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Verbal and Spatial Working Memory in Autism

Diane L. Williams,[1] Gerald Goldstein,[2] Patricia A. Carpenter,[3] and Nancy J. Minshew[4,5]

Verbal and spatial working memory were examined in high-functioning children, adolescents, and adults with autism compared to age and cognitive-matched controls. No deficit was found in verbal working memory in the individuals with autism using an *N*-back letter task and standardized measures. The distinction between the *N*-back task and others used previously to infer a working memory deficit in autism is that this task does not involve a complex cognitive demand. Deficits were found in spatial working memory. Understanding the basis for the dissociation between intact verbal working memory and impaired spatial working memory and the breakdown that occurs in verbal working memory as information processing demands are increased will likely provide valuable insights into the neural basis of autism.

KEY WORDS: Autism; working memory; information processing.

INTRODUCTION

The role of memory in the cognitive function of individuals with autism has been an object of study for many years. While some individuals with autism are often considered to have prodigious rote memory skills, the status of other forms of memory in this population is not well defined, and may in fact be dysfunctional (Minshew & Goldstein, 2001). Working memory has been of particular interest because it is an important component of the executive dysfunction hypothesis of autism (Pennington, 1994). Working memory is a process by which information is actively maintained for very short periods of time while performing some task (Baddeley, 1986, 1992). It may be assessed directly through use of specific, relatively simple tasks, or its role may be inferred in the performance of more complex, problem solving tasks. The hypothesized deficit in working memory in autism is thought to result in a cascade of problems associated with behavior regulation, cognitive flexibility, abstract thinking, and focusing and sustaining attention (Hughes, Russell, & Robbins, 1994; Ozonoff & McEvoy, 1994; Ozonoff, Pennington, & Rogers, 1991).

While there are several conceptualizations of working memory (Baddeley, 1986; Just & Carpenter, 1992; Levy & Goldman-Rakic, 2000; Pennington, 1994), the design of the present study was based on aspects of the model of working memory developed by Baddeley. In this model, the primary component is the central executive, which is responsible for selecting, initiating, and terminating processing routines (e.g., encoding, storing and retrieval) including the selection of strategies for remembering. The central executive coordinates a number of subsystems. This study focuses on two of these subsystems—the articulatory (or phonological) loop and the visuospatial sketchpad. The articulatory loop is comprised of a phonological memory store that holds speech-

[1] School of Medicine, University of Pittsburgh, Pittsburgh, USA.
[2] VA Pittsburgh Healthcare System, School of Medicine, University of Pittsburgh, Pittsburgh, USA.
[3] Carnegie Mellon University, Pittsburgh, USA.
[4] School of Medicine, University of Pittsburgh, Pittsburgh, USA.
[5] Correspondence should be addressed to: School of Medicine, University of Pittsburgh, Webster Hall – Suite 300, 3811 O'Hara Street, Pittsburgh, PA 15213, USA; Tel: 412-246-5485; Fax: 412-246-5470; e-mail: minshewnj@upmc.edu

based material for a brief period and an articulatory control process by which the information in the phonological store is refreshed through articulatory rehearsal. Verbal information that is presented either visually or auditorally is remembered by translating the sensory input into a representational form. The visuospatial sketchpad is responsible for the manipulation and temporary storage of visual information including spatial location. These two subsystems are commonly referred to as verbal and spatial working memory, respectively.

Planning and problem-solving tasks such as the Tower of Hanoi or Tower of London task (Shallice, 1982) and the Wisconsin Card Sorting Test (WCST; Heaton *et al.*, 1993) are thought to require intact working memory skills for successful completion (Kimberg & Farah, 1993). Several studies using planning and problem solving tasks such as these have demonstrated that individuals with high-functioning autism perform significantly worse than matched controls (Bennetto, Pennington, & Rogers, 1996; Hughes *et al.*, 1994; Ozonoff & Jensen, 1999; Ozonoff & McEvoy, 1994; Ozonoff *et al.*, 1991). The executive function (EF) theory has inferred that the poor performance of individuals with autism on these tasks is the result of working memory dysfunction (Ozonoff *et al.*, 1991). The EF literature suggesting that working memory dysfunction is a core deficit in autism appears to make the assumption that individuals with autism cannot retain information in the articulatory loop or the visuospatial sketchpad sufficiently well to solve a pending problem. However, a few recent studies using direct measures of working memory have begun to cast doubt on these conclusions. These studies have failed to yield evidence of an impairment in working memory in autism (Ozonoff & Strayer, 2001; Russell, Jarrold, & Henry, 1996). These studies challenge the view that individuals with autism perform the Tower problems, WCST and similar complex problem solving tasks poorly because of a deficiency in working memory per se.

