Intact and Impaired Memory Functions in Autism

Loisa Bennetto and Bruce F. Pennington
University of Denver

Sally J. Rogers
University of Colorado Health Sciences Center

BENNETTO, LOISA; PENNINGTON, BRUCE F., AND ROGERS, SALLY J. Intact and Impaired Memory Functions in Autism. CHILD DEVELOPMENT, 1996, 67, 1816–1833. This study examined memory functions in individuals with autism. Based on previous evidence of executive function (EF) deficits, we hypothesized that subjects with autism would demonstrate a pattern of intact and impaired memory functions similar to that found in other groups with EF deficits, such as patients with frontal lobe pathology. We compared the performance of high-functioning children and adolescents with autism (n = 10) and clinical comparison subjects (n = 19) matched on sex, CA, and VIQ on measures of memory and EF. The group with autism performed significantly worse than comparison subjects on measures of temporal order memory, source memory, supraspan free recall, working memory, and EF, but not on short- and long-term recognition, cued recall, or new learning ability, consistent with the predictions of the EF theory. The cognitive measures were significantly more intercorrelated in the autism group than the comparison group, consistent with a limit in central cognition.

Several independent studies have found evidence of poor performance on measures of executive function in children, adolescents, and adults with autism (e.g., Hughes, Russell, & Robbins, 1994; McEvoy, Rogers, & Pennington, 1993; Ozonoff, Pennington, & Rogers, 1991; Prior & Hoffmann, 1990; Rumsey & Hamburger, 1988). The tasks used included standard clinical tests such as the Wisconsin Card Sorting Test, Tower of Hanoi, Trail Making Test, Rey-Osterrieth Complex Figure, and Milner Maze, as well as more experimentally based tasks such as Hughes and Russell’s (1993) object retrieval task. These findings have led some researchers to propose a theory of autism based on deficits in executive function (Hughes & Russell, 1993; Ozonoff et al., 1991). “Executive function” (EF) is an umbrella term used by psychologists to refer to goal-directed, future-oriented behaviors that involve planning, flexible strategy employment, inhibition, and organized search (Welsh & Pennington, 1988). Deficits in these skills could explain many of the behavioral symptoms found in autism, including rigid and inflexible behavior, perseveration, inappropriate responding in social situations, inability to learn by experience and to adapt to changing environments, lack of initiative, and concreteness in thought processes (Damasio & Maurer, 1978; Rumsey, 1985; Rutter, 1983).

Executive function impairment is usually associated with patients with frontal lobe lesions. It should be noted, however, that diffuse brain damage (Hefton, Chelune, Talley, Kay, & Curtiss, 1993; Levin et al., 1994) or damage to subcortical structures connected to the frontal lobes (Cummings, 1993) can produce EF impairment. Damage to attentional control systems, such as the cerebellum, may also compromise performance on EF measures (Courchesne et al., 1994). Thus, while patients with frontal lesions provide a good illustration of EF impairment, not all EF impairment is associ-

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ated with frontal lobe pathology. So the finding of EF impairment in autism does not necessarily imply localized frontal lobe pathology.

In addition to showing deficits on EF tasks, patients with frontal lesions also demonstrate a well-characterized pattern of memory deficits (Shimamura, Janowsky, & Squire, 1991). Therefore, in the current study, we evaluated the performance of children and adolescents with autism in the domain of memory. The cognitive neuropsychology of memory is better developed, both in terms of theories and tasks, than is the cognitive neuropsychology of executive functions. Memory theorists distinguish several different types of memory, have developed experimental tasks for each type (and its components), and have demonstrated different profiles of memory impairment across patient groups with different etiologies and lesion locations (Squire, 1987). Thus, the area of memory provides both well-articulated theories and fine-grained measures for further examining neurocognitive deficits in autism.

In the current study, we present a comprehensive assessment of memory performance in autism, and examine whether individuals with autism demonstrate a pattern of memory performance similar to patients with frontal lesions. Similar patterns of memory performance would demonstrate an additional link between the cognitive deficits of individuals with autism and patients with frontal lesions, and would be consistent with an EF theory of autism. However, a fundamental limitation to an EF theory of autism is that “executive functions” comprise a complex set of abilities, which limits the usefulness of this construct as a core deficit of the disorder (Sigman, 1994). One component process that has been proposed to be involved in EF tasks is working memory (e.g., Cohen & Servan-Schreiber, 1992). In the discussion, we will address the implications of our results for a working memory model of autism.

**Memory Functions in Patients with Frontal Lesions**

Frontal lobe pathology is associated with a specific profile of memory dysfunction, which is distinct from the pattern of deficits associated with damage to the medial temporal lobes or diencephalic midline. While traditional amnesic patients generally perform poorly on tasks that require the storage and consolidation of declarative information, patients with frontal lesions exhibit deficits in remembering certain kinds of contextual or spatiotemporal information (Schacter, 1987). In particular, patients with frontal lesions have shown consistent impairment on measures of memory for temporal order and source memory, which we will review below. Shimamura et al. (1991) argue that these kinds of tasks utilize a memory system that allows an individual to access, organize, and manipulate memories, thus allowing consideration of their spatial, temporal, or semantic context. Moscovitch (1994) has coined the term “working with memory” to refer to these executive processes utilized by the memory system. In contrast to their poor performance on temporal order and source memory, patients with frontal lesions are typically not impaired on learning new information or recognition memory, which rely primarily on effective storage and consolidation of declarative information.

On tasks of temporal order memory, several studies have found that patients with frontal lesions have marked impairments (e.g., Eslinger & Grattan, 1991; Milner, Corsi, & Leonard, 1991; Milner, Petrides, & Smith, 1985; Shimamura, Janowsky, & Squire, 1990). Memory for temporal order is often assessed with the Corsi task (cited in Milner, 1971), in which subjects are shown a series of verbal or nonverbal stimuli, and periodically asked which of a pair of stimuli was presented more recently. In addition, recognition trials, in which one of the stimuli is new, are interspersed with the temporal order trials. Thus, the task provides a within-subjects comparison of temporal order memory and recognition memory. Compared to patients with temporal lesions and control subjects, patients with frontal lesions exhibit poor temporal order memory, despite intact performance on the recognition trials.

Patients with frontal lesions may show deficits on temporal order memory tasks because memory for temporal order requires the subject to retain more than the content of the memory. Memory for temporal order also requires organization of distinct memories and retention of their temporal relationship to each other. Impaired processing of temporal variables such as time and order has been cited as a characteristic deficit in patients with frontal lesions (e.g., Grafman, 1989), as well as frontally lesioned animals (e.g., Fuster, 1985).
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On tests of source memory, patients with frontal lesions also show impairment (e.g., Janowsky, Shimamura, & Squire, 1989; Schacter, 1987). The phenomenon of "source amnesia" was first described by Schacter, Harbluk, and Mclachlan (1984) to refer to cases in which an individual was able to remember something without being able to remember where or when the information was originally learned. This effect has been shown with experimental tasks in which subjects are taught fictitious statements, and then later tested for retention of the information and its source. An inability to utilize the source of learned information has also been shown on a variety of multistart learning tasks. Patients with frontal impairments have shown an exaggerated tendency to intrude early list items onto successive lists (Cermak, Butters, & Moreines, 1974; Moscovitch, 1992; Stuss et al., 1982). These intrusions are essentially source errors. Source memory is similar to memory for temporal order because it relies on memory for context, rather than memory for factual information. In fact, source amnesia has been demonstrated to be unrelated to measures of fact recall (Craik, Morris, Morris, & Loewen, 1990; Schacter, Harbluk, & Mclachlan, 1984). A recent developmental study suggested a relation between source errors and executive function deficits in children (Rybash & Colilla, 1994). This study also found that source errors were unrelated to fact recall or digit span.

