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Executive Functions in Young Children with Autism

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The executive dysfunction hypothesis of autism has received support from most studies of older people with autism; however, studies of young children have produced mixed results. Two studies are presented that compare the performance of preschoolers with autism (*mean* = 51 months/4.3 years of age) to a control group matched on age, and verbal and nonverbal ability. The first study (n = 18 autism and 17 control) found no group differences in performance on 8 executive function tasks (A not B, Object Retrieval, A not B with Invisible Displacement, 3-Boxes Stationary and Scrambled, 6-Boxes Stationary and Scrambled, and Spatial Reversal), but did find that children with autism initiated fewer joint attention and social interaction behaviors. The second (longitudinal) study of a subset of the children (n = 13 autism and 11 control) from the first study found that neither groups' performance on Spatial Reversal changed significantly over the course of a year. The results of these studies pose a serious challenge to the executive dysfunction hypothesis of autism.

INTRODUCTION

Executive dysfunction has become a prominent explanatory theory of the triad of symptoms present in people with the disorder autism. This theory has its roots in the 1978 Damasio and Maurer paper that compared the symptoms of autism to those of patients with injuries to the frontal lobes of the brain and impairments on tasks thought to tap "executive" skills or functions. Since that time, research has demonstrated that deficits in executive functions (EFs) are a robust correlate of autism. People with autism have more impaired EFs than people with other developmental disabilities, and these deficits are pervasive (for a review see Pennington & Ozonoff, 1996; Pennington et al., 1997). The relation, however, between executive dysfunction (EDF) and autism has yet to be determined. It remains possible that EDF causes autism, or that autism causes EDF, or that some third factor causes both. Ideally this question would be answered through either a longitudinal study and/or a treatment study beginning prior to the onset of the full triad of autistic behaviors, but these types of studies are extremely difficult to do, particularly because autism cannot be diagnosed at birth. This article presents two studies designed to examine this question through the more feasible methodology of looking at EFs in very young children with autism. Three previous studies have attempted to answer this question, with contradictory results.

In what follows, the definition of EF will be discussed, as well as the theoretical and empirical evidence for the EDF theory of autism. Then, two studies are reported that examine the relation between EDF and autism. The first study examines EFs across a range of tasks in children with autism who are younger (*mean* = 51 months of age) than those in whom an EF deficit has been previously found. The second, a longitudinal study, explores the development of these skills in a subgroup of children from the first study, and the relation of EF to other early characteristics of autism. Finally, the implications of the results of the two studies for the EDF theory of autism are examined in light of new developments in the fields of autism and EF.

In order to understand why EDF has been proposed to explain the deficits in autism, one must first understand what EFs are. Executive function has been defined as "the ability to maintain an appropriate problem-solving set for attainment of a future goal" (Welsh & Pennington, 1988, p. 201). Researchers have since attempted to further specify the cognitive abilities described by this broad term, including planning, flexibility of thought and action, set-shifting, inhibition, and holding a mental representation "on-line" or in working memory.

Executive functions describe brain-based skills that begin to develop in the first years of life. EDF therefore makes a compelling theory of autism because autism is known to be a neurological disorder with deficits appearing within the first 3 years of life. In addition, EDF could explain the symptoms of the autism triad.

Symptoms from the third category in the autism triad, restricted and repetitive interests and behaviors, relate most clearly to deficits in EF. With EDF, perseverative and inflexible behaviors would be seen, as in autism. The language and social aspects of the triad are less clearly related to EF, but researchers have suggested that EDF may cause autism-specific deficits in other cognitive domains that are more closely tied to language and social functioning; for example, Theory of Mind (Hughes & Russell, 1993; Ozonoff, Pennington, & Rogers, 1991) and joint attention (McEvoy, Rogers, & Pennington, 1993). Executive functions themselves also could relate directly to these other two areas; for example, being unable to inhibit a prepotent response and using it rather than one more appropriate to the situation could cause autism-type oddities in social interactions and language.

