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Executive Dysfunction and Its Relation to Language Ability in Verbal School-Age Children With Autism

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In this study, we examined executive dysfunction and its relation to language ability in verbal school-age children with autism. Participants were 37 children with autism and 31 nonautistic comparison participants who were matched on age and on verbal and nonverbal IQ but not on language ability, which was lower in the autism group. Children with autism exhibited deficits compared to the comparison group across all 3 domains of executive function that were assessed including working memory (Block Span Backward; Isaacs & Vargha-Khadem, 1989), working memory and inhibitory control (NEPSY Knock-Tap; Korkman, Kirk, & Kemp, 1998), and planning (NEPSY Tower; Korkman et al., 1998). Children with autism were less developed than the comparison group in their language skills, but correlational analyses revealed no specific association between language ability and executive performance in the autism group. In contrast, executive performance was positively correlated with language ability in the comparison group. This pattern of findings suggest that executive dysfunction in autism is not directly related to language impairment per se but rather involves an executive failure to use of language for self-regulation.

Two decades of research have generated robust evidence of executive dysfunction in autism (Pennington & Ozonoff, 1996; Pennington et al., 1997; Russell, 1997). Given that executive function deficits are characteristic of many neurodevelopmental disorders (Pennington & Ozonoff, 1996), a primary aim of recent research has been to define the specific nature of executive dysfunction in

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autism (Ozonoff, 1997). A clearer specification of the executive deficits in autism may potentially shed light on the neuropsychological and brain bases of the behavioral phenomena that are so strikingly unique to autism and that set it apart from other childhood disorders.

Executive functions have been defined as “mental operations which enable an individual to disengage from the immediate context in order to guide behavior by reference to mental models or future goals” (Hughes, Russell, & Robbins, 1994, p. XXX). These interacting but potentially dissociable operations include working memory, response inhibition, and planning (Dennis, 1991; Robbins, 1996; Ozonoff, 1997; Ozonoff, Strayer, McMahon, & Filloux, 1994). *Working memory* refers to the capacity to maintain information online in the mind while performing another mental operation or activity. Deficits on classic measures of working memory have been found in autism (Bennetto, Pennington, & Rogers, 1996) but not consistently (Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & Strayer, 2001; Russell, Jarrold, & Henry, 1996). Although there is no evidence of an impairment in simple response inhibition (Hughes & Russell, 1993; Ozonoff & Strayer, 1997; Ozonoff et al., 1994), tasks that require a combination of working memory and inhibition (see Diamond, 1990; Diamond, Prevor, Callender, & Druin, 1997; Roberts & Pennington, 1996) have appeared to be especially challenging for individuals with autism (Hughes, 1996; Hughes & Russell, 1993; Russell, 1997). The most robust evidence of executive dysfunction in autism has come from the Tower of Hanoi (AUTHORS, YEAR) and Tower of London (AUTHORS, YEAR) tasks on which individuals with autism have consistently demonstrated impairment (Bennetto et al., 1996; Hughes et al., 1994; Ozonoff et al., 2004; Ozonoff & Jensen, 1999; Ozonoff & McEvoy, 1994; Ozonoff, Pennington, & Rogers, 1991). The Tower tasks require participants to rearrange a set of disks from its original configuration on three pegs to a prescribed goal state in as few moves as possible. In addition to measuring problem-solving and planning ability, these tasks have been conceptualized as tapping combined working memory (generating and maintaining a sequence of moves in mind) and inhibitory control (inhibiting direct placement of a disk to its final destination; Roberts & Pennington, 1996; Russell et al., 1996).

An area of growing interest in child neuropsychology is the potential relation of language impairment to the executive deficits that are frequently found in neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD; Barkley, 1997; Denkla, 1996; Cohen et al., 2000) and autism (Liss et al., 2001; Russell, 1997). However, although interest in the role of language and particularly of the role of self-directed speech in the development of self-regulation and executive control in children traces back several decades to the work of Luria (1961; Luria & Yudovich, 1971), there has been very limited empirical research on this topic. Further, the different possible links between language and executive impairment in autism have not yet been clearly conceptualized and evaluated in relation to one another.