Patients with frontal lesions have also been shown to perform poorly on some types of free recall tests, despite good performance on comparable tests of cued recall and recognition. Specifically, some studies have demonstrated that patients with frontal lesions are impaired in the free recall of multiple trials of words (Jeter, Poser, Freeman, & Markowitz, 1986; Shimamura et al., 1991). Other studies, however, have failed to find clear impairments (see Schacter, 1987, for a review). Cognitive deficits in fluency, organization, and self-monitoring that result from frontal damage may affect self-initiated strategic retrieval skills, as well as the ability to suppress potentially interfering items when doing free recall tasks.

Finally, recent work with both humans and primates suggests a strong tie between the frontal lobes and working memory. Working memory refers to the simultaneous processing and storage of information during the performance of a range of cognitive tasks. It has been described as "representational memory" (Goldman-Rakic, 1987), because subjects must hold a representation of relevant information on line over a delay, and use this information to generate an upcoming action. Goldman-Rakic (1987) has established the role of the dorsolateral prefrontal cortex in spatial working memory, through a series of lesion and single-unit recording studies in nonhuman primates. Working memory has also been shown to rely on the prefrontal cortex in human populations. Gold, Berman, Randolph, Goldberg, and Weinberger (1991) have developed a spatial working memory task for adults, which is conceptually similar to the delayed alternation tasks used with infants and primates. Using regional cerebral blood flow (RCBF) and positron emission tomography (PET), they have demonstrated the role of the dorsolateral and orbital prefrontal cortices in subserving working memory in humans. Finally, Case (1992) has argued for the role of the frontal lobes in the execution of verbal working memory (Counting Span) as well as spatial working memory in children, based on results from EEG studies. Though there appears to be evidence for the role of the frontal cortices in verbal working memory, however, there have been no studies of patients with frontal lesions on this type of task.

While patients with frontal lesions show impairment on certain types of memory tasks, they are typically not impaired on the tasks that involve learning new material, cued recall, or recognition. Such types of memory have been shown to be both theoretically and empirically distinct from "frontal" memory tasks. Schacter (1987) distinguishes between "contextual information," which refers to when and where a specific event occurred, and "item information," which refers to what occurred. Considerable empirical evidence suggests that contextual memory is dissociable from memory for item information in both human and animal subjects (see Schacter, 1997, for a review).

Evidence for Memory Deficits in Autism

The results on memory dysfunction in autism are equivocal. Several studies of memory in autism have proposed that autism is best characterized as an amnesic disorder (Boucher & Warrington, 1976; Delong, 1992). These theories arose and have been supported to some degree by neuropathological studies of autism that have uncovered histological abnormalities in the hippocampus and related structures (Baxman &
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Kemper, 1985; Raymond, Bauman, & Kemper, 1989). Further support has come from evidence of abnormal social behavior and memory loss in monkeys following neonatal ablation of the limbic system (Bachevalier, 1991). Several neuropsychological studies of individuals with autism have also reported evidence consistent with a traditional amnesic theory of autism. Boucher and Warrington (1976) found impairments in free recall and recognition memory. Boucher (1981) found impairments in recall when retrieval cues had to be encoded at input.

In contrast, other studies of subjects with autism have reported intact rote memory skills relative to both retarded and normal control subjects (Barthak, Rutter, & Cox, 1975; Hermelia & O'Connor, 1975; Prior & Chen, 1976). Runsey and Hamburger (1988) examined immediate recall and delayed memory function in a group of high-functioning men with autism using the Wechsler Memory Scale Paragraph and Design tests. They found no significant differences compared to control subjects, suggesting that autism does not affect the consolidation, storage, and retrieval processes that are mediated by the temporal lobes. Boucher (1978) examined echoic memory capacity in children with autism and found no differences compared to normal age-matched control subjects. More recently, Minshew and Goldstein (1993) examined the performance of high-functioning individuals with autism on the California Verbal Learning Test. They found no consistent evidence of poor recall or recognition in autism. Their data did, however, suggest that subjects with autism may have less efficient mechanisms for organizing information.

Several other studies have also found evidence of poor organization affecting the performance of subjects with autism on memory tasks. Ozonoff et al. (1991) found deficits in a group of high-functioning children with autism on a supraspan free recall task, the Bushke Selective Reminding Task. This finding may be explained by difficulties children with autism show in organizing information, as well as in initiating verbal responses. Boucher (1981) examined memory for recent events in children with autism compared to typical children matched on age, and children with mental retardation matched on age and ability level. She found that the ability of children with autism to recall the order in context in which an event occurred was significantly inferior compared to both comparison groups. Ameli, Courchesne, Lincoln, Kaufman, and Grillon (1988) found that the performance of individuals with autism on visual memory tasks was compromised by inflexible cognitive strategies.

In summary, while some studies have found support for impaired memory, others have found evidence of relatively intact memory function. Furthermore, some of the observations of memory dysfunctions in autism are consistent with a deficit in executive processes.

In this study, we will attempt to better characterize the nature of the memory deficit in autism. If individuals with autism mainly have EF impairments, then their profile of memory performance ought to be similar to that exhibited by patients with frontal lesions. Specifically, subjects with autism ought to be impaired on measures of temporal order memory, source memory, and working memory, but not impaired on measures of short- and long-term recognition, cued recall, or new learning ability. This is the main hypothesis of the current study.

Method

Subjects

Two groups of subjects participated in the present study: a group of individuals with autism (n = 19), and a clinical comparison group of individuals without autism (n = 19). Subjects were drawn from a sample of individuals who participated in a research project 3 years ago at our laboratory (Ozonoff et al., 1991). The present autistic group comprised all autistic subjects from the original study who were still living in the area (19 of 23). The present comparison group comprised 14 of the original 20 subjects, plus five new clinical comparison subjects recruited from our laboratory. All comparison subjects had nonautistic learning disorders, including borderline intellectual functioning (n = 2), dyslexia (n = 13), attention deficit hyperactivity disorder (n = 2), genetic disorder (n = 1), and unspecified learning disorder (n = 1). The autistic group was matched with the comparison group on sex, chronological age (CA), and Verbal IQ (VIQ); the groups were not different on handedness, socioeconomic status (SES; Hollingshead, 1975), Performance IQ (PIQ), or Full-Scale IQ (FSIQ), although they were not explicitly matched on these variables.

