central prediction of a double dissociation, children with ADHD/IA differed from those without an attention disorder on the Serial Search task but not on the auditory processing task; the reverse was true for children with RD. Children with ADHD/IA responded more slowly and made more errors on the Serial Search task than did children without attention problems, whereas children with RD made more errors than children without decoding problems on the auditory processing task. Thus, children with ADHD/IA did not exhibit global information processing deficits, nor were they generally inattentive on tasks that required sustained attention. Rather, they processed visual information more slowly, especially in the context of increased cognitive load and of a requirement for integrating multiple component operations. Consistent with our previous findings (Waber et al., 2001; Weller, Harris, et al., 2000), all the referred groups performed more poorly than controls on both tasks, regardless of their attention or reading status.

We also highlighted the specific component operations within the Serial Search task to which children with ADHD/IA were most vulnerable. Children with ADHD/IA did not perform more slowly (compared to referred children without ADHD/IA) on measures of motor response (SRT), basic decision making (Go/No-Go), or Choice Reaction Time, indicating that slower response speed and decision making are not specific features of ADHD/IA. These results are consistent with those of Hynd et al. (1989) and Hayes, Hynd, and Wisenbaker (1986), who found that simple reaction time measures did not differentiate children with ADHD without hyperactivity (ADHD/NO) from controls. Although we predicted group differences for serial search, the parallel search dif-
ference was unexpected. There was no
group difference, however, in the choice
condition, where the stimuli were quite
similar to the ones presented in the
first Parallel Search condition (P1). A
possible explanation, therefore, is that
this difference may reflect the specific
structure of this task, which entailed
the added cognitive load of an unpre-
dictable and intermixed rather than a
blocked presentation (Enns & Akhtar,
1989).

The primary finding, however, was
that children with ADHD/IA were
disproportionately affected by the ad-
dition of distractors, independent of
other component operations of the
task. This suggests that either the pro-
cessing of each search item or the
switching of focus from one item to the
next was slower for the children with
ADHD/IA.

Other possible explanations, particu-
larly in light of the evolution of the
ADHD diagnosis, would include those
related to attention. There was no em-
pirical evidence of a systematic decline
in performance over the course of the
VF task, as might be expected if the
ADHD/IA group had a deficit in sus-
tained attention. Subtle methodological
variation can, however, influence the
likelihood of observing a change in per-
formance over time (Schild & Joesckho,
1990), and our analysis would not have
been sensitive to fluctuating attention.

These findings, therefore, do not con-
closively rule out the possibility that
children with ADHD/IA might also
have problems with sustained atten-
tion. One would expect, however, that
if their slower KTs were due only to
inattention, the slowing would mani-
fest equally across all of the Serial
Search conditions. If this were the case,
we might see a group difference in the
intercept but not in the slope of the line
connecting the KTs for the serial search
stimuli. This was not, in fact, what we
found. There was a clear ADHD slope
difference; the ADHD/IA group was
disproportionately affected as more
distractors were introduced. Finally, there
were no ADHD-related differences for
SRT, for RAP errors, or for RAP RT, as
might have been expected if children
with ADHD/IA had more variable at-
tention than the other children in the
clinical group, or if they were globally
slow.

Slower visual search could, however,
reflect diminished selective attention.
Indeed, Barkly (1997) has suggested
that children with ADHD/IA have an
impairment of selective attention rather
than of sustained attention. The term
selective attention has been used to refer
to the ability to effectively perform an
operation in the presence of conflicting
information (Posner, 1988) that is irre-
levant to the task (Schneider & Shiffrin,
1977). Unfortunately, it can be difficult
to draw a clear distinction, at least at
the behavioral level, between the con-
structs of selective attention and pro-
cessing speed. The WISC-III Coding
subtest, for example, is used as an ex-
emplar of selective attention by some
investigators (e.g., Mirsky, 1996) and of
processing speed by others (Kail &
Hall, 1994; Neubauer & Knorr, 1998;
Salthouse, 1992). Even more confusing,
some theorist define selective atten-
tion as the rate at which encoding,
search, and decision can proceed
(Sergeant & Scholten, 1985).

