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Neuropsychologic functioning in autism: Profile of a complex information processing disorder

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Abstract

Neurobehavioral theories of autism have hypothesized core deficits in sensory input or perception, basic attentional abilities or generalized attention to extrapersonal space, anterograde memory, auditory information processing, higher order memory abilities, conceptual reasoning abilities, executive function, control mechanisms of attention, and higher order abilities across domains. A neuropsychologic battery designed to investigate these hypotheses was administered to 33 rigorously diagnosed autistic individuals with IQ scores greater than 80, and 33 individually matched normal controls. Stepwise discriminant function was used to define the profile of neuropsychologic functioning across domains. The neuropsychologic profile in these autistic individuals was defined by impairments in skilled motor, complex memory, complex language, and reasoning domains, and by intact or superior performance in the attention, simple memory, simple language, and visual–spatial domains. This profile is not consistent with mental retardation or with a general deficit syndrome, but rather with a selective impairment in complex information processing that does not involve visual–spatial processing. This profile is not consistent with a single primary deficit, but with a multiple primary deficit model in which the deficit pattern within and across domains is reflective of the complexity of the information processing demands. This neuropsychologic profile is furthermore consistent with the neurophysiologic characterization of autism as a late information processing disorder with sparing of early information processing. (*JINS*, 1997, *3*, 303–316)

Keywords: Autism, Neuropsychologic function, Cognitive profiles, Information processing

INTRODUCTION

Although autism is now widely accepted as being of neurologic origin, the neurobehavioral basis of the clinical syndrome remains highly controversial, with widely disparate views regarding the core deficit or deficits that underlie the abnormal behavior typical of this syndrome. A neurobehavioral basis for autism first gained acceptance in the 1960s (Rimland, 1964), and a number of neurobehavioral models were proposed and became widely known during the 1960s and 1970s. Some of these theories, such as those postulating core deficits in sensory perception or relating autism to an amnesic disorder, persisted into the 1980s, but others, such as the left hemisphere language theory, were later set aside as a result of incompatibility with evolving research findings demonstrating symmetric bihemispheric abnormalities (Bauman & Kemper, 1985; Rumsey & Hamburger, 1988; Minshew, 1992). In the last 15 years, neurobehavioral theories have existed that hypothesized primary deficits in nearly every aspect of neuropsychologic functioning as the cause of this clinical syndrome. During the early 1980s, these models generally postulated a single primary deficit in an aspect of information acquisition. Such models hypothesized a core deficit in a basic aspect of sensory perception, attention, or memory function. Although these models may now be viewed as simplistic in light of present knowledge about brain organization and about autism, the clinical integrity of information acquisition in autism remains a critical issue for all current neurobehavioral models of autism, and is largely undocumented by neuropsychologic data.

An additional, but little known, theory from the early 1980s hypothesized a selective impairment in auditory information processing based on the initial observations of

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dramatic abnormalities in auditory cognitive potentials with minimal abnormalities in visual cognitive potentials (Novick et al., 1980). This theory was not pursued beyond the initial report, but the disparity between auditory and visual cognitive potential abnormalities was subsequently replicated by several investigators, and issues related to visual information processing and to the involvement of the posterior regions of the cerebral hemispheres persist as important unanswered questions in autism.

Neurobehavioral theories proposed in the late 1980s and the 1990s have hypothesized primary deficits in various aspects of information processing. These theories have proposed core deficits in higher order memory abilities, conceptual reasoning, executive function, complex attentional abilities, or higher order abilities in general. Three of these five theories, the higher order memory, complex attention, and executive function theories, appear to specify a very similar neuropsychologic impairment involving executive control over information processing, but differ largely as a result of the anatomic localization proposed for this function. All of these theories, with the exception of the last theory proposing multiple primary deficits in higher order abilities, are single primary deficit models based on the premise that the behavioral syndrome of autism will be unified at the clinical level by a neuropsychologic deficit in a single domain or sensory modality.

The primary deficits hypothesized in most of these neurobehavioral models were proposed either on the basis of neurophysiologic abnormalities without clinical evidence of a neuropsychologic deficit, or neuropsychologic data obtained prior to the early 1980s before the importance of excluding autistic subjects with coexisting infectious, metabolic, and genetic disorders from research studies was appreciated (Damasio et al., 1980; Rumsey et al., 1984; Creasey et al., 1986; Minshew & Goldstein, 1993). Additionally, many of these models were developed on the basis of studies focusing exclusively on function in a single domain, precluding identification of potential deficits in other domains and consideration of the significance of coexisting deficits for the neurobehavioral formulation.

Although numerous neuropsychologic studies were completed in autism in the 1970s and 1980s (Rumsey, 1992), these studies typically focused on a single cognitive domain. One of the first studies to investigate the profile of neuropsychologic functioning across domains using a comprehensive test battery and strict diagnostic criteria, excluding autistic individuals with other coexisting causes of neurologic abnormalities, involved 10 autistic men with WAIS Verbal and Performance IQ scores above 80 and respective mean scores of 103 and 104 (Rumsey & Hamburger, 1988). This study reported a profile of neuropsychologic functioning in autism that was characterized by dramatic impairments in problem solving abilities, relatively intact language, memory and motor abilities, and intact sensory perception and visual–spatial abilities. This general profile was replicated in several studies (Prior & Hoffman, 1990; Ozonoff et al., 1991), and ultimately became the basis for two neurobehavioral models hypothesizing the predominance of conceptual reasoning (Rumsey & Hamburger, 1988) and executive function (Ozonoff et al., 1991, 1994) deficits. Although the neuropsychologic test battery used by Rumsey and Hamburger (1988) was comprehensive in many respects, the reliance in the motor, memory, and language domains on a few tests predominately of basic abilities and the evidence, albeit less dramatic, of impairments in domains other than problem solving suggested the need for further characterization of the profile of neuropsychologic functioning in autism.