Each subject had obtained an IQ estimate (prorated from five subtests of the
TABLE 1

DESCRIPTIVE CHARACTERISTICS OF THE SAMPLE

<table>
<thead>
<tr>
<th></th>
<th>AUTISTIC GROUP</th>
<th>COMPARISON GROUP</th>
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<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>15.95 (3.3)</td>
<td>15.53 (2.6)</td>
<td>.76</td>
</tr>
<tr>
<td>VIQ</td>
<td>82.52 (15.2)</td>
<td>88.26 (11.4)</td>
<td>-1.36</td>
</tr>
<tr>
<td>PIQ</td>
<td>98.11 (15.8)</td>
<td>97.58 (14.3)</td>
<td>.11</td>
</tr>
<tr>
<td>FSIO</td>
<td>88.89 (11.1)</td>
<td>91.74 (12.1)</td>
<td>-.75</td>
</tr>
<tr>
<td>Reading skill</td>
<td>90.63 (16.7)</td>
<td>84.26 (21.4)</td>
<td>1.02</td>
</tr>
<tr>
<td>CARS</td>
<td>34.89 (4.1)</td>
<td>18.31 (3.0)</td>
<td>12.33***</td>
</tr>
<tr>
<td>SES</td>
<td>45.53 (10.0)</td>
<td>45.31 (15.2)</td>
<td>.05</td>
</tr>
<tr>
<td>Sex (M:F)</td>
<td>17:2</td>
<td>17:2</td>
<td></td>
</tr>
<tr>
<td>Handedness (R:L)</td>
<td>17:2</td>
<td>16:3</td>
<td></td>
</tr>
</tbody>
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Note.—N = 19 for both the autistic group and the comparison group.

***p < .001.

WISC-R: Information, Vocabulary, Similarities, Block Design, and Object Assembly) within the past 3 years. To ensure that the IQ estimates remained valid, two subtests from the WISC-III (Vocabulary and Block Design) were administered to all subjects. There were no significant group differences on age-scaled scores for Vocabulary, t(36) = –1.47, N.S., or Block Design, t(36) = -.20, N.S. Furthermore, paired t tests performed within each group indicated that there was no significant difference between the old (WISC-R) and new (WISC-III) scores for either Vocabulary, t(18) = -.16, N.S., or Block Design, t(18) = 1.82, N.S. Since the prior IQ scores were considered a more stable estimate of intellectual functioning because they relied on more subtests, they were used in subsequent analyses.

To be included in the study, all subjects had to obtain Full-Scale IQ scores above 69. The mean Full-Scale IQ of the autistic group was 88.89 (SD = 11.14), and of the comparison group was 91.74 (SD = 12.11). Since several tasks involved reading, the Letter-Word Identification subtest of the Woodcock-Johnson Revised Tests of Achievement (Woodcock & Johnson, 1989) was administered to all subjects. All subjects in both groups demonstrated sufficient reading ability to complete the study tasks. On this reading measure, the mean standard score of the autistic group was 90.63 (SD = 16.72), and of the comparison group was 84.26 (SD = 21.37). In addition, we required that all subjects were cooperative and attentive enough to understand the testing instructions and to complete all the tasks. No subjects were excluded for this reason. Table 1 contains descriptive characteristics of the sample.

The autistic group comprised 19 individuals between the ages of 11 and 24 (M = 15.95, SD = 3.25). All subjects in this group met the DSM-III-R criteria for Autistic Disorder. n = 11) or Pervasive Developmental Disorder Not Otherwise Specified (PDDNOS; n = 8). In addition, all 19 subjects in the autistic group fell in the autistic range on the Childhood Autism Rating Scale (CARS; Schopler, Reichler, & Renner, 1986). Since this study was designed to examine deficits in high-functioning individuals with autism, the subjects with PDDNOS were retained, with the rationale that any bias they might introduce would be a conservative one against finding the hypothesized differences.

The comparison group consisted of 19 individuals without autism between the ages of 11 and 21 (M = 15.23, SD = 2.56). All subjects in this group received scores below 24 on the CARS, demonstrating that they fell far outside the range indicative of autism (score >30).

Measures

Executive Function Measures

Wisconsin Card Sorting Test (WCST).—This task, which was originally developed by Grant and Berg (1948), measures conceptual problem-solving abilities, including the ability to modify incorrect strategies flexibly and the ability to inhibit prepotent but incorrect responses. The WCST was administered and scored according to the standard Heaton (Heaton et al., 1993) instructions. Three dependent variables were used in this study: number of categories completed, number of perseverative responses (PR), and number of failures to maintain set (FTMS).
Tower of Hanoi.—Researchers have used this disk-transfer task to study the planning and problem-solving capacities of normal and impaired children and adults (e.g., Borys, Spitz, & Dorans, 1982; Levin et al., 1994; Welsh, 1991). It was administered and scored according to the system described by Borys et al. (1982). The dependent variable in this task was a “planning efficiency” score, which reflected the number of moves a subject required to solve the test problems.

Memory Measures

Temporal order versus recognition memory.—This task provided a within-subject comparison of memory for temporal order and recognition memory for both verbal and nonverbal stimuli. It was adapted from the original Corsi Memory Task (Milner et al., 1961). In this task, subjects were shown series of verbal and nonverbal stimuli, and then were asked to judge which of the two stimuli had been presented more recently (for temporal order trials) or which stimulus they had seen before (for recognition trials).

We did not use the original version of this task for several reasons. First, the original version was designed for use with adults. Because the present study examined performance in children, stimuli needed to be modified appropriately for age and ability level (e.g., verbal IQ, reading skill). Second, ceiling and floor effects have compromised previous studies of the Corsi Memory Test. For example, in Milner et al. (1991), normal comparison subjects performed at a mean recognition accuracy of 94% for concrete words, and 96% for representational drawings. The adaptation of this task (which is described above) was piloted with children and adults to ensure that performance on temporal order and recognition conditions yielded equivalent true score variances (Chapman & Chapman, 1978) and was not compromised by ceiling or floor effects. Without these precautions, the argument from differential group performance to a differential deficit would be tenuous at best. Pilot data indicated that normal subjects performed at approximately 75% correct for both temporal order and recognition trials of the Concrete Words task.

There were two tasks in the test series: Representational Drawings and Concrete Words. The Representational Drawings task consisted of a series of 190 cards (8½ × 11 inches). Each card contained two drawings, placed one above the other. Drawings from this task were selected from the Peabody Picture Vocabulary Test (Dunn, 1965) and the Expressive One-Word Picture Vocabulary Test (Gardner, 1979). The subject viewed each card for 3 sec before the examiner turned to the next card. Periodically, a yellow response card appeared, with a question mark between the two drawings. Whenever this happened, the subject was instructed to point to the picture seen more recently. On temporal order cards, both drawings had appeared before. On recognition cards, one of the drawings was new, and the subject merely had to point to the picture seen before. Since no stimulus item appeared more than one time on an inspection card, judgment for relative recency was always for a trial-unique pair.

One hundred of the cards were white inspection cards; the remaining 90 were yellow response cards. Forty-six response cards tested temporal order discrimination; 29 tested recognition memory. The remaining cards were “dummy” trials, which included several easy recency and recognition trials at the beginning of the deck that were designed to help the subject familiarize himself or herself with the task. The first several cards in the deck were inspection cards; response cards and inspection cards alternated thereafter. Recognition response cards occurred following 16, 32, and 64 intervening items. Three levels of temporal order memory were tested (i.e., 4 vs. 32, 4 vs. 64, 4 vs. 128).