Alternative theories have proposed that individuals with autism perform poorly on executive function tasks because of primary or inherent deficiencies in conceptual reasoning and planning abilities (Frith, 1989; Frith & Happé, 1994; Just, Cherkassky, Keller, & Minshew, 2004; Minshew, Goldstein, & Siegel, 1997; Minshew, Sweeney, & Luna, 2002). These models, the central coherence and complex information processing-underconnectivity models, were proposed on the basis of documentation of a constellation of deficits in higher order cognitive abilities and intact basic abilities in the same domains. In more detailed studies of individual cognitive domains, Minshew and colleagues demonstrated a relationship between increasing information processing demands and the emergence of deficits. For example, in the case of verbal linguistic tasks, increasing grammatical complexity of sentences resulted in the emergence of deficits in high functioning autistic individuals, as did the transition from words, to sentences to stories (Minshew, Goldstein, & Siegel, 1995). In a study of memory using an extensive battery of tests, memory for simple information was demonstrated to be intact, documenting the preservation of basic associative memory processes (Minshew & Goldstein, 2001). However, as the complexity of the task was increased, deficits became progressively more apparent, reflecting the reduced use of contextual structure and organizational strategies to support memory.

An intriguing finding emerging in the recent autism literature is that while verbal working memory may be relatively intact, as described above, spatial working memory may not be intact. The evidence, however, is inconsistent. Ozonoff and Strayer (2001) used a spatial memory-span task (recall of the location of three to five geometric shapes on a computer screen) and a box search task (participants had to search for objects hidden behind colored boxes using a method that required holding the color of the boxes in working memory during the search). Significant differences between autism and control participants were not found for either of these two tasks. Other measures of spatial working memory such as eye movement studies have also provided different results. The delayed oculomotor response task (memory-guided saccade) has been used as a measure of spatial working memory since the development of the technique with non-human primates by Goldman-Rakic and collaborators (Kojima & Goldman-Rakic, 1982). In this procedure, the participant fixates on a central point, a peripheral target is presented and then extinguished, and the task is to make an eye movement to the remembered location of the target following a delay. Minshew, Luna, and Sweeney (1999) showed that individuals with autism did significantly less well on this task than did controls with increased rates of response suppression errors and impaired precision in reaching the target; their saccades were very close to the target location but did not achieve the precise location. They did not fail to remember the location but it appeared the neural circuitry did not have the computational power to calculate the precise location. Koczat, Rogers, Pennington, and Ross (2002) found this same deficit in parents of children with autism. However, in another study that used a memory-guided saccade task with slightly different parameters, the participants with autism had increased rates of response suppression errors and took longer to make a saccade to the remembered target, but they did not differ from the normal controls in saccade accuracy (Goldberg *et al*., 2002).

The present study attempts to address the inconsistent literature regarding verbal working memory and spatial working memory in individuals with autism by using tasks that assess the status of working memory components without the confound of planning or reasoning tasks. We also examine the hypothesized intactness of verbal working memory and impairment of spatial working memory by assessing these different abilities in the same individuals with high-functioning autism.

METHOD

Participants

Participants were divided into two groups based on age, so as to be sensitive to developmental changes that occur with maturation. The adult group was composed of 31 individuals with autism (29 males and 2 females) and 25 controls (21 males and 4 females) between the ages of 17 and 48 years. The child and adolescent group consisted of 24 children with autism (22 males and 2 females) and 44 controls (33 males and 11 females) from 8 to 16 years of age. Demographic and psychometric data are presented in Table I.

In this and related research, we have restricted the samples to individuals with high-functioning autism. These individuals meet all diagnostic criteria for autism but are not mentally retarded and have connected speech. This is a widely used research strategy based on the supposition that high functioning individuals have the same disorder as low functioning individuals, an assumption that is supported by a growing body of evidence (Bauman & Kemper, 1990, 1994; Courchesne *et al*., 2001; Piven *et al*., 1995; Szatmari *et al*., 2000). The study of individuals with high-functioning autism assured obtaining participants who could cooperate for testing, and who were unlikely to have the numerous additional disorders commonly associated with low functioning autism. Working memory dysfunction has been proposed as representing a core area of dysfunction in autism. If this dysfunction is related to the autism and not to the mental retardation, it should be present in all cases of autism even high-functioning individuals. Because the sample was based upon consecutive admission of all referrals meeting inclusion criteria, it is likely to be a random sample of individuals with high functioning autism.