The present study was designed to provide further amplification of the profile of intact and deficient abilities in autism relevant to the investigation of a number of neurobehavioral models in acceptance since 1980. These models have hypothesized core neuropsychologic deficits in (1) sensory input or perception (Ornitz & Ritvo, 1968; Ornitz, 1983); (2) attention to extrapersonal space (Ornitz, 1985; Ornitz et al., 1985; Dawson & Lewy, 1989); (3) anterograde memory resulting in a Korsakoff's type amnesia (DeLong, 1978; Boucher, 1981; Bachevalier, 1991), or in higher order memory abilities (DeLong, 1992; Bachevalier, 1994; Bauman & Kemper, 1994); (4) auditory information processing (Novick et al., 1980); (5) conceptual reasoning (Rumsey & Hamburger, 1988); (6) executive function (Ozonoff et al., 1991, 1994); (7) multiple control mechanisms of attention involving selective attention (Courchesne et al., 1984, 1987), attention to extrapersonal space (Courchesne et al., 1993a; Townsend & Courchesne, 1994), and shifting attention (Courchesne et al., 1993b); and (8) higher order abilities across domains with equal involvement of both the auditory and visual modalities (Minshew et al., 1992; Minshew & Goldstein, 1993; Minshew et al., 1994a; Smith & Bryson, 1994). All of the deficits proposed in the most recent versions of these theories were in evidence by the time the present study was designed and initiated, with the exception of the impairment in cross-modal shifting of attention in response to a complex contingency (Courchesne et al., 1993b).

To test the original primacy arguments hypothesized in these eight theories, and to provide a more detailed characterization of the profile of intact and deficient neuropsychologic abilities in autism, a more comprehensive test battery than those previously published was designed so as to include tests of (1) multiple aspects of attention; (2) simple sensory and higher cortical sensory perception; (3) elementary motor and skilled motor abilities; (4) multiple aspects of auditory and visual memory; (5) oral and written language functions ranging from phonetics and simple word knowledge to semantic–pragmatic language and text comprehension; (6) problem solving; and (7) the rule-learning, concept formation, and flexibility aspects of abstraction. With regard to attention, tests were included from all four factors in the Mirsky model (Mirsky et al., 1991) as well as tests of other relevant aspects of attention so as to provide an assessment of encoding, sustained attention, selective attention, attention to extrapersonal space, focused attention, and intramodal shifting of attention. Thus, all of the attentional impairments proposed in neurobehavioral models of autism were considered except for the deficit in cross-modal shifting of attention. In the sensory domain, tests of tactile sensory perception were selected to address hypotheses proposing primary impairments in sensory input or perception. In the motor domain, consideration in test selection was given to both elementary motor and skilled motor abilities based on our hypothesis of generalized involvement of higher order abilities related to neocortical function (Minshew, 1992; Minshew et al., 1992; Minshew & Goldstein, 1993). Relevant to the selective auditory information processing model, tests presenting information in both the auditory and visual modalities were included in all domains in which this issue was relevant, namely, language, memory, and reasoning. Within the language and memory domains, test selection also reflected the need to address hypotheses implicating either basic or higher order abilities. The assignment of language and memory tests to simple or complex domains was based on objective operational definitions and previous research findings, as reviewed in Minshew & Goldstein (1993), Minshew et al. (1994b), and Minshew et al. (1995). In the case of language tests, assignment to the simple or complex domain was based on whether the test assessed procedural or mechanical language skills, as exemplified by phonetics, word fluency, and spelling, or interpretative skills, as exemplified by text and metaphor comprehension. In the case of memory, classification of tests as simple or complex was based on whether tasks were dependent on simple associative processes or required a mediational strategy to promote remembering. Thus, associative memory tasks, such as short-term recall of simple information, were classified as tests of simple memory abilities, while tasks that involved consistent long-term retrieval and delayed recall of complex information requiring a self-initiated organizational strategy, were classified as involving complex memory processes (Minshew & Goldstein, 1993). Test selection for the reasoning domain included problem solving tests, consistent with the study of Rumsey and Hamburger (1988), and tests of the rule-learning and self-initiated concept formation aspects of abstraction, consistent with our previous observations (Minshew et al., 1992). A visual–spatial domain was added to the eight domains above to complete the profile of abilities in autism. Visual–spatial abilities have long been recognized as an area of intact function or strength in autism and thus have not been a consideration in neurobehavioral models, but are important in defining the profile of neuropsychologic functioning.

METHODS

Research Participants

The participants for this study consisted of 33 individually matched pairs of high functioning autistic and normal control adolescents and young adults between the ages of 12 and 40 years. All participants had Full Scale and Verbal IQ scores above 80, and demonstrated sufficient cooperation to complete testing. Demographic data for the two groups are provided in Table 1. The absence of a significant disparity between the mean Verbal and Performance IQ scores in our autistic subjects is comparable to that obtained by Rumsey and Hamburger (1988). The lack of a significant Verbal–Performance IQ difference is typical of school age and adult autistic individuals with Full Scale IQs over 80 (Mesibov, 1996; Siegel et al., 1996).

Potential autistic subjects were excluded if found to have an associated neurologic, genetic, infectious, or metabolic disorder, such as tuberous sclerosis, fragile-X syndrome, or fetal cytomegalovirus infection. The diagnostic instruments elicited early developmental history, and individuals with impairments in social interaction and restricted patterns of behavior, but with no clinically significant delay in language, cognition, and adaptive behavior, were considered to have Asperger’s disorder and were excluded.

The diagnosis of autism was established through expert clinical evaluation in accordance with accepted clinical descriptions of high functioning autism (Rutter & Schopler, 1987; Minshew & Payton, 1988; Rapin, 1991; Minshew, 1996a) and two structured diagnostic instruments, the Autism Diagnostic Interview (ADI: Lecouteur et al., 1989; Lord et al., 1994) and the Autism Diagnostic Observation Schedule (ADOS: Lord et al., 1989). Technician reliability in administration and scoring of these instruments was established through training with Dr. Catherine Lord, one of the developers of these instruments. Ongoing reliability of administration and diagnostic accuracy were documented through review and rescoring of the audiotaped ADI and videotaped ADOS for all 33 autistic subjects by Dr. Lord or a member of her research group. Eligibility for the study was dependent on consistency of diagnosis across all assessments. The autistic sample in this study was functionally and behaviorally comparable to the samples of Rumsey and Hamburger (1988), Lord’s highest functioning group for the ADOS (Lord et al., 1989), and Ozonoff’s highest functioning group (Ozonoff et al., 1994).