The most notable hypothesis concerning the connection between language and executive dysfunction in autism has been proposed by Russell and his colleagues (Russell, 1997; Russell, Jarrold, & Hood, 1999; see also Hughes, 1996) who have theorized that autistic executive deficits derive at least in part from a failure to use internal, self-directed speech to regulate nonroutine behaviors. Accordingly, a weakness in the use of verbal self-reminding to maintain response rules in working memory would make individuals with autism vulnerable to errors in standard executive tasks that pit a novel and arbitrary response rule against a prepotent response tendency. Russell and his colleagues (AUTHORS, YEAR) have used this explanation to account for autistic deficits on measures such as the Windows task in which participants must point to an empty container to receive a candy reward visible in an adjacent container (Hughes & Russell, 1993) and the Luria hand game (Luria, Pribram, & Homskaya, 1964), which requires participants to point a finger when the examiner makes a fist and vice versa (Hughes, 1996). Importantly, Russell (1997) did not connect the proposed autistic deficit in verbal self-regulation to autistic language impairment per se but rather characterized it as the very essence of the autistic executive deficit itself, that is, as a failure to use (internal) language in the service of self-regulation.

In a recent study investigating the relation between verbal ability and executive function in autism, Liss et al. (2001) compared high-ability, school-age children with autism to a control group of nonautistic children with language impairment matched on age and nonverbal IQ. Liss et al. found that deficits exhibited by children with autism on the Wisconsin Card Sorting Test (AUTHORS, YEAR) disappeared when the lower verbal IQ of the autism group was statistically controlled with analysis of covariance (ANCOVA). Liss et al. interpreted these findings as suggesting that executive dysfunction is strongly mediated by language deficits in autism. Liss et al. also suggested that their findings provided support for Russell's (1997) hypothesis of a deficit in verbal self-regulation in autism. However, Liss et al.'s conclusions may have not been justified.

Regarding Liss et al.'s (2001) conclusion that language impairment may mediate executive dysfunction in autism, the use of ANCOVA to correct for nonrandom group differences is problematic (Miller & Chapman, 2001) and was not necessarily appropriate as Liss et al. acknowledged. The most common criticism of such a use of ANCOVA is that removal of variance associated with a nonrandom group difference (e.g., in verbal IQ) has the effect of altering and potentially misrepresenting the very nature of the diagnostic group variable (e.g., in degree of autism severity) and thus makes its adjusted relation to the dependent variable uninterpretable. However, this criticism may not be so damaging if the claim is simply that verbal deficits contribute to executive dysfunction in autism rather than that executive deficits do not exist apart from verbal deficits in autism. An additional concern in the use of ANCOVA involves the assumption of "homogeneity of regression" (Tabachnick & Fidell, 2001). This is the assumption that the slope of the regression between the dependent variable (e.g., executive function performance) and the covariate (e.g., verbal IQ) is comparable between groups. If the relation between the covariate and the dependent variable were different between groups, then the adjusted group means would be meaningless. A final issue is the possibility that another factor, such as nonverbal IQ, may share a large portion of the variance associated with verbal IQ, making the effects of the verbal IQ covariate on the executive function variable nonspecific. In other words, executive functions may covary with a factor, such as general intelligence, common to both verbal and nonverbal IQ.

With regard to Liss et al.'s (2001) second conclusion, the findings that would be expected on the basis of Russell's (1997) hypothesis are somewhat counterintuitive. If strong correlations were found between autistic executive skills and verbal ability, this would suggest that even in the context of diminished group performance, children with autism with more advanced verbal skills were using these skills to succeed at executive tasks. In contrast, the Russell (1997) hypothesis would seem to predict a lack of association between verbal skills and executive performance in children with autism who have functional language skills, indicating a failure to exploit verbal capacities in the service of executive control.

Our aims of this study were twofold. The first was to profile executive control abilities across a range of executive tasks measuring working memory, combined working memory and inhibitory control, and planning ability in children with autism. In particular, we sought to assess the replicability of deficits in the latter two domains, which represent the combined findings of a number of independent studies, in a single sample of school-age children with autism. Our second aim was to examine the relations between executive control and language ability in children with autism as compared to nonautistic children. Although this aim was exploratory based on the prior research discussed previously, we foresaw two general possibilities. First, we might find autistic executive deficits accompanied by a lack of association between language and executive ability in the autism group, providing support for Russell's (1997) hypothesis and suggesting a mainly functional link between relatively independent language and executive control capacities that is either inoperative or weakened in autism. The second possibility is that we would find a positive association between language and executive function, perhaps reflecting overlapping, non-system-specific neuropathology in the distributed neural networks subserving these functions. Although our study was not designed to distinguish conclusively between these two possibilities, we sought to analyze our data in ways that could provide further insight into how language and executive function may be related in autism.