The procedure for the Concrete Words task was similar to that of the Representational Drawings task. Two concrete nouns appeared on each card. Nouns chosen for this task were high on a rating of concreteness, low on a rating of ambiguity, and had a mean age of acquisition under 7 years (Gilhooly & Logie, 1980; Toglia & Battig, 1978). Finally, words that appeared elsewhere in the test battery (e.g., on a different memory task) were excluded to prevent a possible priming effect. The subject was instructed to read aloud the words on the inspection cards. On the response cards, the subject was instructed to point to the appropriate word.

Prior to the task administration, each subject performed a verbal practice task, which was designed to teach the concepts of temporal order and recognition memory, as well as the task instructions. Each experimental task required approximately 10 min to complete. There were two dependent
variables for this task: the percent of correct responses for temporal order, and the percent of correct responses for recognition.

California Verbal Learning Test—Children's Version (CVLT; Delis, Kramer, Kaplan, & Ober, 1986).—This task measured learning and retention of verbal information. It provided information on verbal learning processes, strategies, and patterns of errors. In particular, the CVLT yielded information on free recall, cued recall, and recognition memory, as well as learning rates and retention over both a short and long delay. Furthermore, analysis of error patterns on the CVLT allows for an examination of source memory deficits.

Stanford-Binet Intelligence Scale, Fourth Edition—Memory for Digits Test (Thorndike, Hagen, & Sattler, 1986).—This is a standardized test of short-term auditory memory for digits (Digits Forward and Digits Reversed).

Working Memory—Sentence Span.—This task was adapted for use with children (Siegel & Ryan, 1989) from the procedure developed by Daneman and Carpenter (1980). This task requires the subject to process verbal information on-line and to store the results of this processing for later recall. The experimenter read simple sentences that were missing the last word, and instructed the subject to supply the missing word. At the end of a set of such sentences, the experimenter asked the subject to recall the supplied words in the order the sentences were presented. Set sizes ranged from two to six sentences, with three trials at each set size. The dependent variable was the total number of trials correct.

Working Memory—Counting Span.—This task was designed by Case, Kurland, and Goldberg (1982) and has been used in a study of children with learning disorders (Siegel & Ryan, 1989). In this task, the experimenter instructed the subject to count aloud the yellow dots interspersed with blue dots, all arranged randomly on an 8½ x 11 inch card. After the subject counted the yellow dots on each of a set of cards, the experimenter asked the subject to recall, in order, the number of yellow dots that appeared on each card. There were five set sizes (two to six cards) with three trials at each size. The dependent variable was the total number of trials correct.

Procedure

All subjects were tested at our laboratory. Informed consent was obtained from both parents and children participating in the study. The first author tested 74% of the subjects in the autistic group, and 79% of the subjects in the comparison group. The remainder of the subjects were tested by a trained masters-level research assistant, blind to the diagnoses of the subjects and the hypotheses of the experiment.

Measures in the experimental battery were presented in a fixed order for all subjects. First, Letter-Word Identification was administered to screen for reading ability. Following this were Temporal Order versus Recognition Memory (Words), the CVLT learning and immediate recall trials, Block Design, Counting Span, Digit Span, the CVLT delay trials, Temporal Order versus Recognition Memory for Pictures, Sentence Span, and Vocabulary. Though this increased the risk of order effects, it was necessary because of the large number of verbal memory tasks in the battery (e.g., to control for priming effects). The full testing battery took approximately 2 hours; the attention span and cooperation of all subjects were sufficient that testing was conducted in one session, with time for several breaks. Subjects were paid $25 for their participation in the study. Although all subjects were informed that they could discontinue testing at any time, none chose to do so.

Results

Preliminary Analyses

All dependent measures were examined for violations of the required assumptions. For several variables (i.e., intrusion and recognition errors on the CVLT), the distribution of scores was significantly skewed and nonparametric analyses were consequently employed. Of all the variables examined, there was only one main effect of tester, which is within the number that would be expected by chance. In addition, there was not a significant difference in the number of subjects with autism and comparison subjects tested by each examiner, \( \chi^2(1, n = 38) = .14, \text{ N.S.} \) Consequently, data were collapsed across the testing condition for all subsequent analyses.

Since a large number of statistical tests were performed, significant results may have capitalized on chance, and the overall probability of a Type I error likely exceeded 5%. However, the primary hypothesis of this study predicted a specific pattern of results across a range of tasks, which included both impaired and intact performances. Setting the acceptable alpha too low would reduce
the power of being able to detect a group difference on the tasks for which intact performance was predicted. To lower capitalization on chance and reduce the number of statistical comparisons, specific analyses were planned a priori. In addition, we report exact p values for all analyses for which p was less than .05, and caution the reader to interpret the results conservatively.

PROFILE OF INTACT AND IMPAIRED MEMORY FUNCTIONS

Based on the literature on frontal lobe functioning, we predicted a specific profile of results on the memory tests in this study. Specifically, we predicted that subjects with autism would perform worse than comparison subjects on tasks of temporal order memory, source memory, and working memory. In contrast, we predicted there would be no group differences on tasks of cued recall, short-term recognition, and long-term recognition. To evaluate the fit of the predicted pattern to our data, an omnibus test was conducted, using all variables for which there were strong a priori hypotheses based on studies of patients with frontal lesions, or studies of frontally lesioned animals. Specifically, we predicted that subjects with autism would perform worse than comparison subjects on the two temporal order memory tasks and the two working memory tasks, and would have a higher number of intrusions and false positives on the CVLT. We predicted no group differences on the two recognition memory tasks, and the cued recall and recognition trials of the CVLT.

Two composite scores were computed for each subject with autism: one based on tasks that were predicted to be worse than comparison subjects (predicted-lower), and one based on tasks that were predicted to show no difference (predicted-same). The composites were computed as follows. For each subject with autism, each component variable was converted to a standardized effect size, based on the mean and standard deviation of the comparison group [(score − $M_c$) / $SD_c$]. By using standardized effect size scores, we have accounted for the mean performance of the comparison group. Next, the two composite scores were computed for each subject by averaging the predicted-lower effect sizes and predicted-same effect sizes. The mean effect size was $-3.33$ (SD = 4.35) for the predicted-lower variables, and $-.35$ (SD = 1.10) for the predicted-same variables, revealing a difference of nearly 3 SDs between the two composites.

To test the strength of the pattern of predicted results, a paired t test was computed for these two composite variables. This test indicated that there was a significant difference between the predicted-lower and predicted-same variables, $t(18) = -3.68, p = .002$. Since this test described the size of the difference, but tells less about the pattern of individual performance, a sign test was conducted for each composite variable. For 17 of 19 subjects with autism, the score on the predicted-lower variable was lower than the score on the predicted-same variable, yielding an observed significance level of $p = .0007$.

These omnibus analyses suggest that the overall predicted pattern of results is present in this sample. Further analyses were conducted to describe this pattern in more detail.