Posner and Petersen (1990) have the-
ORIZED that attention is guided, as if it
were a spotlight; in order for this guid-
ing to occur, the spotlight must be dis-
engaged, moved, and then re-engaged.
The slower and less efficient perfor-
mance of the ADHD/IA group on the
Serial Search task, as well as on other
measures of processing speed, could
reflect differences in these operations.
The observation that performances on
serial search tasks follow the same de-
velopmental course as performances on
other processing speed measures
(Enns, Brodeur, & Trick, 1998; Kail,
1988) raises a relevant question. If there
is a global mechanism that controls the
developmental change in processing
speed, might it also affect the speed
with which the attentional spotlight
can be disengaged, moved, and then
re-engaged? This is a very basic ques-
tion with important implications for
developmental disorders, where issues
of processing and attention seem to be
so inextricably linked.

A persistent clinical question is
whether children with the inattentive
subtype of ADHD are best understood
as having an attention disorder or
whether they would be more properly
classified along the spectrum of learn-
ing disability. Our study, which was
based on children referred for learning
problems, allowed us to address this
question to some extent. The double
dissociation between ADHD and RD is
consistent with the conclusion that RD
and ADHD are distinct clinical phe-
nomena that can be comorbid.

Rutter (1978) has argued that in
order for disorders to be considered
separable, they must differ from each
other along dimensions that are inde-
pendent of the diagnostic criteria used
to identify them. In this study, perfor-
mances on a single-word reading mea-
sure were used to assign children to
reading groups. Parent and teacher
questionnaire data were used to assign
children to attention groups. Perform-
ances on computerized measures of
information processing provided ex-
ternal validation for the distinction be-
 tween the RD and ADHD groups by
way of a disorder-task interaction
(Fletcher, 1985).

Alternative criteria for evaluating
differences between disorders include
causation, etiology, outcome, and re-
sponse to treatment (Szatmari, 2000).
With respect to the latter point, few
would argue that the disorganization
and slow cognitive tempo of children
with ADHD would improve in response
to extra reading help. The alternative
argument is less clear. Because all the
referred groups performed worse than
the control group on information pro-
cessing tasks, it may very well be that
interventions (e.g., support in using
metacognitive strategies) that appear
to benefit children with ADHD might
help other children with learning im-
pairments. Until we understand more
about the causation of RD and ADHD/
IA and until data pertaining to the in-
formation processing capacities of chil-
dren with other forms of ADHD are
collected, it may be best to consider the usefulness (Szatmari, 2000) of distinguishing children with ADHD from those with other learning disorders. Because children with ADHD are at high risk for academic problems and because we suspect that they would benefit from small-group or individualized instruction, perhaps the most useful approach for now is to consider them to be children with a form of learning disability.

The present study did have some limitations. Children were assigned to diagnostic groups based on questionnaire data, without structured interviews. This procedure was, however, objective and multimodal. Clinical interviews and questionnaire data excluded other potential causes for the observed symptoms. If classification errors did occur, they would most likely have resulted in the inclusion of children without ADHD into the ADHD/IA group, potentially reducing the likelihood of finding group differences. Another potential limitation was that the ADHD/RD group comprised only nine children and, thus, their performance might not generalize to the larger ADHD/RD population. In addition, we excluded a priori children who were already receiving stimulant medication. This could have biased our sample against more severe cases or against children who, for whatever reason, are identified early.

The design of this study did not allow us to consider other important questions. Because children with clinical levels of hyperactivity/impulsivity were excluded, we could not compare the performance of the different ADHD subtypes. Moreover, because the visual and auditory tasks used in this study were not constructed to be analogous but differed across multiple dimensions, we could not clarify whether the processing speed vulnerability of children with ADHD/IA was limited to the visual system or whether it might have been specific to output rather than to input operations. Finally, the design of the larger study from which these data were derived required that the information processing tasks be administered in a standard order. Therefore, for this study, we could not assess the potential effect that administration order (i.e., RAP first and VF last) might have had on the performance of the children within the ADHD group. It is noteworthy, however, that in our previous study (Weiler, Bernstein, et al., 2000) we identified specific, ADHD group deficits on other visual processing speed tasks that were administered at various points during the child's testing day.

From a clinical standpoint, these findings shift the focus of concern for children with ADHD/IA from inattention to inefficiency of visual information processing, perhaps including those operations that are necessary to enable a child to fluidly shift visual focus. The presence of such information processing inefficiencies could explain why these children are said to encounter more academic problems even though many would not receive a formal diagnosis of learning disability.