All participants had Verbal and Full Scale Wechsler IQ scores above 72 and at least second grade reading skills. Autism and control participants within the two age groups did not differ significantly with respect to age, Verbal, Performance, or Full Scale IQ scores. All participants were required to be in good medical health with no history of seizures, birth injury, or head trauma. All participants communicated in complete spoken sentences and did not have attention or behavioral problems that prevented them from completing testing. The participants with autism did not have any associated or causative genetic, metabolic, or infectious conditions. Eligibility for participation was based on the age appropriate version of the Wechsler Intelligence Scales (WISC-III; Wechsler, 1991; WAIS-III; Wechsler, 1997a), the Kaufman Test of Educational Achievement (K-TEA; Kaufman & Kaufman, 1985), the Autism Diagnostic Observation Schedule (ADOS; Lord *et al*., 1989; Lord, Rutter, DiLavore, & Risi, 1999), and the Autism Diagnostic Interview-Revised (ADI-R; LeCouteur *et al*., 1989: Lord, Rut-

Table I. Age and Intelligence Test Data for the Autistic and Control Groups*

	Age		VIQ		PIQ		FSIQ	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Adults with Autism ($n = 31$)	26.58	8.68	111.10	16.47	103.13	16.64	108.65	16.75
Adult Controls ($n = 25$)	26.76	9.08	108.00	10.19	110.20	12.84	109.76	11.63
Children/Adolescents with Autism ($n = 24$)	11.75	2.36	112.50	16.53	106.38	14.21	109.67	16.07
Children/Adolescents Controls ($n = 44$)	12.39	2.16	110.25	9.84	108.05	11.09	109.95	10.66

*None of the differences are statistically significant ($p < .05$).

ter, & Le Couteur, 1994). The diagnosis of autism provided by the two structured instruments was confirmed by expert clinical opinion.

Controls were community volunteers recruited through advertisements in neighborhoods with the same socioeconomic level as the families of origin of the participants with autism. They were pre-screened by completing a questionnaire on demographic information and family and personal history of medical, neurological, and psychiatric disorders. Inclusion criteria included good physical health, no regular medication use, and good peer relationships based on parent or self-report and staff observations during eligibility testing. Exclusion criteria included a personal history of neuropsychiatric disorders; learning disability or brain insults prior to or after birth; a family history in first degree relatives of developmental cognitive disorders, mood and anxiety disorders; and, autism in first-, second-, and third-degree relatives.

In addition to the participants above who completed the study, other potential participants were recruited but were excluded from participation when they had difficulty completing the experimental task because of failure to respond to the test stimuli appropriately or to maintain attention. Nine individuals with autism and six potential controls were eliminated for these reasons. In addition, two individuals with autism and two potential controls were removed from the sample because their response times on the *N*-back task were significant outliers relative to the other participants' responses.

The study was approved by the University of Pittsburgh Medical Center Institutional Review Board and written informed consent was obtained from participants or their guardians.

Procedure

Verbal Working Memory Tasks

N-back Letter Task: To investigate the status of the various components of the working memory system and to evaluate the role of increasing processing load, it is necessary to begin with procedures that purposely reduce the complexity of the task. These procedures place the demand on working memory storage capacity rather than this capacity in combination with problem solving and associated conceptual processes. The *N*-back task is a measure of working memory that uses simple stimuli and instructions that has been used in numerous studies of working memory (Smith & Jonides, 1999). In the *N*-back task a continuous stream of items is viewed (e.g., letters) and the participant decides whether the current item matches the stimulus presented a designated number of stimuli back. The *N*-back task included three experimental conditions: baseline (0-back), 1-back, and 2-back. In each condition, letters were presented randomly, one at a time, on a computer screen with stimulus duration of 500 milliseconds and an inter-stimulus interval of 1000 milliseconds. In the baseline (0-back) condition, participants were asked to remember a target letter that was presented at the beginning of each sequence of letters. Participants responded by pressing a button when they saw the target letter on the screen. For the 1-back condition, the participants responded when the current letter matched the letter immediately preceding it. For the 2-back condition, the participants responded when the current letter matched the letter that was viewed two letters back, i.e., two matching letters with one different letter in between them. Each of the conditions began with a practice trial on paper. Additional practice trials occurred before each condition on the computer (10 computer practice trials for both 0-back and 1-back conditions, and 15 trials for 2-back condition for a total of 35 practice responses). A practice trial was immediately followed by a run of 20 letters in the condition practiced. Each of the conditions was presented twice in a testing session in a counterbalanced format for a total of 6 response conditions yielding 120 test responses. The stimulus letter in each trial was drawn from a set of 15 letters: A, F, H, I, J, K, L, M, O, P, Q, R, S, U, and Y.