EXECUTIVE FUNCTION MEASURES

Independent group t tests were performed on the executive function measures. Performance data on these and other dependent measures are presented in Table 2. On the WCST, the autistic group made more perseverative responses, $t(36) = 3.68, p = .001$, and completed fewer categories, $t(36) = -2.79, p = .009$, than the comparison group. In contrast, there was not a group difference in the mean number of failures to maintain set. On the Tower of Hanoi, the autistic group had a worse total efficiency score than the comparison group, $t(35) = -7.45, p < .001$. Thus, as discussed elsewhere (Ozonoff & McEvoy, 1994), this group of high-functioning persons with autism had longitudinally stable deficits on these two executive function measures.

MEMORY MEASURES

Temporal Order versus Recognition Memory

Because previous studies suggest that different hemispheres may mediate memory for verbal information and pictures (e.g., Milner et al., 1961), performances on the concrete word (Word) and representational drawing (Picture) tasks were analyzed separately. Both tasks were analyzed via a 2 × 2 mixed-model ANOVA, with task (temporal order, recognition) as the within-subjects factor and group as the between-subjects factor.

The ANOVA for the Word tasks yielded a group × task interaction, $F(1, 35) = 4.96, p = .03$. Post hoc analyses showed that this interaction was attributable to the fact that
TABLE 2

**Performance Data and Group Differences**

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<th></th>
<th>Autistic Group</th>
<th>Comparison Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Executive function:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WCST categories</td>
<td>3.36 (2.51)</td>
<td>5.11 (1.41)**</td>
</tr>
<tr>
<td>WCST perseverative responses</td>
<td>60.57 (47.93)</td>
<td>17.16 (17.85)**</td>
</tr>
<tr>
<td>WCST FTMS</td>
<td>.68 (1.25)</td>
<td>1.05 (1.35)</td>
</tr>
<tr>
<td>Tower of Hanoi</td>
<td>23.58 (9.70)</td>
<td>42.89 (5.32)**</td>
</tr>
<tr>
<td>Temporal order memory:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal order-pictures</td>
<td>61.05 (12.89)</td>
<td>69.68 (9.71)*</td>
</tr>
<tr>
<td>Recognition-pictures</td>
<td>79.53 (15.50)</td>
<td>86.11 (8.93)</td>
</tr>
<tr>
<td>Temporal order-words</td>
<td>64.28 (10.71)</td>
<td>73.26 (11.50)*</td>
</tr>
<tr>
<td>Recognition-words</td>
<td>74.83 (10.44)</td>
<td>75.89 (9.00)</td>
</tr>
<tr>
<td>Digit span</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digits forward</td>
<td>5.68 (2.71)</td>
<td>6.05 (1.96)</td>
</tr>
<tr>
<td>Digits reversed</td>
<td>4.68 (2.36)</td>
<td>5.26 (2.32)</td>
</tr>
<tr>
<td>Total span</td>
<td>10.37 (4.67)</td>
<td>11.32 (3.64)</td>
</tr>
<tr>
<td>Standard age score*</td>
<td>43.00 (9.81)</td>
<td>45.00 (6.32)</td>
</tr>
<tr>
<td>Working memory:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sentence span</td>
<td>3.53 (2.07)</td>
<td>6.37 (2.29)**</td>
</tr>
<tr>
<td>Counting span</td>
<td>4.53 (3.95)</td>
<td>7.53 (2.50)**</td>
</tr>
</tbody>
</table>

* Percent correct (chance = 50%)
* Standard age score (mean = 50, SD = 8)
* p < .05.
** p < .01.
*** p < .001.

Subjects with autism performed differentially worse than comparison subjects on the Temporal Order condition compared to the Recognition condition, as predicted. Specifically, analyses indicated that the groups were different on the Temporal Order task, \( t(36) = -2.45, p = .02 \), but not on the Recognition task, \( t(36) = - .33, p = .74 \).

The corresponding ANOVA for the Picture tasks yielded a main effect of group, \( F(1, 35) = 5.86, p = .02 \), and a main effect of task, \( F(1, 35) = 56.34, p < .001 \). There was not a group \times task interaction.

Notably, performance on these tasks does not appear to be compromised by a restricted range of scores. Mean level of performance for all subjects was well above chance (50% correct) and below ceiling (100% correct) for all four tasks. From the Word task, one can infer from comparison subjects’ performance that the Temporal Order and Recognition conditions of the Word task both had an accuracy level midway between chance and perfect performance (i.e., 75% correct). Tasks with a mean level of performance in this range tend to be more reliable and yield observed-score variances more similar to true-score variances (Chapman & Chapman, 1978). Thus, differential deficits are less likely to be artifacts of testing error. In contrast, for the Picture task, comparison subjects’ mean level of performance on the Temporal Order condition was lower than performance on the Recognition condition. Though the variance on both conditions is similar, it is still worth considering that this pattern may reduce the capability of detecting a true differential deficit.

**California Verbal Learning Test (CVLT), Children’s Version**

A series of \( t \) tests were performed to compare the performance of the autistic and comparison groups on the free recall and cued recall scores of the CVLT (see Table 3). The autistic group recalled fewer items than the comparison group on the final three learning trials of List A: Trial 3, \( t(36) = -2.22, p = .03 \); Trial 4, \( t(36) = -2.25, p = .03 \); and Trial 5, \( t(36) = -2.08, p = .04 \). Consequently, their total recall score for List A was lower than that of the comparison subjects, \( t(36) = -2.10, p = .04 \). There were no group differences on the first two learning trials of List A. Similarly, there were no group differences on the free recall trial of the interference list, List B.

Since the autistic group learned fewer items than the comparison group on the
TABLE 3
CVLT PERFORMANCE

<table>
<thead>
<tr>
<th></th>
<th>AUTISTIC GROUP</th>
<th></th>
<th>COMPARISON GROUP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>List A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number correct</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>5.58 (2.78)</td>
<td>6.64 (2.48)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td>8.00 (3.40)</td>
<td>9.53 (2.76)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td>9.21 (3.87)</td>
<td>11.58 (2.23)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 4</td>
<td>9.16 (4.62)</td>
<td>11.95 (2.80)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 5</td>
<td>9.68 (4.08)</td>
<td>12.00 (2.60)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (1-5)</td>
<td>41.63 (17.42)</td>
<td>51.90 (12.28)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>List B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number correct</td>
<td>6.16 (2.85)</td>
<td>6.21 (2.10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>List A short delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent recalled from List A, Trial 5:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free</td>
<td>81.15 (.32)</td>
<td>91.44 (.14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>86.85 (.30)</td>
<td>93.14 (.16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>List A long delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent recalled from List A, Trial 5:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free</td>
<td>90.04 (.26)</td>
<td>93.94 (.14)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cued</td>
<td>88.83 (.23)</td>
<td>96.83 (.15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total perseverations</td>
<td>5.79 (6.29)</td>
<td>3.47 (2.78)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total intrusions</td>
<td>19.32 (31.69)</td>
<td>2.21 (2.55)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delayed recognition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correct (of 15)</td>
<td>13.16 (3.08)</td>
<td>13.89 (2.28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>False positives</td>
<td>5.26 (7.62)</td>
<td>.32 (.58)**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B (shared category)</td>
<td>1.21 (1.48)</td>
<td>.16 (.50)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B (semantic, similar)</td>
<td>1.05 (1.58)</td>
<td>0*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B (nonshared category)</td>
<td>.47 (1.02)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semantic Similar to A</td>
<td>1.37 (1.80)</td>
<td>.16 (.38)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unrelated</td>
<td>.79 (1.48)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phonetically similar</td>
<td>.37 (1.01)</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p < .05.
** p < .01.
*** p < .001.