METHOD

Participants

Participants were 37 school-age children with autism (32 boys), all of whom had developed fluent speech, and a comparison group of 31 nonautistic children (24 boys). All children were recruited through community sources (e.g., newspaper advertisements, parent advisory councils) to participate in a study of language and social cognition. Participants in the autism group were judged to meet the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; American Psychiatric Association, 1994) criteria for autism (n = 32) or pervasive developmental disorder–not otherwise specified (PDD–NOS; n = 5) by an expert clinician. Clinical diagnoses were confirmed using the Autism Diagnostic Interview–Revised (ADI–R; Lord, Rutter, & LeCouteur, 1994), an experimenter-administered parent interview that yields ratings for social, communication, and repetitive behavior symptoms based primarily on behaviors reported for the 4- to 5-year age period, and the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000; Lord, Rutter, DiLavore, & Risi, 1999), an interactive behavioral observational instrument that assesses concurrent autism symptoms in the social and communication domains. All children in the autism group met criteria for autism on the ADI–R with the exception of 1 child who was 1 point below the diagnostic cutoff score for the social symptoms and 4 other children who were 1 point below the diagnostic cutoff score for repetitive behavior symptoms. On the ADOS, 32 children met cutoff scores for a diagnosis of autism, and 4 met for a less severe ADOS diagnosis of autism spectrum disorder. Only 1 child did not meet ADOS diagnostic criteria. This child met ADOS cutoff scores for autism in the social symptom domain (but not in the communication domain) and met full criteria for autism on the ADI–R and was therefore included in the sample. Children with Rett syndrome, childhood disintegrative disorder, or with autism-related medical conditions (e.g., neurofibramatosis, tuberous sclerosis, Fragile-X syndrome) were not included in this study. All comparison group participants were assessed for autistic symptomatology with the ADI–R and ADOS and were confirmed not to meet diagnostic criteria for autism or PDD–NOS on these instruments according to expert clinical judgment.

IQ was assessed with the Differential Ability Scales (DAS; Elliott, 1990), which yields a full scale as well as separate verbal and nonverbal IQ scores. Age-equivalent verbal and nonverbal IQ scores were calculated by averaging the age-equivalent scores for each of the DAS subtests. Language level was assessed with the Peabody Picture Vocabulary Test (PPVT–III; Dunn & Dunn, 1997) and the Expressive Vocabulary Test (EVT; Williams, 1997), which are measures of one-word receptive and expressive vocabulary, respectively. The PPVT–III requires children to choose one of four pictures corresponding to a word spoken by the examiner. On initial trials, the EVT requires children to name pictured objects (Items 1–38); on later trials, children must give a synonym for the word with which the examiner describes the picture (Items 39 and above). As can be seen in Table 1, autism and comparison participants were well matched on age and verbal and nonverbal IQ. However, the autism group scored lower than the comparison group on the two language measures that were administered.

Measures

All measures were administered in two visits scheduled approximately 2 weeks apart. During the first visit, diagnostic assessments and IQ and language testing were completed. During the second visit, the executive function tasks were administered in counterbalanced order.

IQ and Language

Because we were interested in IQ and language scores as potential correlates of executive functions, we used non-age-adjusted scores for these tests so that they would be comparable to the executive function measures, which were not adjusted for age. Verbal and nonverbal IQ scores were calculated by averaging the age

TABLE 1
Participant Characteristics

	Autism[a]			*Control*[b]				
Characteristic	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*t(66)*	*p*
Age	7;11	1;9	5;6–11;10	8;3	2;1	5;1–11;8	0.8	.44
DAS Verbal IQ	87	19	61–133	88	13	64–122	0.4	.69
DAS Verbal Age Equivalent	6;4	2;8	3;1–16;3	7;2	2;7	2;7–15;6	1.3	.21
DAS Nonverbal IQ	91	22	49–153	91	17	50–114	0.1	.90
DAS Nonverbal Age Equivalent	6;11	2;9	3;6–16;3	7;7	2;9	3;1–13;3	0.9	.36
PPVT–III standard score	88	19	58–134	102	12	79–130	3.5	.001
PPVT–III RAW SCORE	85	32	44–173	109	29	35–107	3.1	.002
EVT standard score	83	18	40–136	92	11	67–110	2.3	.02
EVT raw score	61	23	36–152	71	20	35–107	2.0	.05