Table 1. Demographic data for autistic and control subjects

	Autistic Group		Control Group	
Variable	*M*	*SD*	*M*	*SD*
Age	20.91	9.69	21.21	9.99
Education (years)	10.54	2.90	11.24	3.07
SES[a]	3.75	1.43	3.30	1.26
Verbal IQ	102.48	16.35	101.30	12.42
Performance IQ	97.45	11.19	99.09	10.59
Full Scale IQ	100.09	12.96	100.48	11.65
Male:Female	29:4		29:4	

[a]These values reflect middle-class status (e.g., administrative personnel, small business owners).

Neuropsychiatrically normal, medically healthy, control participants were recruited from community volunteers as individual age, sex, race, and IQ matches for the autistic participants. Potential control participants were excluded if they had a history or evidence of birth or developmental abnormalities; acquired brain injury; poor school attendance; a learning or language disability; a current or past history of psychiatric or neurologic disorder; a medical disorder with implications for the central nervous system or requiring regular medication usage; or a family history of autism, developmental cognitive disorder, learning disability, mood disorder, anxiety disorder, alcoholism, or other neuropsychiatric disorders thought to have a genetic component.

To qualify as a match for an autistic participant, the age difference for an autism–control pair could be no more than 6 months for participants 17 years old or younger and no more than 12 months for subjects older than 17 years. Wechsler Full Scale IQ scores for a pair could differ by no more than 5 points. Socioeconomic status (SES) of the family of origin was determined with a modification of the Hollingshead method (Hollingshead, 1957) and matched at a group level.

Neuropsychologic Test Battery

The tests and variables used in the present study are listed in Table 2. To maintain a reasonable participants-to-variable ratio, no more than five variables were considered for each domain. The domain assignments of tests reflected the generally accepted classification systems (Lezak, 1983) and followed previous methods (Rumsey & Hamburger, 1988; Minshew et al., 1992). In this study, the verbal fluency test was assigned to the simple language domain as a test of language production ability. This assignment was consistent with its use in the Rumsey and Hamburger (1988) study. The Trail Making Tests A and B (Reitan & Wolfson, 1993) were assigned to the motor domain and reasoning domain, respectively, at the time of battery design, since performance on Trails A more strongly reflects the psychomotor demands of the task (Reitan & Wolfson, 1993) whereas Trails B more strongly reflects the executive function demands of the task. Delayed recall of the Rey–Osterrieth Figure (Osterrieth, 1944) was assigned to the memory domain as a test of memory for complex visual information, consistent with Lezak (1983); the means and standard deviations for the copy score are provided under the visual–spatial domain in Table 2. The group mean score of 32 for our autistic participants on the copy score was within the established range of normal function for individuals of this age, IQ, and educational level (Lezak, 1995), thus documenting that any impairments found in delayed recall would be related to memory for complex visual material and not to a visual–spatial deficit. Similarly, the Developmental Test of Visual-Motor Integration (DVMI: Beery & Buktenica, 1989) was selected *a priori* for its demands on skilled motor abilities and assigned to the motor domain, although it is also viewed as a test of visual–spatial perception.

The test battery was administered by a trained neuropsychology technician working under the supervision of a clinical neuropsychologist. Test sessions were adjusted in length to the individual participant's capabilities.

Data Analysis

The major statistical method used to demonstrate the profile of deficits and intact abilities was Wilks's stepwise discriminant analysis. The stepwise procedure generates the discrimination by sequential entering of variables. The most discriminating variable, typically the one that produces the highest *F* ratio, is entered first, followed by other variables that combine with the first variable in a way that increases discriminatory accuracy. Variables are entered or removed until a preestablished tolerance test is failed, indicating that additional entry of available variables would make no further contribution to discriminative accuracy. The statistical significance of the classification matrices generated by this method was evaluated with *kappa*, a coefficient of agreement for nominal scales. Relatively high *kappas* indicate that the variables passing the tolerance test discriminated well between autistic subjects and controls, while low *kappas* indicate the reverse. According to the Landis and Koch criteria (1977), a *kappa* of .40 to .75 indicates fair to good agreement beyond chance while a *kappa* less than .40 indicates poor agreement beyond chance. Examination of variables passing the tolerance test compared to those failing the tolerance test provided some additional information regarding the nature of the abilities that best distinguished or failed to distinguish autistic from control participants. In domains with a *kappa* in the good agreement range, failure of a test to pass the tolerance test did not necessarily mean that the individual test did not discriminate well between autistic participants and controls but that, for various reasons including high intercorrelations and multicollinearity, the test did not add further to the accuracy of the prediction beyond that achieved with the combination of entered variables. In such cases, evaluation of individual test performance is necessary to determine if tests failing the tolerance test did or did not demonstrate between-group differences. For this reason, *p* values based on *t* tests are provided in Table 2 for each of the test variables and variables with significant *p* values are marked with asterisks. Correspondingly, in domains with poor agreement *kappas*, even though some tests passed the tolerance test, they did not have sufficient discriminatory accuracy to achieve satisfactory agreement levels.

Since stepwise analyses are exploratory in nature and can capitalize on chance, we followed Shutty's (1991) recommendation that preliminary direct method analyses should be performed prior to using stepwise procedures. The direct method, involving entering all variables simultaneously, was found to yield the same classification rates as the stepwise method. The stepwise method was employed in the final analyses and reported here, because of the additional information it provides concerning the discriminatory power of the combinations of individual tests.