Learning trials, retention scores for each of the delay trials were calculated relative to each subject's performance on the final recall trial of List A. There were no group differences on the percent of information retained across the short or long delays for either free or cued recall. After a short delay, the subjects with autism remembered an average of 81% on the free recall trial and 87% when they received cues. The comparison subjects remembered 91% on the free recall trial and 93% on the cued trial. After a 30-min delay, the subjects with autism recalled 90% on the free recall trial and 89% when they received cues. The comparison subjects recalled 94% on the free recall trial and 97% when they received cues.

The format of the CVLT allows for coding of recall errors that might interfere with performance on the cued and free recall trials. An analysis of these error types allowed for us to examine the degree to which subjects were influenced by an inappropriate context (i.e., a source other than the current list) in generating responses. The autistic and comparison groups were compared on the total number of perseverations and intrusions made across trials on the CVLT. perseverations were defined as repetitions of the same word within a given trial; intrusions were defined as responses that were not on the target list. Note that the term "perseveration" used here does not carry the same meaning as perseverative responses on EF tasks like the WCST; an increased number of perseverations on the CVLT reflects not only a perseverative response style, but also a severely impaired short-term memory, since subjects are repeating the same word(s) within a several second response period. There was no group difference on the
total number of perseverations across all recall trials. In contrast, the subjects with autism made more intrusion errors than the comparison subjects across all recall trials, \( r(36) = 2.35, p = .03 \).

An analysis of the type of intrusion errors made by the subjects with autism and the comparison subjects yielded several interesting results. All intrusion errors were scored as falling into one of four exclusive categories. Source errors were defined as items that appeared on a previous list. Semantic intrusions were words that were semantically similar to one of the categories on the target list, excluding source errors. Phonetic intrusions were those intrusions that were phonetically similar to one of the words on the target list (e.g., "bat" for "hat"), and were not scorable as source or semantic errors. Unrelated intrusions comprised all other intrusions. Mann-Whitney tests were performed to examine group differences on these error types. There was a group difference on the number of source errors made \( (U = 87.5, p = .006) \), with subjects with autism making more source errors than comparison subjects. Though the autistic group made more total semantic intrusions than the comparison group, this difference did not reach statistical significance. There were no group differences on the number of phonetic or unrelated intrusion errors.

On the delayed recognition trial of the CVLT, the two groups did not differ on the number of correct items endorsed, but the autistic group made more false positive errors than the comparison group \( (U = 85, p = .005) \). Furthermore, the subjects with autism and the comparison subjects differed on the types of distractor items they endorsed. Compared to the comparison subjects, the subjects with autism endorsed more items that were semantically similar to words on the target list. These words were either items from List B that shared the same semantic category as List A \( (U = 93.5, p = .01) \), a similar semantic category with List A \( (U = 114.0, p = .05) \), or were new words that were semantically similar to a category on List A \( (U = 105.0, p = .03) \). In contrast, the groups did not differ on semantically unrelated false positives.

**Digit Span**

The groups did not differ on the raw score of the Stanford-Binet Digits Forward task, Digits Reversed task, or the total score of this test (see Table 2). A standard age score was also calculated for each subject on the total score (Thorndike et al., 1986); mean performance levels of the autistic and comparison groups on this score indicated that both groups were within the normal range when compared to other children their age.

**Working Memory Span Tasks**

The mean score of the autistic group was lower than that of the comparison group on both the Sentence Span task, \( r(36) = -4.02, p < .001 \), and the Counting Span task, \( r(36) = -2.80, p = .008 \). Because verbal short-term memory is thought to be one of the requisite abilities for performance on these types of dual tasks (e.g., Baddeley, 1986), Pearson correlation coefficients were computed between Digit Span Forward and each working memory task: Counting Span, \( r(38) = .60, p < .001 \); Sentence Span, \( r(38) = .36, p = .03 \). Analyses of covariance were performed on both working memory tasks, with forward digit span as the covariate. The group difference remained for both the Sentence Span task, \( F(1, 37) = 16.62, p < .001 \), and the Counting Span task, \( F(1, 37) = 9.87, p = .003 \).

**Relations Among Dependent Measures**

Pearson correlation coefficients were computed to assess the relations between FSIQ, short-term declarative memory, executive function, working memory span, memory for temporal order, and a composite score from the CVLT that reflects the ability to inhibit irrelevant responses in recall. Short-term declarative memory was measured by forward digit span. Composite scores were made from the two executive function tasks, the two working memory span tasks, the temporal order memory tasks (Word and Picture), and the recognition memory tasks (Word and Picture). The inhibition composite score from the CVLT was computed by transforming the total number of intrusions and false positives into z scores. The sum of these two numbers was then restandardized. The correlation analyses were performed separately for the autistic and comparison groups. The higher scores of the comparison group on the EF tasks, and the fact that adult-level performance on the WCST is reportedly achieved by age 10 (Welsh, Pennington, & Groisser, 1991), raises the possibility that the comparison group's performance level is close to ceiling on the standard EF tasks.

The intercorrelation matrix is presented in Table 4. To facilitate comparison, all variables were recoded so that a positive score...
reflected good performance. Below we summarize the correlations that were significant at $p < .05$ or lower. In the autistic group, working memory was related to FSIQ, verbal STM, executive function, recognition memory, and the CVLT inhibition composite. Executive function was also related to FSIQ, temporal order memory, and the CVLT inhibition composite. The CVLT inhibition composite was also related to FSIQ and recognition memory. Recognition memory was also related to temporal order memory and verbal STM. Finally, verbal STM was also related to temporal order memory. In the comparison group, working memory was related to FSIQ, verbal STM, executive function, and the CVLT inhibition composite. Executive function was also related to verbal STM, and FSIQ was correlated with recognition memory.

Of the 21 correlations produced by this matrix, 13 were significant at $p < .05$ or lower in the autistic group, compared to six in the comparison group; both proportions are greater than would be expected by chance (e.g., 1/21). The correlations in the two groups were compared via Fisher’s Z transformation (Cohen & Cohen, 1983). Four of the 21 correlations were significantly different between the two groups. Executive function and FSIQ ($Z = 2.25, p = .005$), executive function and CVLT inhibition ($Z = 2.44, p = .007$), verbal STM and recognition memory ($Z = 2.75, p = .003$), and FSIQ and recognition memory ($Z = -2.33, p = .01$). In all but the last case (FSIQ and recognition memory), the correlations were higher in the autistic group.

**Discussion**

This study examined memory functions in a sample of high-functioning individuals with autism and age- and IQ-matched clinical comparison subjects. The results of the study help to clarify the nature of memory functions in autism, and suggest important implications for the existence of an impairment in general cognitive processes in this disorder.

Subjects with autism displayed a predicted pattern of performance across a variety of memory tasks. They demonstrated a profile of intact and impaired functioning similar to that found in patients with executive function deficits, such as patients with frontal lobe pathology.