Correct responses or "hits" and errors (either "misses" or "false alarms") were measured. A miss occurred if the participant did not respond to the target condition, failing to notice that the presented letter matched the previous one (1-back condition) or the letter two letters earlier (2-back condition). A "false alarm" occurred if the participant responded any time other than when the target was displayed. The dependent measures were the response time for hits, the miss rate computed as a percent error, and the false alarm rate, also a percent error. Error rates of both types were very low, and therefore were not subjected to statistical analysis. The mean response times for hits for each of the three test conditions are presented in Table II. This task was administered to children and adults.

Wechsler Memory Scale (WMS-III; Wechsler, 1997b) Letter-Number Sequencing Subtest (Adults):

Table II. Mean Response Times for Hits for the Three Conditions of the *N*-back Task for the Autism and Control Groups

	Response Time for Hits					
	0 Back		1 Back		2 Back	
	M	*SD*	*M*	*SD*	*M*	*SD*
Adults with Autism	404.19	51.86	460.10	99.41	570.03	128.91
Adult Controls	403.52	48.15	449.00	91.46	554.08	121.34
Children/Adolescents with Autism	423.50	76.06	500.42	119.67	576.79	127.26
Children/Adolescents Controls	458.90	82.18	506.02	108.95	623.14	150.98

This procedure is described in the WMS-III manual as a measure of verbal working memory that uses auditory stimuli. For this subtest, the participant is read strings of letters and numbers one at a time ranging in length from 2 to 8 items for a total of 7 items or levels. The participant is asked to first give the numbers in ascending order and then the letters in alphabetical order. The measure used was the age adjusted scaled score.

Wide Range Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990) Number/Letter Memory Subtest (Adolescents/Children): This procedure is equivalent to WMS-III Number Letter Sequencing. The participant is asked to repeat a randomly mixed series of numbers and letters (e.g., 6-L-8) that are read aloud by the examiner. The age adjusted scaled score was the measure used.

Spatial Working Memory Tasks

WMS-III Spatial Span Subtest (Adults): This procedure includes forward and backward span conditions. A board containing 10 cubes in fixed locations is presented, and the examiner taps the cubes in a specified sequence starting with a 2-block sequence, gradually increasing to a 9-block sequence for eight levels. Two trials of different combinations are given at each level. In the forward condition, the participant is asked to repeat the sequence. In the backward condition, the sequence must be repeated backwards. The age corrected scaled score is used as the measure.

WRAML Finger Windows Subtest (Children): A card with window-like openings is presented. The examiner puts a pencil into a sequence of these windows and the participant is asked to use his or her finger to repeat the sequence. The measure used was the age adjusted scaled score.

RESULTS

N-back Task

Error rates for ‘‘misses’’ and ‘‘false alarms’’ were obtained, but the autism participants and controls in the two age groups made very few errors of either type. For the adults, the mode and median for all of the percentage error scores except for ‘‘miss’’ errors on the 2-back conditions were zero. The same result was found for the children/adolescents. Therefore, it did not appear to be appropriate to pursue further statistical analyses of the error data.

Repeated measures analyses of variance (ANOVA) were conducted to compare the response times of the autism and control groups in each of the three *N*-back task conditions. Means and standard deviations are presented in Table II. Results of the statistical analysis are presented in Table III. In both age groups there was a significant main effect for condition. As expected, the response time increased as the number of items to be remembered increased. This increase in response time was equally apparent for both the participants with autism and the control participants. There was no interaction obtained between the condition and group membership for either age group. Neither autism age groups performed significantly differently from the matched participants in any of the three conditions.

WMS-III and WRAML

Results for the WMS-III and WRAML are presented in Table IV. For the WMS-III, taken by the adults, a statistically significant difference between the autism and control groups was not found for Letter Number Sequencing, but was found for Spatial Span. On the WRAML subtests, taken by the adolescents and children, the Number/Letter Test

Table III. Repeated Measures Analysis of Variance Results for the Two Age-Matched Groups for the Three *N*-back Conditions

Source	df	*F*	*p*	ES	Power
Adults					
Condition	2/108	73.55	<.001	.58	1.00
Group	1/54	.20	>.05	.98	.07
Condition×Group	2/108	.17	>.05	.00	.08
Children/Adolescents					
Condition	2/132	72.10	<.001	.52	1.00
Group	1/66	.01	>.05	.57	.05
Condition×Group	1/66	.00	>.05	.00	.05

ES = Effect size.