Table 2. Psychometric data used for discriminant analysis

	Autistic group		Control group		
Tests entered into prediction equations	*M*	*SD*	*M*	*SD*	*p*
Attention domain					
WAIS–R Digit Span	9.88	3.81	10.52	2.46	.424
Serial Digit Learning (correct responses)	16.52	8.17	17.42	7.91	.648
Continuous Performance Test (mean reaction time correct responses)	0.34	0.62	0.23	0.66	.487
Letter Cancellation (omissions)	1.09	1.63	0.45	1.00	.061
Number Cancellation (omissions)	3.27	4.03	4.39	5.38	.342
Sensory perception domain					
Luria-Nebraska Tactile Scale:					
Simple Touch errors	0.29	0.55	0.17	0.48	.407
Stereognosis errors	0.46	0.59	0.21	0.42	.096
Sharp–Dull Discrimination errors	0.88	0.80	0.58	0.72	.189
Position Sense errors	0.00	0.00	0.08	0.41	.328
Finger Position errors	0.67	1.27	0.46	1.02	.535
*Halstead-Reitan: Fingertip Number Writing (errors)	5.38	4.30	2.79	2.84	.019*
Motor domain					
Finger Tapping—dominant hand	44.27	13.78	45.19	16.24	.805
Developmental Test of Visual–Motor Integration (total points)	15.42	32.43	22.18	31.69	.465
*Grooved Pegboard—dominant hand (time in seconds)	86.73	18.30	70.67	16.03	.000*
*Trail Making A (time in seconds)	31.52	15.81	20.45	7.99	.001*
Simple language domain					
WAIS–R Vocabulary	9.45	3.02	9.70	2.26	.713
K-TEA Reading Decoding	97.48	13.60	102.79	10.19	.078
Controlled Oral Word Association (FAS) (number of words)	36.00	13.31	34.00	16.18	.586
K-TEA Spelling	102.58	16.93	100.91	11.50	.642
Woodcock Reading Mastery–Word Attack	107.24	11.55	103.52	15.53	.273
Complex language domain					
*Woodcock Reading Mastery—Passage Comprehension	92.27	15.04	104.27	14.34	.002*
*K-TEA Reading Comprehension	91.36	14.43	103.06	12.45	.001*
*Test of Language Competence—Metaphoric Expression (scaled score)	6.85	3.25	9.42	3.70	.004*
*Binet Verbal Absurdities (raw score)	9.30	3.64	12.48	3.97	.001*
Token Test (number correct)	18.03	2.19	18.42	5.19	.690
Simple memory domain					
Paired-Associate Learning (number correct)	42.55	23.13	48.76	24.21	.290
3 Word Short Term Memory (number of correct sequences)	3.24	3.04	2.91	3.15	.663
Maze Recall (correct/incorrect)	0.42	0.61	0.52	0.57	.534
CVLT A List—Trial 1 (number correct)	4.50	3.90	6.30	3.90	.072
Complex memory domain					
Paired-Associates—Delayed Recall	16.00	7.46	17.45	6.13	.390
CVLT A List—Long Delay	7.00	5.49	9.00	5.55	.146
*Nonverbal Selective Reminding—Consistent Long-Term Retrieval	19.94	15.09	37.39	16.09	.000*
*WMS–R Logical Memory—Delayed Recall (elements)	5.58	5.79	8.45	6.02	.052*
*Rey-Osterrieth Figure—Delayed Recall (number of elements)	16.83	8.58	21.94	7.49	.012*
Reasoning domain					
Trail Making B (time in seconds)	65.48	37.19	52.42	23.31	.093
Halstead Category Test (errors)	46.24	28.71	40.73	22.46	.388
Wisconsin Card Sorting Test (perseverative errors)	16.45	15.48	13.27	11.13	.342
*Binet Picture Absurdities (raw score)	20.00	11.46	27.52	6.12	.002*
*20 Questions (% constraint seeking)	35.49	23.82	56.08	14.02	.000*
Visual–spatial domain					
WAIS–R Picture Completion	8.76	2.22	9.21	2.27	.415
WAIS–R Object Assembly	9.88	3.63	9.73	2.88	.852
WAIS–R Block Design	10.79	3.25	9.70	2.14	.113
Rey-Osterrieth Copy	31.30	4.80	33.09	3.75	.096

* An asterisk denotes *p* values that represent statistically significant differences between groups.

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RESULTS

The results of the Wilks's stepwise discriminant analyses are provided in Table 3, including test variables failing the tolerance test, test variables passing the tolerance test in order of entry, percentage of correct classifications based on test variables passing the tolerance test, and *kappa* coefficients. Discriminant analyses revealed *kappas* in the *fair* to *good* agreement range (.40–.75) for five domains. Autistic participants thus were found to perform significantly more poorly than controls in the four domains of motor function, complex language, complex memory, and reasoning. Autistic subjects were found to perform significantly better than matched controls in the simple language domain. *Kappas* were in the *poor* range for the attention, sensory perception, simple memory, and visual–spatial domains, indicating poor discrimination between the performance of autistic and control participants.

Attention domain

The *kappa* for this domain was in the *poor* range, indicating that autistic participants were not distinguishable from controls on the basis of performance in the attention domain. Only the cancellation tests (Mesulam, 1985) passed the tolerance test, and performance on these tests revealed a very low rate of omissions by both groups, with no specific predilection for errors in any of the visual quadrants. Notably, the only tests in the attention domain to pass the tolerance test were those with a psychomotor speed component, whereas tests of attentional processes alone did not. Thus, a motor impairment rather than an impairment in attention may have been responsible for the entry of the cancellation tests into the classification equation.

The fourth factor in the Mirsky model relates to shifting attention, and refers to complex attentional abilities generally agreed to be of frontal origin. In the Mirsky model, this ability is assessed by the Wisconsin Card Sorting Test (WCST: Grant & Berg, 1948), although the WCST is more commonly classified in the reasoning domain, as was done in this study. Regardless of its domain classification, the performance of our autistic participants on the WCST was indistinguishable from that of controls, and thus changes in the domain assignment of the WCST would not have altered the findings of this study with regard to attention.