Subjects with autism performed worse than comparison subjects on temporal order memory for verbal information. Their intact performance on the recognition portion of the task indicates that their impairment on temporal order memory was not the result of a generalized STM deficit. Since this task was carefully constructed so that attentional demands and item difficulty were consistent across the two conditions, we are more confident that this finding reflects a differential deficit, rather than just differential performance.
There was not, however, a group × task interaction on the representational drawing portion of this task. There are several possible explanations for this null result. First, using a similar version of this task, Milner et al. (1991) found a deficit on temporal order for concrete words in patients with both left and right frontal lesions, but found a deficit in temporal order for representational drawings only in patients with right frontal lesions. Thus, the Temporal Order for Words task may be more sensitive in detecting impairment, regardless of lesion location. Second, performance on picture recognition was relatively good in both groups. This finding is consistent with previous findings that recognition memory for pictures develops early and reaches high levels of accuracy at a young age (Brown & Scott, 1971). The fact that there was a significant effect of task (with recognition memory better than temporal order memory) in both groups may have made it more difficult to detect a group × task interaction.

On the CVLT, subjects with autism demonstrated a flatter learning curve on the List A learning trials than comparison subjects. While the two groups’ performances were similar on early learning trials, subjects with autism were unable to increase their span on the last two trials. This result may reflect the decreased ability of subjects with autism to use strategic organization or planning in recall. This poor performance on supraspan learning is consistent with previous studies of the performance of children with autism on the Bushke Selective Reminding Test (Ozonoff et al., 1991) and the CVLT (Mishew & Goldstein, 1993).

The pattern of errors made by children with autism on both recall and recognition trials of the CVLT is consistent with a deficit in source memory. On recall trials, the subjects with autism made more intrusion errors than comparison subjects. The nature of their intrusion errors reflected a failure to use the context of the current list to constrain responses: they recalled more words that had appeared on a previous but no longer correct list, and tended to recall words that were semantically similar to the target list. Similarly, subjects with autism endorsed more false positive items than comparison subjects on the recognition trial. They tended to endorse false positive items that were semantically similar to the target list, but they did not endorse unrelated false positive items. This pattern of errors suggests that previous exposure to target words primed the appropriate semantic categories, but the subjects with autism failed to use the context of the current task to deselect inappropriate responses. For example, when asked to recall words from the target list that were "things to eat," one subject responded with "apples, oranges, bananas, plums, grapes, lemons, coconut, pineapples, berries." Only "bananas" and "grapes" were on the target list.

Finally, subjects with autism demonstrated intact performance on Digit Span, a measure of auditory short-term memory. There were no group differences on either the Digits Forward or Digits Backward portions of this task. This may seem surprising, since Digits Backward is a more demanding task, which may draw upon more organizational and on-line processing resources than Digits Forward. However, the additional processing demands may not be significant enough to affect performance in subjects with relatively intact STM. Moreover, performances on these two subtasks are highly correlated in the normal population (Thorn-dike et al., 1986).

Thus, across a variety of memory tasks, subjects with autism demonstrated a consistent pattern of memory functions that is similar to that observed in patients with frontal lesions. This pattern included impairment on temporal order memory for verbal information, supraspan verbal learning, and the ability to maintain the appropriate context of the information they had learned. In addition, subjects with autism showed an impairment in two standard tasks of EF. The results of this study suggest that there is a similarity between individuals with autism and patients with frontal lesions on memory, as well as EF tasks.

In addition, the pattern of intact performance of subjects with autism does not support the existence of traditional amnesic deficits in autism. Subjects with autism demonstrated intact functioning on standard declarative memory functions that are typically compromised in classic amnesia. In particular, they were not different from comparison subjects on tasks of standard rote memory, verbal long-term memory, or recognition memory, either for verbal or pictorial information. These results are consistent with both previous neuropsychological studies of autism (e.g., Mishew & Goldstein, 1993), and behavioral observations of often very good rote memory in individuals with autism.
Although these results point to similarities between individuals with autism and patients with frontal lesions, and provide support for an EF theory of autism, there are several caveats to consider. First, as mentioned in the introduction, deficits on EF and other tasks sensitive to frontal damage do not necessarily indicate the existence of frontal lobe pathology. Thus, even though we found that individuals with autism are most severely impaired on tasks that are sensitive to frontal lesions, we do not necessarily expect localized damage or dysfunction in the frontal lobes. Second, though patients with frontal lesions exhibit many social and cognitive deficits, the fact remains that they are not autistic. A review of the effects of early frontal lesions in children indicates that such individuals tend to present as conduct disordered rather than autistic (Pennington & Bennetto, 1993). Third, deficits in executive functions are not specific to autism. Impairments on EF tasks have been found across a range of neuropsychiatric and developmental disorders, including early-treated PKU (Diamond, Clarattaro, Donner, Djalil, & Robinson, 1994; Welsh, Pennington, Ozonoff, Rouse, & McCabe, 1990), Attention Deficit Hyperactivity Disorder (Grodzinsky & Diamond, 1992; Pennington, Groisser, & Welsh, 1993), Tourette syndrome (Bornstein, 1990), and Fragile X syndrome in females (Mazzocco, Hagerman, Cronister-Silverman, & Pennington, 1992). Thus, an impairment in EF cannot be necessary and sufficient to cause the spectrum of symptoms associated with autism, if this impairment is of similar severity and kind as those found in these other disorders.

Finally, the subjects in this study have participated in other studies in this area (Ozonoff & McEvoy, 1994; Ozonoff et al., 1991). Thus, it is important to address the potential threat this poses to the validity of our findings. As is common in low-incidence disorders, the same subject group is often used for multiple studies, which consequently increases the risk of Type I error. Since it is usually not possible for a lab to recruit independent samples for each study, it is critical that these findings be replicated with an independent group before strong conclusions are drawn.

To understand more clearly the nature of these memory and EF deficits, and address some of the preceding caveats, we need to examine the component processes that might be involved in these neurocognitive tasks.

**Working Memory in Autism**

We propose that the pattern of impairments found in this study may reflect a more general deficit in Working Memory (WM). The construct of WM was first proposed by Baddeley and Hitch (1974) to refer to the simultaneous processing and storage of information during complex cognitive tasks. While working memory has been a very useful construct in understanding performance on EF and other complex tasks, it too is beset with multiple and sometimes inconsistent theoretical definitions. Currently, there are several different ways to define and measure this construct in humans (e.g., Baddeley, 1986; Case, 1985; Halford, Maybery, O'Hare, & Grant, 1994), and even more in the animal literature.

As an initial examination of possible WM deficits in autism, the current study assessed the performance of subjects with autism on two verbal working memory span tasks. We found that subjects with autism performed worse than comparison subjects on both tasks, which provides preliminary evidence for a deficit in WM. As mentioned above, however, WM is a complex construct; the WM span tasks in this study were designed to measure concurrent storage and processing of verbal information, and do not include control tasks to allow for a more careful assessment of individual components such as capacity or processing efficiency, or other factors such as counting time and articulation speed. Thus, there are several alternative explanations that could account for these results. For example, on the Sentence Span task, it is possible that the subjects with autism had more difficulty filling in the missing word because of deficits in understanding relevance (e.g., Frith & Happe, 1994). This increased processing load could leave less processing space available for storage or the execution of other effortful processes in working memory. Although no subject from either group failed to find a missing word on these tasks, future research on nonverbal WM in autism is important. In addition to affecting differential processing demands, difficulty with finding the relevant word could have increased the response times of subjects with autism. Longer response times on this, or the Counting Span task, could mean that subjects with autism performed worse simply because they had to hold onto the information over a longer delay (Towse & Hitch, 1993). Future studies that measure or control for response speed are needed to sort out these possibili-
ties. Nonetheless, these findings provide preliminary evidence of a WM deficit and indicate the importance of further examination of possible subcomponents of EF in autism.