In addition to being a compelling theoretical explanation of autism, empirical work has demonstrated EDF in adults, adolescents, and older children with autism (Bennetto, Pennington, & Rogers, 1996; Hughes & Russell, 1993; Ozonoff, 1995a; Ozonoff et al., 1991; Prior & Hoffmann, 1990; Rumsey, 1985; Rumsey & Hamburger, 1988, 1990; Steel, Gorman, & Flexman, 1984; but see Minshew, Goldstein, Muenz, & Payton, 1992; Russell, Jarrold, & Henry, 1996; Schneider & Asarnow, 1987). In fact, in reviewing studies of this kind, Pennington and Ozonoff (1996) found that people with autism performed significantly worse than controls on 25 of 32 EF tasks across the 14 studies reviewed, with an average effect size of .98. Many studies further noted that scores on EF tasks were highly predictive of group membership. Executive dysfunction is pervasive in autism, and the deficits are different in type and worse in severity than those found in other developmental disorders (Pennington & Ozonoff, 1996).

Thus, there is good theoretical and empirical evidence for an EF deficit in autism. None of these studies, however, can answer the question of whether EDF causes the autism triad. Although longitudinal studies beginning at birth would most accurately answer this question, these are impractical because autism cannot be diagnosed as early as birth. A more feasible way to examine this question is to study the EFs of very young children with autism. Although a study utilizing this approach could not lead to a positive conclusion about cause, it could lead to a negative conclusion; namely, that if no EF deficits were found at very early ages, it is unlikely that they underlie development of the full triad of behavioral symptoms.

Three studies have been done with very young children with autism; however, their results differ. McEvoy, Rogers, and Pennington (1993), Wehner and Rogers (1994), and Dawson, Meltzoff, Osterling, and Rinaldi (1998) explored EFs in young children with autism. The Dawson study demonstrated deficits in young children with autism (*mean* = 5.4 years of age) as compared to two matched control groups on a task similar to the A not B with Invisible Displacement task (Diamond, Prevor, Callender, & Druin, 1997) used in the present study. The McEvoy et al. study compared a group of young children with autism (also *mean* = 5.4 years) to two matched control groups on four well-validated EF tasks: A not B, Delayed Response, Spatial Reversal, and Delayed Alternation. All but Spatial Reversal exhibited either ceiling or floor effects. On Spatial Reversal, children with autism made significantly more perseverative errors than did matched controls.

A study of EFs in even younger children used three of the same tasks as the McEvoy et al. (1993) study (Wehner & Rogers, 1994). In this study, a group of children with autism (*mean* = 3.5 years of age) was compared to a developmentally delayed control group matched on both verbal and nonverbal ability. Preliminary analyses indicated that again, on two tasks, performance was near ceiling; however, unlike the McEvoy et al. study, the two groups performed *equally* well on the Spatial Reversal task. So, deficits have been found on Spatial Reversal and on A not B with Invisible Displacement at a *mean* of 5.4 years of age, but not at a *mean* of 3.5. One possible explanation of these discrepant results is that the EF deficit in autism emerges between these two age ranges and therefore is *not* primary.

Due to the use of Spatial Reversal in both the McEvoy et al. (1993) and the Wehner and Rogers (1994) studies, a comparison of performance across the two studies on this task could be made. There was less than 6 months difference in the chronological ages of the two studies' developmental delay control groups and very little difference in performance on this task. In contrast, there was almost a 2 year chronological age difference between the two autism groups, with the older group (McEvoy et al.) making more perseverations. These comparisons raise the question of whether perseverative behavior may increase as children with autism grow older. In fact, there is evidence suggesting that repetitive behaviors increase between the ages of 2 and 5 years in autism (Stone, Hoffman, Lewis, & Ousley, 1994).

Several other testable explanations for the Wehner and Rogers (1994) null results exist. First, due to the wide range of ages (23–68 months) included in the Wehner and Rogers study, developmental differences may swamp and therefore mask true group differences. Second, Spatial Reversal may not tap executive deficits in very young children with autism; that is, there is a deficit, but it is not manifested in ways that would appear on this task. Third, the variables scored from Spatial Reversal may not be sensitive enough; of particular concern is the confounding of perseverative errors and chance responding because there are only two response options on any given trial.