Sensory perception domain

The *kappa* for the sensory perception domain was in the *poor* range, indicating that an impairment in sensory perception was not a core feature of neuropsychologic functioning in autism. Two tests passed the tolerance test, both involving higher cortical sensory perception rather than elementary sensory abilities. Examination of individual test performance revealed nearly error-free performance on all tests of sensory perception except for a small number of errors in both the autistic and control groups on Fingertip Number Writing (Reitan & Wolfson, 1993). Thus, neither the *kappa* for this domain nor performance on individual

Table 3. Discriminant analysis results by domain and by order of entry

Domain	Tests failing tolerance test	Tests passing tolerance test	% Correct	% Jackknife	*kappa*
Attention	Serial Digit Learning; Digit Span; Continuous Performance	Letter Cancellation; Number Cancellation	66.7	66.7	.33
Sensory perception	Luria-Nebraska Tactile Scale: Touch, Position, Finger Position and Stereognosis items	Finger Tip Writing; Luria-Nebraska Sharp/Dull Tactile Scale item	64.6	62.5	.29
Motor	Finger Tapping; Developmental Test of Visual Motor Integration	Grooved Pegboard; Trail Making A	75.8	75.8	.52
Simple language	WAIS–R Vocabulary	K-TEA Reading Decoding; K-TEA Spelling; WRMT–R Word Attack; Controlled Oral Word Association	71.2	66.7	.42
Complex language	WRMT–R Passage Comprehension; TLC—Metaphoric Expression	K-TEA Reading Comprehension; Verbal Absurdities; Token Test	72.7	65.2	.45
Simple memory	Paired Associates; 3 Word Short Term Memory; Maze Recall	CVLT Trial 1	65.2	65.2	.30
Complex memory	Paired Associates—Delayed; CVLT Long Delay	NVSRT-Consistent Long Term Retrieval; WMS–R Logical Memory—Delayed Recall; Rey Figure—Delayed Recall	77.3	75.8	.55
Reasoning	Category Test; Wisconsin Card Sort Test	20 Questions; Picture Absurdities; Trail Making B	75.8	72.7	.52
Visual–spatial	WAIS–R Picture Completion, Object Assembly	WAIS–R Block Design	56.1	56.1	.12

tests supported the presence of an impairment in sensory input or perception as the cause of the clinical syndrome of autism.

Motor domain

The *kappa* for the motor domain was in the *fair* to *good* range of agreement, indicating that an impairment in skilled motor abilities was a significant feature of the neuropsychologic profile in autism. The discrimination was achieved with two tests: the Grooved Pegboard (Matthews & Klove, 1964); and Trails A, both of which involve skilled motor behavior. In contrast, there was no difference between autistics and controls on the Finger Tapping Test (Reitan & Wolfson, 1993), the only test of elementary motor skills. Thus, the *kappa* for the motor domain provides support for an impairment in skilled motor movements as a significant feature of the neuropsychologic profile in autism.

Simple language domain

The *kappa* for the simple language domain was in the *fair* to *good* range of agreement, and was exceptional in that it reflected a superior performance by the autistic participants relative to individually matched controls. Tests in this domain assessed basic language abilities, such as fluency, phonetics, spelling, and vocabulary. Reassignment of the verbal fluency test to the reasoning domain as a test of executive function would not therefore have altered the findings of the present study in terms of support for the executive function model.

Complex language domain

The *kappa* for this domain was in the *fair* to *good* range of agreement, indicating that impaired function in the Complex Language Domain was a significant feature of the profile of neuropsychologic functioning in these autistic individuals. The tests entered into the classification equation included the Reading Comprehension subtest from the Kaufman-Test of Educational Achievement (K-TEA: Kaufman & Kaufman, 1985), the Verbal Absurdities subtest from the Stanford-Binet Intelligence Scale (Terman & Merrill, 1973), and the Token Test (Boller & Vignolo, 1966). These tests assess multiple higher order features of language, specifically text comprehension, verbal problem solving, and the comprehension of complex grammatical constructions, respectively. Of further note, tests entered into the classification equation involved information presented in both the auditory and visual modalities.

Two tests in this domain were not selected for the classification equation: Passage Comprehension from the Woodcock Reading Mastery Test–Revised (Woodcock, 1987) and Metaphoric Expression from the Test of Language Competence (Wiig & Secord, 1989). However, failure of these variables to pass the tolerance test was likely related to multicollinearity, as examination of *p* values for these variables (Table 2) and previous studies revealed that the autistic participants performed significantly less well than controls on both of these tests (Minshew et al., 1995).

Simple memory domain

The *kappa* for the simple memory domain was in the *poor* range of agreement, indicating that an impairment in basic associative memory abilities was not a core feature of the neuropsychologic profile in autism. Of the five variables in the simple memory domain, only Trial 1 of the California Verbal Learning Test A List (CVLT: Delis et al., 1987) passed the tolerance test. This was the only task in the simple memory domain that involved free recall of a lengthy list of material outside the immediate span of attention and without stimulus cues, which may account for its selection. This variable was not associated with a significant intergroup difference. The tests in this domain assessed simple associative processes in both the visual and auditory modalities. The failure of the simple memory domain to distinguish between autistic and control participants on these tests supports the integrity of basic memory processes and the absence of an amnesic disorder in autism.

Complex memory domain

The *kappa* for the complex memory domain was in the *fair* to *good* range of agreement, indicating that impaired complex memory abilities are a significant feature of the profile of neuropsychologic functioning in autism. Tests in this category included delayed recall and consistent long-term retrieval of complex visual and auditory information. Three variables were entered into the classification equation. The long-term retrieval measure from the Nonverbal Selective Reminding Test (NVSR: Fletcher, 1985) was the single best group discriminator, followed by the delayed recall score for story recall from the Logical Memory Test (Wechsler, 1987), and the delayed recall score for the Rey-Osterrieth Figure. All three tests require sustained retention of complex information in long-term memory for which performance would benefit from the use of mediational strategies. Notable also is the entry into the classification equation of tasks in both the visual and auditory modalities.

Reasoning domain

The *kappa* for this domain was in the *fair* to *good* range of agreement indicating that impairments in the reasoning domain were a significant feature of the neuropsychologic profile in autism. The three tests entered into the classification equation were the 20 Questions procedure (Olver & Hornsby, 1966), Picture Absurdities (Thorndike et al., 1986), and the Trail Making Test B. The first two of these tests require self-initiated concept formation to produce a solution, whereas Trails B assesses the cognitive flexibility aspect of abstraction. Trails B is also commonly conceptualized as an executive function test. The selection of both concept formation and executive function tests does not support a single primary deficit in the executive function aspect of abstraction, but rather a broader impairment in conceptual reasoning abilities as proposed by Rumsey and Hamburger (1988).