Note. Age is given in years;months. DAS = Differential Ability Scales; PPVT–III = Peabody Picture Vocabulary Test; EVT = Expressive Vocabulary Test.
[a]$n = 37$. [b]$n = 31$.

equivalents for the subtests comprising each DAS subscale. To construct a language covariate, we took the mean raw score for the PPVT–III and EVT, which were strongly correlated in the autism group, $r(35) = .83$, $p < .001$ and in the comparison group, $r(29) = .91$, $p < .001$. Again, raw scores rather than standard scores were used because like the executive function measures, they were not adjusted for age. A recent study (Condouris, Meyer, & Tager-Flusberg, 2003) demonstrated that these vocabulary tests, especially when combined into a composite language measure, were significantly correlated with the Clinical Evaluation of Language Fundamental (Semel, Wiig, & Secord, l995; Wiig, Secord, & Semel, 1992), an omnibus test of expressive and receptive language ability, and with measures of spontaneous language production in children with autism. As with the standardized scores, there were no significant group differences on the two IQ measures, but the autism group scored significantly lower than the comparison group on the two language measures. For readers familiar with the EVT, it is worth noting that the lower score of the autism group cannot be attributed to a problem with providing synonyms. As can be seen from the autism group's mean raw score and standard deviation for the EVT in Table 1, the large majority gave correct responses above the point at which they were required to provide synonyms (Item 39). Inspection of individual scores revealed that 4 of the 37 children with autism and 2 of the 31 comparison participants scored 38 or below.

Executive Functions

Seven executive functions tasks were administered providing measures of working memory (Word Span Forward and Backward; Block Span Forward and Backward; Isaacs & Vargha-Khadem, 1989), working memory and inhibitory control (Day–Night, NEPSY Knock-Tap; Korkman, Kirk, & Kemp, 1998), and planning (NEPSY Tower; Korkman et al., 1998). Each task was preceded by a brief training procedure consisting of a maximum of four practice trials to ensure participants' comprehension of task instructions. No corrective feedback was given during test trials.

Word span. The word span task was similar to the "nonverbal recall" span task used by Russell et al. (1996) except that in this study, a backward as well as a forward condition was included. In the forward task, children heard the examiner speak a sequence of words at the rate of one word per second. For each trial, a fixed sequence was randomly preselected from a set of nine words, all of which were single-syllable, high-frequency concrete nouns (arm, boat, brush, chair, dress, knife, mouse, ring, tree). After each sequence was spoken, participants were immediately presented with a 3×3 grid containing nine line drawings corresponding to the set of nine words and were instructed to touch the pictures in the same order as the words were spoken. For each trial, the arrangement of the pictures in the grid changed so as to prevent children from using a fixed visual representation of the array to help encode the word sequence and to introduce a visual search component to the task (thus requiring participants to maintain the word sequence in working memory while searching for and pointing to each successive item). Following the word span forward task, all participants were administered a word span backward task, which was exactly the same as the forward task except that children were instructed to touch the pictures in the reverse order from the spoken sequence. For both the forward and backward tasks, children were given two different trials of each sequence length, which ranged from two to seven words. One point was given for each trial correct. Testing was discontinued when a child failed both trials of any one sequence length.

Block span. In the block span test (Isaacs & Vargha-Khadem, 1989), children were asked to watch as the examiner pointed to an unstructured array of nine identical, black blocks affixed to a white board and to point to the blocks in the same sequence as the examiner in the blocks forward test and in the reverse order from the examiner in the blocks backward test. Children were administered two different trials of each sequence length, which ranged from two to eight blocks, and they earned 1 point for each trial correct. Testing was discontinued when a child failed both trials of any one sequence length.

The forward word and block span tasks required children to maintain a given sequence, whether verbal or visually encoded, in working memory and to use that information to carry out a response by pointing to the items in the correct order. The backward word and block span tasks required, in addition, that children manipulate the given information into the reverse order before carrying out their pointing response and were therefore expected to impose increased demands on working memory capacity.