Table IV. Results for WMS-III and WRAML Verbal and Spatial Working Memory Tests

	Autism Group		Control Group			
	M	*SD*	*M*	*SD*	*t*	*p*
WMS-III Letter Number	12.14	3.15	12.54	1.91	−.55	>.05
WMS-III Spatial Span	14.86	3.74	17.96	2.37	−3.48	<.001
WRAML Number/Letter	9.57	2.97	9.88	2.54	−.30	>.05
WRAML Finger Windows	9.48	2.89	11.26	3.16	−2.18	<.05

did not discriminate significantly between the autism and control groups. However, there was a statistically significant difference for Finger Windows. In summary, statistically significant differences between the autism and control groups in both age ranges were not obtained for the verbal working memory tests, but were found for the spatial working memory tests.

Correlations with IQ

The observed difference between verbal and spatial working memory performance may be task specific in the sense that the test chosen for study may differ in level of difficulty. Thus, if the autism groups do more poorly than controls on the spatial tasks but not on the verbal tasks, it may be because the spatial tasks are more difficult and, therefore, more sensitive to cognitive deficits associated with autism. A traditional method of evaluating task difficulty is to evaluate the degree of association between task performance and general intelligence (Full Scale IQ). We therefore provide correlations between Full Scale IQ and performance on the visual and spatial working memory tasks in the four groups studied in Table V.

The only significant correlations with Full Scale IQ were in the autism groups. In the adult autism group, there were significant correlations with both a verbal and a spatial working memory task. There is about the same degree of strength of association between performance on both types of memory tasks and general intelligence. In the child/adolescent autism group, there was only a significant correlation with a verbal working memory task. This pattern of

Table V. Pearson r Correlations Between Full Scale IQ and Measures of Verbal and Spatial Working Memory

Test	Autism Adults	Autism Children/Adolescents	Control Adults	Control Children/Adolescents
1-Back	.11	.16	.15	−.08
2-Back	−.20	.21	.14	.02
WMS-III Letter Number	.51**	X	−.10	X
WRAML Letter Number	X	.50*	X	.41
WMS-III Spatial Span	.45*	X	.21	X
WRAML Finger Windows	X	−.02	X	.05

*Correlation is significant at the .05 level (2-tailed).
**Correlation is significant at the .01 level (2-tailed).

results would suggest that the groups with autism did more poorly than controls on the spatial working memory tasks for reasons other than differing levels of task difficulty.

DISCUSSION

The children, adolescents and adults with autism performed at similar levels relative to the cognitive and age-matched controls on the working memory tasks that involved the articulatory loop and performed poorer than the controls on the tasks that involved the visuospatial sketchpad. These findings demonstrate a dissociation between verbal and spatial working memory in the same individuals with autism. While intact verbal working memory and impaired spatial working memory have been demonstrated in individual studies, we believe that this is the first study to demonstrate this dissociation in the same group of individuals with autism.

The integrity of verbal working memory is consistent with the literature documenting intactness of short-term memory and associative learning in autism (Bennetto *et al.*, 1996; Hermelin & O'Connor, 1970; Minshew *et al.*, 1997; Minshew & Goldstein, 2001; Rumsey & Hamburger, 1988). The presence of this result on two different verbal working memory tasks in the same individuals with autism endorses the robustness of the finding. These findings are consistent with other studies demonstrating intact verbal working memory in individuals with autism. In a study of verbal working memory, Ozonoff and Strayer (2001) reported that their sample of non-retarded individuals with autism performed similarly to a clinical control group diagnosed with Tourette Syndrome and a control group with typical development on an *N*-back task using four geometric shapes (a green square, a blue circle, a magenta diamond, and a yellow star). While the task clearly possesses visual elements, it could also be considered to have a verbal component because each of the geometric shapes was easily labeled with a single word allowing use of the articulatory loop during the memory process. The results of the current study are also consistent with Russell *et al.* (1996) in which children with autism were found to have superior performance on a verbal recall measure of the articulatory loop as compared to verbal mental age-matched children with moderate learning difficulties.