Visual–spatial domain

The discriminant analysis for the visual–spatial domain revealed a *kappa* in the *poor* range of agreement. Review of the performance of the two groups on these tests revealed that the autistic group performed as well or better than controls on all three subtests, indicating that even the slight increase in correct classifications above chance was related to superior function by the autistic participants and not to a subtle deficit in visual–spatial function. These results confirm the integrity of visual–spatial abilities as a feature of the profile of neuropsychologic functioning in autism.

DISCUSSION

The study of non-mentally-retarded autistic individuals provides the maximal opportunity for defining the impairments associated with autism and demonstrating their specificity to autism rather than to the confounds associated with mental retardation. The greater capabilities of high functioning autistic individuals have been essential to the application of more sophisticated methods for investigating cognitive function to the study of autism. These methods have included clinical and experimental neuropsychologic tests, cognitive psychology tests, cognitive evoked potentials, and, in the future, functional imaging technologies requiring activation paradigms. The validity of the subgroup method in all of these studies was based on the premise that the participants have the disorder under study. Non-mentally-retarded autistic individuals have all of the clinical features and developmental history associated with autism (Kanner et al., 1972), the same neuropathologic findings as have been demonstrated in mentally retarded autistic individuals (Bauman & Kemper, 1994), the same imaging abnormalities (Piven et al., 1996), and the same family history characteristics (Piven et al., 1997).

The present study of the profile of neuropsychologic functioning in non-mentally-retarded autistic adolescents and young adults provides evidence within the same subject sample of significant impairments in the motor, complex language, complex memory, and reasoning domains. This profile was further defined by intact or superior performance in the attention, sensory perception, simple memory, simple language, and visual–spatial domains. These results provide empiric evidence of previously undocumented impairments in skilled motor, complex language, and complex memory abilities that redefine the profile of neuropsychologic functioning reported for autism in prior studies (Rumsey & Hamburger, 1988; Prior & Hoffman, 1990; Ozonoff et al., 1991). The deficient and intact abilities identified in the present study define a pattern of cognitive functioning in autism that is characterized by selective impairment of certain higher order abilities, sparing or enhancement of simpler abilities in these same domains, and intact basic skills.

The intact abilities identified in this study are of particular significance in demonstrating that the neuropsychologic profile in autism is not that of a general deficit syndrome or of mental retardation, as autistic participants performed as well or better than individually matched normal controls on many tests. This profile is also in sharp contrast to the neuropsychologic profile reported for schizophrenia, in which subjects perform more poorly than controls on most tests, and hence, are often considered to have a general deficit syndrome (Chapman & Chapman, 1973). Intact neuropsychologic abilities may prove to be as much of a determinant of the behavioral expression of autism as deficient skills. For example, the focus on details and reaction to trivial environmental changes so characteristic of autism might not be features of this clinical syndrome if basic attention, sensory perception, and associative memory abilities were not sufficiently intact to support the awareness of details. Thus, neuropsychologic functioning in autism is best characterized by a two-part model giving equal consideration to intact abilities and deficits.

The results of the present study confirm and significantly extend the definition of neuropsychologic functioning reported for autism by Rumsey and Hamburger (1988) and replicated by others (Prior & Hoffman, 1990; Ozonoff et al., 1991) as characterized by prominent impairment in problem solving abilities in the absence of clinically significant impairments in sensory perception, memory, or language ability. The profile reported by Rumsey and Hamburger is identical to that obtained in the present study in the reasoning, simple memory, simple language, and sensory perception domains. The documentation by the present study of significant impairments in domains other than reasoning reflects the expansion of the test battery to include tests of higher order abilities in other domains, the separate consideration of simple and complex memory and language tests, and the utilization of a much larger sample.

A direct examination of subject performance in the Rumsey and Hamburger study (1988) reveals findings essentially identical to ours, including indications of the presence of impairments in domains other than reasoning. In the Rumsey and Hamburger study, the motor domain consisted solely of the Grooved Pegboard Test, which revealed impaired performance bilaterally by the autistic participants ($p = .05$), but below the significance level established for the study. This was interpreted as lack of evidence for unilateral brain dysfunction as the cause of autism. Review of their data for the Trail Making Test also reveals poorer performance on Trails A (scores twice that of controls) than on Trails B (scores 1.5 times that of controls), mirroring the findings of the present study and our prior study (Minshew et al., 1992), and providing further evidence of a clinically significant impairment in skilled motor function as a feature of the neuropsychologic profile in autism. The language domain in the Rumsey and Hamburger study was confined to tests of formal language and, thus, did not find the deficits in complex

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language reported in the present study. The memory domain was composed of one test of simple associative processes, list learning on the Verbal Selective Reminding Test (Buschke & Fuld, 1974), and a second test of complex memory abilities (recall of paragraphs and designs from the Wechsler Memory Scale–Revised). As in the present study, the performance of the autistic subjects in the Rumsey and Hamburger study on these two tests was divergent, with impaired performance on the test of complex memory abilities ($p = .05$) and intact performance on the simple memory test ($p = .92$).

Since the Rumsey and Hamburger study, there have been a number of studies focusing on function in individual neuropsychologic domains that have provided evidence of the impairments reported in the present study in reasoning (Ozonoff et al., 1994; Klinger & Dawson, 1995), complex memory (Tager-Flusberg, 1991; Minshew & Goldstein, 1993; Minshew et al., 1996), complex language (Minshew et al., 1995), and skilled motor function (Smith & Bryson, 1994; Hughes, 1996; Leary & Hill, 1996). Of these deficits, the impairments in complex memory abilities and skilled motor movements have been the most recent to be documented, and remain incompletely defined. In addition, in a recent factor analytic study of the neuropsychologic performance of 3- to 7-year-old autistic children with Performance IQ scores greater than 80, Rapin and colleagues described a four-factor structure involving separate factors for simple and complex language abilities, a factor for motor abilities, and a factor for visual–spatial skills (Fein et al., 1996; Rapin, 1996). This factor structure is consistent with the results of the present study.