Day–Night. Following the same procedure as Gerstadt, Hong, and Diamond (1994), children were instructed to say “day” to a picture of the moon and stars and “night” to a picture of the sun. Participants were presented with eight moon and eight sun stimuli in pseudorandom order for a total of 16 test trials.

Knock–Tap. This task was taken from the NEPSY (Korkman et al., 1998) and was administered according to the standard procedure. Children were instructed to knock with their knuckles on the table when the examiner tapped with flat palm and vice versa. A total of 15 trials were given in pseudorandom order.

Both the Day-Night and Knock-Tap tasks required participants to hold an arbitrary response rule in working memory and to inhibit a prepotent response (to name the picture shown, to copy the hand movement of the examiner). These tasks were therefore viewed as measures of combined working memory and inhibitory control.

Tower. NEPSY Tower (Korkman et al., 1998), modeled after Shallice's (1982) Tower of London, was used as a measure of planning ability and administered according to the standard NEPSY procedure. Children were asked to rearrange three different colored balls situated on three vertical pegs to reach a goal state, shown on a picture board, in a prescribed number of moves without violating the rules (moving only one ball at a time directly from one peg to another). There was a total of 20 possible trials, which increased in difficulty from one to seven moves for the correct solution. Following NEPSY procedures, only trials solved in the optimum (i.e., fewest possible) number of moves were scored as correct and awarded 1 point for a total possible score of 0 to 20. Testing was discontinued after four consecutive incorrect responses.

The executive functions tasks were chosen on the basis of their expected sensitivity to executive deficits in children within the age and ability range we studied. Given that the span tasks began with a relatively simple sequence of two and continued until the highest attainable sequence was reached, there was little likelihood of floor or ceiling effects on these measures. The NEPSY Knock-Tap and Tower tests were specifically designed for children from the ages of 5 through 12 years, which corresponded well with the age range of our sample. Although typically developing children have been found to reach near-ceiling levels of accuracy (≈90% correct) by the age of 7 years on the Day–Night test (Gerstadt et al., 1994), we included this measure because of prior evidence that tasks requiring combined working memory and inhibitory control are particularly difficult for children with autism (Hughes, 1996; Hughes & Russell, 1993; see also Roberts & Pennington, 1996; Russell, 1997).

RESULTS

Prior to statistical analyses, a screening was conducted to check for skewness and kurtosis in the distribution of the data for each variable. At an alpha level of .01, the screening revealed negative skew in the distribution of Day–Night and Knock-Tap scores. Because of the negative skewness, these variables were reflected, and a logarithmic transformation was applied, resulting in a relatively normal distribution. The transformed variables were rereflected to shift values in the correct direction, and these variables were used in all statistical analyses.

A multivariate analysis of variance (MANOVA) including all seven executive tasks revealed overall poorer performance on the executive function tasks by the autism group, $F(7, 57) = 2.32$, $p < .05$. Post hoc univariate analyses of variance (ANOVAs) were conducted to compare group means for each executive measure. As shown in Table 2, children with autism performed significantly less well on Block Span Backward, Knock-Tap, and Tower.

Following Liss et al. (2001), a multivariate analysis of covariance (MANCOVA) was conducted covarying for language level using the composite raw score from the PPVT–III and EVT. When language level was entered into the MANOVA as a covariate, $F(7, 56) = 10.0$, $p < .001$, the group difference in executive functions was no longer significant, $F(7, 56) = 1.8$, $p > .10$. As can be seen in Table 2, post hoc univariate ANCOVAS with language as the covariate showed no group differences on the executive function measures, with the exception of a significantly higher, language-adjusted score for the autism group on Word Span Forward.

We conducted a second MANCOVA testing the effect of covarying for the DAS verbal age-equivalent score. Correlational analyses showed that the DAS verbal score was strongly associated with language level in the autism group, $r(35) = .89$, $p < .001$, and in the comparison group, $r(29) = .88$, $p < .001$. However, in the MANOVA, although the verbal ability covariate was highly significant, $F(7, 56) =$