It has been proposed that WM permits one to solve problems that are transient, context-specific, and require the integration of information over space or time (Pennington, 1994). From this perspective, the results of the present study shed light on other cognitive symptoms found in autism. In other areas of research, empirical links have been found between WM and discourse processes (e.g., Carpenter & Just, 1989), narrative generation (e.g., Dennis, 1991; Grafman, 1989), learning (e.g., Baddeley, 1986), and reasoning and novel problem solving (e.g., Carpenter, Just, & Shell, 1990; Kyllonen & Christal, 1990), all of which are deficient in autism.

How does this model relate to social impairment, the core feature of individuals with autism? There has been a tendency in autism research to explain social impairment in terms of a specific deficit (see Baron-Cohen, Tager-Flusberg, & Cohen, 1993, for a review). However, given what is known about the relationship between cognitive and social development, one must consider whether a social impairment could be explained in terms of impairment of a general cognitive process. Frye, Zelazo, and Palfai (1992) have demonstrated similar age-related changes in both theory of mind and cognitive tasks, which each shared a common logical structure. They suggest that a developmental change in cognitive complexity underlies the developmental shifts in children's abilities, regardless of the task content. Russell, Mautner, Sharpe, and Tidswell (1991) have shown that children with autism are unable to pass strategic deception tasks not because they are unable to represent another person's mental state, but because they have less executive control over their behavior and are unable to inhibit inappropriate responding. In addition, executive function and working memory tasks have been shown to be related to other areas of social ability in autism. McEvoy et al. (1993) have shown a relationship between executive function tasks and joint attention behaviors in preschoolers with autism.

The current study did not examine social deficits in autism; thus we can only speculate on the relationship between general cognitive processes, such as WM, and social tasks. Further research is necessary to determine whether WM is particularly stressed in the types of social cognition tasks children with autism fail. As a preliminary look at the relationship between WM and other symptoms of autism, we performed a series of correlations between our cognitive variables and subjects' ratings on the CARS. In the autistic group, the CARS score was related to VIQ, r(19) = -.85, p < .001; FSIQ, r(19) = -.54, p = .02; WM Sentence Span, r(19) = -.72, p = .001; and the CVLT inhibition composite, r(19) = -.68, p = .002. In all cases, a higher CARS score (i.e., more symptoms endorsed) was related to worse performance on the task. There were no significant correlations in the comparison group. The relationship between the CARS and IQ is not surprising, since low verbal abilities is one of the hallmarks of autism. Similarly, correlations with WM Sentence Span and CVLT inhibition could be reflecting the verbal deficit. Nonetheless, these correlations suggest that cognitive constructs such as WM or the inhibition of inappropriate context may be related to some of the symptoms of autism.

Thus, an impairment in WM could explain what appears to be a more specific impairment in social cognition. Effective social interaction depends upon the on-line integration of constantly changing, context-specific information. In fact, the subtlety and complexity of the cues that must be processed in a social interaction, as well as the selection of appropriate responses, likely place a far greater load on WM than do the tasks described in this study.

Therefore, we suggest that the primary deficit in autism may be one of general impairment rather than specific modular impairment. Deficits in central cognitive processing have been suggested by others to account for some of the social impairments of autism (e.g., Courchesne et al., 1994; Frith & Happé, 1994; Hughes et al., 1994). In the present study, there is additional evidence for a deficit in a central cognitive process: there was a stronger pattern of intercorrelations among the dependent variables in the autistic group compared to the comparison group. Other studies of children with autism have found a similar pattern of stronger relationships in the autistic compared to control groups between cognitive variables (Ozonoff et al., 1991; Yirmiya, Sigman, Kasari, & Mundy, 1982) as well as between cognitive variables and neurophysiologic indices (Mishaw, Goldstein, Dombrowski, Panchalingam, & Pettigrew, 1993). A deficit in
a central cognitive process would limit development in many domains and permit less differentiation of domains than is found in normal development.

So far, we have discussed the possibility of a general impairment in WM to account for the cognitive deficits found in this study, as well as some of the social deficits in autism. However, there are several challenges to this model. First, many of the tasks employed in this study were verbal in nature. Individuals with autism are typically weak in language skills, and thus poor performance on these tasks could be an artifact of poor verbal abilities (e.g., a deficit in semantic encoding). However, the subjects with autism in this study were matched with comparison subjects on verbal IQ to ensure that their ability to understand verbal information was not significantly worse than comparison subjects. In addition, there is evidence from this study and others (e.g., Amiel et al., 1988; Ramondo & Milech, 1984; Tager-Flusberg, 1991) that individuals with autism are able to encode semantic information.

Second, to recall or recognize a piece of information, subjects must be attending sufficiently to the to-be-remembered information during the encoding stage. There is evidence that some individuals with autism have an impairment in shifting attention rapidly from one stimulus or modality to another (Courchesne et al., 1994), which could affect their performance on the memory and EF tasks used in this study. Some types of memory (e.g., Temporal Order) were measured with tasks that controlled, within subjects, the attentional demands needed for performance. Future research in this area would benefit from more control tasks to ensure that differences in attentional demands are not biasing results.

Finally, before we can be confident that any cognitive deficit is primary to autism, we need to establish the causal relation between the deficit and the also present social deficits of autism. For the model we have proposed above, this relation has not yet been established empirically. We offer several alternative explanations for further research. The first possibility is that individuals with autism have a primary deficit in WM that is so severe and occurs early enough in development that it interferes with the infant’s ability to engage in other developmental tasks such as imitation and intersubjectivity. The WM deficits in other developmental disorders may be less severe, or manifest at a later stage. A second possibility is that the WM deficits in autism are secondary to some other cause. All of the evidence for an executive deficit in autism has come from cross-sectional studies. Hence, this evidence is only correlational, and thus tells us little about the causal relationship between WM and other deficits in autism. Even though these studies have controlled for IQ and clinical status, it could still be the case that growing up autistic has unique effects on the development of WM. Social interactions provide unrelenting practice in shifting cognitive set and distinguishing different contexts. A third possibility is that there are two deficits involved in autism: a general deficit in WM, and a specific deficit in some other area of development, perhaps related to human sociability. For example, there is evidence of an imitation deficit in autism (DeMeyer et al., 1972; Rogers, Bennetto, McEvoy, & Pennington, in press). An early deficit in imitation would prevent the infant from entering into the social “dance.” A general deficit in WM would make later understanding of the social world difficult, since social interaction is transient, context-specific, and requires the integration of information from diverse sources. Further research is needed to distinguish these competing possibilities.

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