Our findings of significant coexisting deficits in skilled motor, complex language, complex memory, and reasoning abilities, involvement of the auditory and visual modalities, with intact or superior abilities in the attention, sensory perception, simple language and simple memory domains, have significant implications for neurobehavioral models proposed for autism in the past 15 years. All but one of these models have hypothesized the presence of a clinically apparent deficit in a single domain or modality of neuropsychologic functioning as the basis for the clinical syndrome of autism. The argument for primacy in each of these models was based on evidence provided of the current presence of the specified deficit in autistic children, adolescents, and adults. Other mechanisms for primacy were often proposed, but without the support of empiric data. These alternative arguments typically hypothesized temporal primacy, with an onset of the proposed primary deficit in early life preceding all other manifestations of autism, primacy at the neurobiologic level in terms of the way in which the brain accomplishes the involved function, or a combination of both of these. However, neither the neurobehavioral models themselves, nor the present study, have data to support or refute these alternative arguments. Thus, the major questions for the single primary deficit models are which of the hypothesized deficits can be demonstrated to be present, and of these, which ones can feasibly produce the pattern of neuropsychologic deficits and intact abilities that has been defined for autism in this and other studies.

Neurobehavioral models from the early 1980s postulating inconstancy of sensory input, generalized inattention, or amnesia are clearly not supported by the findings of this study in the attention, sensory perception, and simple memory domains. A revision of one of these early models (Ornitz, 1985) and one recently developed model (Courchesne et al., 1993b; Townsend & Courchesne, 1994) have hypothesized a generalized form of neglect or inattention to extrapersonal space as a primary deficit in autism. Neglect and attention to extrapersonal space were specifically investigated in the present study with the auditory, visual, and somatosensory double simultaneous stimulation tasks from the Halstead-Reitan Sensory–Perceptual Examination (Reitan & Wolfson, 1993) and two cancellation tasks, which revealed the absence of evidence of unilateral or bilateral neglect or inattention to extrapersonal space. A review of the two theories proposing neglect as a central deficit reveals that this deficit was inferred on purely theoretical grounds (Ornitz, 1985) or on the basis of nonquantitative imaging abnormalities of parietal cortex (Townsend & Courchesne, 1994). Thus, the models hypothesizing deficits in attention to extrapersonal space or neglect also are not compatible with the findings reported in this study or with the profile of neuropsychologic functioning defined in other studies.

The most recently proposed neurobehavioral theories for autism have hypothesized core deficits in various aspects of information processing rather than in its acquisition. The first of the information processing models proposed a selective defect in auditory processing (Novick et al., 1980). A selective impairment in auditory information processing is not, however, supported by the findings of the present study, which instead yielded evidence of comparable difficulty in the processing of auditory and visual information in multiple domains. In the complex memory and complex language domains, the long-term retrieval score from the Nonverbal Selective Reminding Test and the Reading Comprehension score from the K-TEA were the first variables selected for the classification equation. Similarly, Picture Absurdities, Verbal Absurdities, and Trails B were all selected for the classification equation, thus demonstrating difficulty in the analysis of both visual and auditory material in the reasoning domain. Because Picture Absurdities requires the formulation of a verbal response and Trails B involves numbers and letters, it could be argued that performance on these tests reflects a language impairment or a verbal reasoning deficit, rather than difficulty analyzing visual information. However, the superior performance of our autistic subjects in the Simple Language Domain would not support an impairment in the capacity to formulate language or read letters as the cause of impaired performance on Picture Absurdities and Trails B. In addition, other studies in autism have provided evidence in high functioning autistic individuals of difficulty with problem solving tasks, such as the Tower of Hanoi (Borys et al., 1982), which have no language component (Ozonoff et al., 1991). Thus, the results of the present and other studies suggest that autistic individuals have difficulty with the processing of information regardless of the modality of presentation.

Two of the more recently proposed information processing models have hypothesized primary deficits in conceptual reasoning (Rumsey & Hamburger, 1988) or in executive function (Ozonoff et al., 1991, 1994) as a result of frontal systems dysfunction. The findings of the present study confirm the presence of significant impairments in reasoning and problem solving. However, the absence of difficulty on the part of the autistic participants in this study on the WCST and the selection of the 20 Questions procedure and Picture Absurdities test as the first and second variables to be entered into the classification equation does not support cognitive inflexibility or inability to shift sets as the defining feature of the reasoning impairment in autism; rather, these data suggest that the deficit in reasoning abilities is broader or more generalized. The presence of significant deficits in multiple other domains does not support the primacy or predominance of reasoning deficits. The final consideration with regard to assessing the viability of these two models is whether the deficits in other domains can be accommodated within the frontal systems localization proposed in both models. Although complex memory and skilled motor deficits are compatible with a frontal systems localization, deficits in higher order language comprehension and reading comprehension are not and would indicate more widespread involvement beyond frontal systems.

A third model in the executive-function–reasoning category hypothesizes a deficit in an executive function that regulates the attachment of meaning to information during memory and learning, and further proposes that this function resides in the hippocampus or limbic system (DeLong, 1992; Bachevalier, 1994). This model, therefore, argues primacy both at the clinical level in terms of the primacy of a memory and learning impairment, and also at the neurobiologic level in terms of how the brain assigns meaning to incoming information. The neuropsychologic findings cited in this model as support for a deficit in the assignment of meaning to information appear to be the same impairments demonstrated in the present and other studies with tasks that are conventionally assigned to the reasoning, complex memory, and complex language domains. From a clinical neuropsychologic perspective, the classification of all of the tests demonstrating impairments in this study as tests of memory and learning would defy accepted conventions for the classification of such tests and the underlying premise that these measures reflect separate functions in the brain. The primacy argument of this model lacks construct validity and is therefore not supported at the clinical level.