TABLE 2
Group Means and Group Differences on Executive Function Tasks

		Language Not Covaried			Language Covaried		
Task	*n*	*M*	*SD*	*F*	*M*	*SE*[a]	*F*
Word Span Forward							
Autism	37	4.8	1.9	0.2	5.1	.27	5.5*
Control	31	4.6	2.0		4.2	.29	
Word Span Backward							
Autism	37	2.4	1.9	2.0	2.7	.26	0.0
Control	31	3.0	1.6		2.7	.29	
Block Span Forward							
Autism	37	4.9	2.1	0.4	5.2	.33	0.6
Control	31	5.2	2.3		4.8	.36	
Block Span Backward							
Autism	37	2.9	2.4	7.7**	3.4	.35	1.8
Control	31	4.6	2.6		4.1	.38	
Day–Night[b]							
Autism	37	12.3	4.1	0.8	12.7	.56	0.0
Control	30	13.4	2.6		12.8	.62	
Knock–Tap[b]							
Autism	36	11.3	3.8	4.6*	11.7	.50	1.1
Control	29	13.2	2.6		12.7	.56	
Tower							
Autism	37	7.4	4.1	4.1*	8.4	.55	0.0
Control	31	9.7	5.0		8.7	.61	

[a]Estimated marginal means and standard errors with averaged Peabody Picture Vocabulary Test and/or Expressive Vocabulary Test raw scores as the covariates. [b]Although the untransformed means and standard deviations are reported, the analyses of variance were conducted with the transformed variables.

*$p < .05$. **$p < .01$.

8.4, $p < .001$, the group difference in executive functions remained significant, $F(7, 56) = 2.2$, $p < .05$. Post hoc univariate ANCOVAS with verbal ability as the covariate showed that group differences remained for Block Span Backward, $F(1, 65) = 5.9$, $p < .02$ and Knock-Tap, $F(1, 62) = 3.7$, $p < .05$ but not for Tower, $F(1, 65) = 2.5$, $p > .10$.

Our finding that group differences in executive functions were no longer significant when language ability was covaried was similar to the finding of Liss et al. (2001) discussed in the introduction to this article. However, to assess whether the relation between language and executive ability suggested by the MANCOVA was (a) specific to the effects of language level on executive functions and (b) truly implicated language level in the executive functioning of children with autism, we conducted partial correlational analyses that examined the unique variance explained by language ability and by nonverbal ability in the executive capacities of each group. Nonverbal scores were calculated by averaging the age-equivalent scores for each of the DAS nonverbal subtests. Language score and nonverbal score were strongly correlated in the autism group, $r(35) = .76$, $p < .001$ and in the comparison group, $r(29) = .86$, $p < .001$. Table 3 displays the partial correlations for each group between executive function scores and language score with the effects of nonverbal ability removed (second column) and between executive function scores and nonverbal score with the effects of language ability removed (third column).

Focusing on the three executive function measures on which the groups initially differed, it can be seen that language ability was significantly associated with Knock-Tap and Tower scores in the comparison group but not in the autism group when the effects of nonverbal ability were removed. Block Span Back-

TABLE 3
Partial Correlations Between Language, Nonverbal, and Executive Function Scores

	Autism[a]		*Comparison*[b]	
Task	*Language Score*[c]	*Nonverbal Score*[d]	*Language Score*[c]	*Nonverbal Score*[d]
Word Span Forward	.05	.50**	.08	.39*
Word Span Backward	.17	.17	.19	.33
Block Span Forward	–.27	.59***	.02	.49**
Block Span Backward	–.02	.46**	.06	.58***
Day–Night	.10	.09	–.05	.26
KnockûTap	.13	.27	.35*	–.02
Tower	.24	.43**	.39*	.20

[a]$n = 37$. [b]$n = 31$. [c]Partial correlation with the effects of nonverbal score removed. [d]Partial correlation with the effects of language score removed.

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

ward was not associated with language ability in either group but was strongly correlated with nonverbal ability in both groups. Thus, the correlational analyses indicate that the results of the MANCOVA are misleading in so far as they appear to implicate the autism group's relatively lower level of language development in the executive deficits that were found. Rather, the correlational analyses showed that in contrast to the comparison group, the autism group's performance on executive tasks did not vary as a function of language capacity, consistent with Russell's (1997) hypothesis that individuals with autism do not use language in the service of executive control.

DISCUSSION

In the following, we discuss our findings in terms of (a) the profile of executive deficits found in autism and (b) the possible role of language in executive dysfunction in autism.