Most important, these results suggest that clinicians, parents, and teachers should be mindful of the likely vulnerability of children with ADHD/IA to increases in processing demands. As these children are required to comprehend large amounts of information, to perform a task rapidly, to flexibly shift between activities, or to link a sequence of cognitive operations in an on-line fashion, their performance may deteriorate, causing them to appear inattentive and disorganized. If the source of their problem is, in fact, primarily cognitive, strategies that focus on attentiveness per se may be less effective than those that modulate the pace of presentation. Providing additional time to make transitions between activities or topics, simplifying multistep tasks, supporting the development of metacognitive strategies, teaching organizational techniques, relaxing overall time constraints, and moderating the amount and speed of output required may be productive approaches to intervention for these children.

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AUTHORS' NOTES

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APPENDIX

Visual Filtering Task

Motor Response and Decision Tasks

This set included one response condition (simple reaction time: SRT) and two decision conditions (Go/No-Go and Choice Reaction Time).

SRT. The stimuli were presented using the same random interval schedule for each child, varying from 1,500 to 3,400 ms. The child was instructed to respond as quickly as possible and press the button on the right side as soon as the X appeared. The stimulus remained on the screen until the child’s response; the next stimulus appeared after a pseudorandom interval.

Go/No-Go. The stimuli were presented, and the child was instructed to respond as quickly as possible and press the right button if the X was on gray, but not to respond if the X was on white. Gray and white trials were randomly interspersed. The stimulus remained on the screen until the child’s response.

Choice Reaction Time. The stimuli were presented, and the child was instructed to respond as quickly as possible and press the right button if the X was on gray and the left button if the X was on white. Gray and white trials were randomly interspersed. The stimulus remained on the screen until the child responded.

Visual Search

This test included 121 Parallel Search and Serial Search stimuli. The order of the stimuli (20 stimuli of each of the six types, plus an initial, discarded trial) was determined using a random selection without replacement procedure, with the sequence adjusted to ensure that five of each stimulus type were presented within each quarter of the test (i.e., 30-stimulus block). Stimuli were presented at regular intervals: The stimulus remained on the screen until the child responded. A gray masking field (the same size as the stimulus, with a central fixation dot) appeared 500 ms after a response and remained on the screen for 350 ms, until the next stimulus appeared.

The Parallel Search task included three conditions. Parallel Search (P1) was similar to Choice Reaction Time, but the X appeared at random locations within the 3 x 3.7 degree array rather than at central fixation. Parallel Search–Gray (P2) was the same as P1, but added randomly shaped gray patches. Parallel Search–Lines (P/S) was the same as P2, but with 15 vertical line fragments (each the length of one diagonal of the X target) superimposed.

The Serial Search task included four conditions: Parallel Search–Lines and three sets (S40, S80, and S100) of stimuli with 40%, 80% or 100% of the 15 superimposed line fragments laterally displaced and rotated off the vertical to provide increasing distractors. The P/S condition served as both the final Parallel Search condition and the baseline Serial Search condition. Two-week test–retest reliability of an average of the Parallel Search reaction time score was .77.

Rapid Auditory Processing

The stimuli were patterned after the complex tone stimuli described by Tallal and Piercy (1974) and were created as follows: Two steady-state three-formant complex tones, which are perceived as nonspeech, were generated with the cascade version of the Klett (1980) synthesizer. Formants are the resonant frequencies of vowels that directly relate to the vocal tract shape for a particular vowel production (Fucci & Lass, 1999). Each stimulus was 875 ms in duration and had formant frequency values of 497, 750, and 1500 Hz. The two complex tones differed in their fundamental frequency (F0); the F0 of one tone was 100 Hz and the F0 of the other tone was 180 Hz. A waveform editing program was used to cut each of these complex tones into three shorter stimuli, with durations of 40, 75, and 250 ms, yielding six stimuli in all. The amplitude of each of these six stimuli was ramped over the final 10 ms to yield a gradual decline, and the overall rms level of the six stimuli was equated. Stimulus pairs were created by pairing the two stimuli (one with an F0 of 100 Hz and one with an F0 of 180 Hz) for a given stimulus duration (40, 75, or 250 ms) in all four possible combinations (AA, BB, AB, BA) with silence files (interstimulus intervals, ISI) separating the stimuli within a pair by 10, 50, 100, or 400 ms in duration. This yielded 48 stimulus pairs in all, which were then used to create the task. Two-week test–retest reliability for the total error score was .85.