The remaining single primary deficit model in autism hypothesizes multiple deficits in the control mechanisms for attention, namely in selective attention (Courchesne et al., 1984, 1987), attention to extrapersonal space (Courchesne et al., 1993a; Townsend & Courchesne, 1994), and shifting attention (Courchesne et al., 1993b), and argues that current deficits in these mechanisms for controlling the focus of attention are the cause of the clinical manifestations of autism. The empiric support for this model was based on data derived from the testing of high functioning school age and adult autistic individuals, who were thus similar in function to the autistic subjects in the present study. The empiric support for the deficits in selective attention and in the focus of attention consisted of neurophysiologic abnormalities in cognitive potentials in the presence of intact subject performance on the attentional task (Courchesne et al., 1984, 1985, 1987) and on qualitative imaging abnormalities involving volume loss in the parietal lobes (Townsend & Courchesne, 1994), and not neuropsychologic data. The empiric support provided for the shifting attention deficit was based on data from high functioning autistic adolescent and young adult autistic subjects using a modality shift experiment to a complex contingency paradigm (Courchesne et al., 1993b). Thus, the attentional task used to demonstrate a shifting attention deficit in autism involved a substantial information processing component in addition to the demand to shift attention across modalities. Thus, we would propose that the difficulty high functioning autistic individuals have been reported to have on this task reflects the information processing or cognitive demands of the task rather than the demand for a shift in attention at the perceptual level. The present study has provided a comprehensive evaluation of attention assessing the four elements of attention in the Mirsky model as well as attention to extrapersonal space. The results of this study fail to provide evidence of a clinically discernible deficit in encoding, sustained attention, the ability to selectively focus attention, to attend to all quadrants of extrapersonal space, and to make cognitive shifts in attention, in individuals who nonetheless have all the signs and symptoms of autism as well as deficits in higher order abilities across multiple domains. The findings of this study fail to support the primacy arguments of this model of clinically apparent deficits in the control of attention as the cause of the signs and symptoms of autism, or of attentional deficits as the cause of impairments in skilled motor, complex language, complex memory, and reasoning abilities.

The findings of the present study are most consistent with a multiple primary deficit model, as has been proposed previously by Rutter (1988) and Goodman (1989). The presence of coexisting impairments in skilled motor, complex language, complex memory, and reasoning abilities in autism suggest a central problem with the capacity for processing the complex features of information within these domains. Complexity as defined by the data in this study is linked to domain, and thus to the manner in which the brain accomplishes the processing of the most complex information within each domain. Domains vary in and of themselves in terms of complexity, and the relative complexity of the information processing demands of the various neuropsychologic domains may explain the preponderance of symptomatology in autism in domains with the highest complex information processing demands. Although the test battery for the present study did not include tests of theory of mind or nonverbal communicative abilities (Baron-Cohen, 1995), such deficits are consistent with a complex information processing model and have been interpreted as such by others. Klinger and Dawson, for example, have said that the "social impairments displayed by individuals with autism result from an inability to process social information because of its novel unpredictable nature" (Klinger & Dawson, 1995, p. 120). To this, we would add that social information is exceedingly complex, as a result of multiple competing sources of information, and a rapid pace of information presentation.

Notable for its absence among the domains demonstrating impairments in this study was the visual–spatial domain. Visual–spatial ability has long been accepted to be an area of strength in autism, as evidenced by the preservation of function on the Performance IQ scale with declining Full Scale IQ and by the often remarkable facility with tasks such as puzzle assembly. Although visual–spatial tasks are complex, they are spared by the faulty information processing mechanism in autism. Thus, it appears that the brain mechanisms mediating the processing of visual–spatial information are likely to be different at a neurobiologic level from the mechanisms used for processing complex information in other domains (Rutter, 1983). One additional possible explanation for the concurrent involvement of social, language, and reasoning domains and sparing of the visual–spatial domain in autism is that the neural systems subserving social, language, and reasoning abilities must be interconnected in order for these cognitive functions to occur and be appropriate. In contrast, the visual–spatial system can function independent of these other neural systems without affecting clinical competence in this domain.

The profile of neuropsychologic functioning documented in the present study is consistent with the profile for information acquisition and information processing defined in autism with evoked potentials. Neurophysiologic studies in autism in the last decade have demonstrated a profile that is characterized by intact brainstem potentials, intact midlatency potentials, and abnormalities in late, endogenous potentials (reviewed in Minshew, 1991, 1996b). This neurophysiologic profile provides independent corroborating evidence of the integrity of information acquisition and of early events in information processing in autism, and of the primacy of impairments in late events in information processing. The selective involvement of late information processing potentials in autism and the sparing of early information processing potentials supports the unusual constellation defined in this study of deficits in the most complex abilities within domains with preservation of simpler abilities within these same domains.

The neuroanatomic basis of autism and of the deficit profile defined in the present study is not yet known and is controversial. The prevailing neurobehavioral models for autism demonstrate wide debate with regard to how the brain accomplishes the identification of information as important and arrives at a determination of the appropriate response. Thus, a major limitation on neurologic localization in autism is that it is not known how the normal brain subserves these complex abilities, with the exception of the general consensus that this often involves neural systems rather than regional brain structures. Current neurobehavioral models for autism are consistent in hypothesizing that the brain abnormality underlying autism is most likely to be at the neural systems level. Equally compelling evidence exists at present implicating cerebral cortex, limbic structures, and the cerebellum in the affected neural systems in autism, as well as the abnormal development of neural connections between these regions (Horwitz et al., 1988; Bauman & Kemper, 1994; Courchesne et al., 1994; Zilbovicius et al., 1995; Minshew, 1996b; Piven et al., 1996).

In conclusion, the use of a comprehensive neuropsychologic test battery has provided evidence within a single cohort of autistic individuals of the coexistence of deficits in skilled motor, complex language, complex memory, and reasoning abilities, and involvement of both visual and auditory information processing. This test battery has furthermore provided evidence of intact or superior simpler abilities in these same functional areas, and the integrity of information acquisition and visual–spatial abilities. The neuropsychologic profile defined in this study is not readily explainable in terms of a single primary deficit, but is most compatible with a multiple primary deficit syndrome resulting from a disorder of complex information processing that spares visual–spatial processing. This neuropsychologic pattern is consistent with the neurophysiologic characterization of autism as a late information processing disorder.

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