Profile of Executive Function Deficits in Autism

The pattern of executive function deficits we found in school-age children with autism when compared to a control group of children of similar age and verbal and nonverbal IQ was largely consistent with prior research. As expected, children with autism performed significantly less well than comparison participants on the Knock-Tap task, replicating Hughes's (1996) findings with the Luria (1961) hand game, a highly similar task. Following others (Diamond et al., 1997; Roberts and Pennington, 1996; Russell, 1997), we have conceptualized these tasks as requiring children to combine working memory and inhibitory control so as to withhold a prepotent motor response (to copy the examiner's hand movement) by maintaining a conflicting response rule (e.g., to knock when the examiner taps and vice versa) in active memory. Russell (1997) further proposed that the functional deficit underlying poor performance by children with autism on these and similar tasks (Hughes & Russell, 1993) is an impairment in the ability to use inner speech to maintain arbitrary response rules in working memory and to guide behavior accordingly.

We also viewed the Day–Night task as a measure of combined working memory and inhibitory control, but children with autism did not show deficits on this measure. In fact, Russell et al. (1999) also did not find evidence of an impairment on this task in a group of children with autism who were older but of significantly lower ability than the children in our study. Russell et al. (1999) argued that the need to make a verbal response in the Day–Night task precluded the use of subvocal rehearsal to maintain the task rules in working memory. This would have the effect of eliminating any advantage derived from verbal self-reminding in the control group, resulting in the lack of a group difference on this task. Both our findings and those of Russell et al. (1999) are thus consistent with a deficit in verbal self-regulation in autism.

We also found that children with autism performed significantly less well than the comparison group on the Tower task that we administered. This has been one of the most consistently replicated findings in the neuropsychology of autism, with deficits found among both children and adults with autism and across a wide range of IQ (Bennetto et al., 1996; Hughes et al., 1994; Ozonoff & Jensen, 1999; Ozonoff & McEvoy, 1994; Ozonoff et al., 2004, 1991). It has been proposed that the Tower of London and Tower of Hanoi tasks measure combined working memory (maintaining verbal and/or visual representations of the correct sequence of move in mind) and inhibitory control (inhibiting direct placement of a disk to its final destination; Roberts & Pennington, 1996; Russell et al., 1996). This would be consistent with the autism group's poor performance on Knock-Tap. From a developmental perspective, it is possible that the relatively rudimentary executive processes involved in combined working memory and inhibitory control, such as those tapped by the Knock-Tap task, are most crucial at lower levels of performance on the Tower task. In our sample, mean Tower scores indicated that children with autism were able to solve, on average, three-move problems and that comparison participants were able to solve, on average, four-move problems. We would suspect that at more advanced levels of performance, such as on five- to seven-move problems, higher level problem-solving, planning, and working memory processes would increasingly come into play. The fields of clinical and cognitive neuropsychology have already produced several task analyses of the complex planning processes involved in the Tower of London and Tower of Hanoi (e.g., Goel & Grafman, 1995; Ward & Alport, 1997), and the operationalization of these processes in future autism research will help to elucidate the exact nature of the robust deficits revealed by these tasks in individuals with autism.

Finally, children with autism exhibited a deficit on the Block Span Backward task. This finding suggested that working memory capacity in the autism group was taxed by the additional requirement of manipulating information (i.e., reordering the sequence) while holding it in mind. The caveat to this explanation is that a similar deficit was not found on the Word Span Backward task, although the group difference on this task was in the direction of a relative autistic impairment. Prior studies that have investigated working memory independently of inhibitory control in school-age children with autism have not found evidence of an autism-specific deficit (Ozonoff & Strayer, 2001; Russell et al., 1996) with one exception (Bennetto et al., 1996). Two possibilities may account for the inconsistency between our findings and those of prior studies. First, the fact that each of the backward span tasks were administered after the forward tasks may have engendered a prepotent response tendency to repeat the given sequence in forward rather than backward order. However, our informal observations during task administration did not support this conclusion. Second, it may be that these relatively simple working memory tasks are more sensitive to deficits in school-age children than the more demanding processing and storage working memory tasks used in other studies (e.g., counting the dots on a series of cards while maintaining a mental record of all prior responses) in which processing speed may account for most of the variance in performance (see Russell et al., 1996).