The spatial working memory tasks revealed deficits in individuals with high functioning autism in this study, supporting the conclusions obtained from the saccadic eye movement studies (Koczat *et al.*, 2002; Minshew *et al.*, 1999). These findings are in contrast to those reported by Ozonoff and Strayer (2001), who found intact spatial working memory in their group of individuals with high functioning autism. However, the spatial memory span and box search tasks used in the Ozonoff and Strayer study could have been verbally mediated, since the colored shapes and hidden objects could be named, thus facilitating performance through verbal coding of the information. This would involve use of the articulatory loop rather than only the visuospatial sketchpad.

The explanation for the dissociation between intact verbal working memory and impaired spatial working memory is unclear. Review of the impairments revealed by saccadic eye movement studies show that autistic individuals move their eyes close to the target location but do not get to the precise location (Minshew *et al.*, 1999). One possibility is that unlike letters that may provide a degree of scaffolding for memory, there is no analogue in spatial memory, and thus the brain may have to utilize a higher degree of computation to achieve the same degree of task accuracy. Control participants may use a strategy of some sort to facilitate performance on the spatial working memory tasks such as using self-talk to verbally note the location while the individuals with autism perform the task using only visual information. Alternatively, the dissociation between verbal working memory and spatial working memory may represent neurobiological differences in the two memory systems. Recent functional neuroimaging work with normal populations suggests that verbal working memory and spatial working memory are mediated by different domain-specific cortical networks with some overlapping neural circuitry but also some different neural circuitry (Gruber & von Cramon, 2003; Smith & Jonides, 1998). Therefore, there may be a neurobiologic substrate that is distinct that can be selectively impaired resulting in one subsystem being affected and not the other. Luna *et al.* (2002) presented evidence from a fMRI study with non-mentally retarded adults with autism that suggested a functional disconnectivity of the neural circuitry underlying spatial working memory.

This study has the limitation of involving only individuals with high functioning autism excluding mentally retarded individuals who could not comprehend and cooperate for the procedures. However, the study of high functioning autism has become a well-accepted procedure that allows for investigation of questions that cannot be addressed in more impaired individuals. The documentation of executive function deficits that formed the basis of the executive dysfunction theory was itself based on the study of high functioning individuals. It is important to note that in the executive function theory the descriptions of the verbal working memory deficit characterize it as a "core deficit." If that is the case, then it should be present in all cases of the disorder and use of restricted samples should not compromise the drawing of conclusions concerning the presence or absence of putative core deficits.

The present study found no deficit in verbal working memory in high functioning children, adolescents and adults with autism using a well-established experimental test of verbal working memory and clinical tests of verbal working memory. The distinction between this test and others used in the past to infer a deficit in verbal working memory is that this test did not involve the confound of a complex cognitive demand, thus demonstrating that verbal working memory is not the basis for impaired performance on tasks that tax complex cognitive abilities. Rather the evidence suggests that impaired performance on these complex cognitive and language tasks reflect inherent impairments in these abilities as proposed by the central coherence and complex information processing-underconnectivity models (Frith & Happé, 1994; Just *et al.*, 2004; Minshew *et al.*, 1997; Minshew, Meyer & Goldstein, 2002).

A question remains as to what extent the spatial working memory deficit might contribute to impaired performance on planning and problem solving tasks. The answer to this depends on the extent to which spatial working memory contributes to task performance. The oculomotor delayed response task documents that the spatial working memory deficit in autism is subtle and lies in the precision of locating a dot of light in the peripheral vision after a delay. The Tower of Hanoi task has provided the strongest and most consistent evidence of executive dysfunction in autism. A subtle impairment in spatial working memory would seem to have little relevance to performance on the Tower of Hanoi problem for which the primary challenge is in developing a strategy. In a paper under review, we report the analysis of the performance of high functioning autistic individuals on a large number of planning, problem solving, reasoning, and executive function tests (Williams, Goldstein, & Minshew, 2004). This analysis reveals that high functioning individuals with autism are able to perform certain rule learning and executive function tasks unless there is a problem solving demand.

In summary, we found no deficit in verbal working memory or the articulatory loop in high-functioning children, adolescents, and adults with autism. These same individuals exhibited difficulties in spatial working memory or the visuospatial sketchpad. These data do not support spatial or verbal working memory impairments as the core deficits underlying problem solving and planning impairments in individuals with autism but substantiate inherent deficits in problem solving itself as the source of difficulty on tasks such as the Tower of London/Hanoi. Further understanding of the breakdown that occurs in verbal working memory as information processing demands are increased and of deficiency in spatial working memory will likely provide valuable insights into the neural basis of autism.

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