Language and Executive Dysfunction in Autism

In addition to investigating between-group differences in executive abilities, we also examined within-group relations between language and executive functioning. Given that the autism group's level of language ability was significantly lower than in the comparison group, we experimented with statistically controlling for this difference by entering the composite language score from the PPVT–III and EVT as a covariate in a multivariate analysis of variance on the executive functions measures. In doing so, we found that group differences on executive tasks were no longer significant, which was similar to the finding recently reported by Liss et al. (2001). However, within-group correlational analyses did not support a direct link between level of language ability and executive functioning in autism, such as was suggested by Liss et al. Rather, the results indicated that whereas executive ability covaried with language level in the comparison group, executive ability was unrelated to language ability (and language impairment) in the autism group.

Specifically, in the comparison group, we found a positive association between language scores and scores on Knock-Tap and Tower, two of the tasks on which the autism group showed deficits. In contrast, in the autism group, there was no association between language level and executive performance when nonverbal ability was partialed from the correlations. We interpreted these findings as suggesting that unlike nonautistic comparison participants, children with autism did not use their language skills in the service of executive control such as to maintain task rules in working memory or on Tower in particular, to verbally encode and rehearse the sequence of moves necessary for a correct solution. On the third executive task, Block Span Backward, on which the autism group performed relatively poorly, there was no correlation with language ability in either group. This would be expected given that this was a spatial working memory task (requiring maintenance and manipulation of a sequence of points to an unstructured array of blocks) in which verbal mediation would be of little use.

We emphasize that our use of MANCOVA to control for the group differences in language level was not an appropriate application of this statistical technique. As we have shown, the differential relation of language to executive ability between the two groups clearly violated a critical assumption of ANCOVA. The MANCOVA thus adjusted group means on the basis of a relation between language and executive function that did not exist in our autism group. Our point was to demonstrate one of the pitfalls of this statistical technique when its assumptions are not met.

It was notable that when the DAS verbal score was entered as the covariate in the second MANCOVA we conducted, there were still significant group differences in executive function scores. Although the DAS verbal score and the composite language score were strongly related in both groups, our language measure was a stronger correlate of executive functions, at least in the comparison group. Further, whereas the groups were equivalent in verbal IQ, the autism group scored significantly lower on both of the language measures relative to the comparison group. Thus, although verbal IQ is often used as a proxy measure of language capacity, our findings suggest that these measures are not interchangeable. The inconsistencies we found may be attributable to the fact that verbal IQ tests typically assess verbal reasoning and conceptualization skills (e.g., identifying the similarities between words), whereas the language measures we used tap more basic lexical knowledge, retrieval, and association processes. However, we must also consider the possibility that our language measures were psychometrically superior to the DAS and simply more sensitive to variation and deficits in language functioning. The measures comprising our composite language score included many more items than the DAS verbal subscale and therefore may have been able to detect differences in functioning that were undetectable by the DAS, particularly at the lower end of the scale.

Nevertheless, our finding of differences between the verbal IQ and language measures does raise the question of what aspects of language development are most closely related to verbal self-regulation and executive function. Although the language tests we administered were primarily measures of lexical knowledge and access, they were found to correlate significantly with omnibus measures of overall language skills in children with autism (Condouris et al., 2003). Thus, we are not able to judge from this data whether more specific language developments bolster the capacity for internal speech and verbal self-regulation.

The role of language capacities in executive function and dysfunction has become of increasing interest in research on neurodevelopmental disorders in which impairments of language and executive control often coexist. Although we have interpreted our data as suggesting an autistic deficit in verbal self-regulation that is independent of general language impairment, we view our data analyses less in terms of a final conclusion and more as an initial attempt to explore the possible links between language and executive processes in autism. Genetic and behavioral studies have brought increasing attention to the overlap between structural language impairment and neurodevelopmental disorders such as autism and ADHD (Alarcon et al., 2002; CLSA, 2001; Cohen et al., 2000; Hafeman & Tomblin, 1999; Herbert et al., 2002; Kjelgaard & Tager-Flusberg; 2001; Rapin & Dunn, 1997), which are also characterized by executive dysfunction. The co-occurrence of language and executive impairment in these neurodevelopmental disorders may be due to common genetic factors that result in neuropathology in the overlapping neural networks that subserve language and the verbal working memory functions necessary for executive control (Chein & Fiez, 2001; Fiez, 2001). However, it is also possible that etiologically distinct, brain-based deficits in language and in the executive use of verbal working memory develop interactively and jointly contribute to the neurofunctional deficits in verbal self-regulation that have been identified. Future research can investigate these possibilities.

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