This article presents two studies designed to further examine these issues. The first study addressed three of the potential explanations for the differences between the Wehner and Rogers (1994) results and those found by McEvoy et al. (1993), with a specific focus on expanding the number and type of EF tasks used, as well as providing a complete error analysis. The second study examined the hypothesis that children with autism perform less well on EF tasks (more perseveratively) as they grow older. These two studies also provided an opportunity for replication of either set of results.

STUDY 1

This first study examined EFs in children who were over a year younger than those in whom EF deficits have been found previously. Although half of the children also had participated in the Wehner and Rogers (1994) study, the age range was more narrow than that study, addressing the critique that developmental variation may have been swamping their results. All children in the present study were administered Spatial Reversal and seven other EF tasks: A not B, Object Retrieval, A not B with Invisible Displacement, 3-Boxes Stationary, 3-Boxes Scrambled, 6-Boxes Stationary, and 6-Boxes Scrambled (Diamond et al., 1997). The use of a variety of tasks addressed the possibility of early EF deficits that were not tapped by the Spatial Reversal task. All tasks were EF tasks in that they required "appropriate set maintenance to achieve a future goal" (Welsh, Pennington, & Groisser, 1991, p. 134) including manipulations to the following: delay over which mental representations must be maintained, amount and complexity of the information being maintained and manipulated, and presence of prepotent activation of a currently nonrewarding response (Roberts & Pennington, 1996). In addition, these tasks had also been linked to frontal cortex functioning (Diamond et al., 1997), their performance required no verbal comprehension or response, that is, it could be completed in a nonverbal fashion, and they were appropriate for the mental and chronological ages of the children. An added benefit of using these tasks was that the recent Diamond et al. study provided some normative data for these tasks. Finally, errors on the Spatial Reversal task were examined as they were in the previous studies, but also in a manner that more clearly differentiated between perseverations and chance. All other tasks also were subjected to an equally careful error analysis. It was hypothesized that children with autism would, on average, perform less well on the EF tasks than the matched control group with a significant proportion of children in the autism group performing below the mean for the control group.

In addition to the EF battery, children were given the Early Social Communication Scales (Mundy, Hogan, & Doehring, 1996). Children of these young ages with autism have consistently demonstrated deficits on this measure in the area of joint attention, and not as consistently in social interaction, while performing as many acts of behavior regulation as children in control groups (McEvoy et al., 1993; Mundy & Sigman, 1989). It was hypothesized that children with autism would show the typical deficits in joint attention and social interaction, but not behavior regulation, whether they demonstrated EF differences or not. Further, it also was hypothesized that there would be a significant correlation between joint attention and performance on spatial reversal, as well as between social interaction and spatial reversal, replicating the McEvoy et al. (1993) results.

Method

Participants

Eighteen children with autism, aged 40 to 61 months (*mean* = 51 months), were compared to 17 nonautistic children with a variety of developmental delays (*mean* = 51 months). Children were recruited through local mental health professionals with diagnostic experience in the area of developmental disabilities. All children in the autism group were diagnosed with autism by experienced clinicians in a large autism clinic independent of this study. This diagnosis was verified using the Autism Diagnostic Interview–Revised (ADI-R) of the child's primary caregiver (Lord, Rutter, & Le Couteur, 1994).

The control group was a heterogeneous clinical group that included children with Down syndrome ($n = 6$), with specific speech/language delays ($n = 5$), and with general cognitive delays ($n = 6$). No child in this group reached the clinical cutoff on the ADI-R, and the two groups differed significantly in their scores in each of the three autism-specific content areas: "Qualitative impairments in reciprocal social interaction," "Communication," and "Repetitive behaviors and stereotyped patterns" (see Table 1).

There were no significant differences between the two groups in chronological age (CA); in verbal (VMA) or nonverbal (NVMA) mental ages as measured by the Mullen Scales of Early Learning for infants (Mullen, 1989) and for early childhood (Mullen, 1992); or in socioeconomic status (SES) from the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975; see Table 1).

Because the groups of children discussed above were matched groupwise, a less stringent matching procedure, ancillary analyses also were undertaken

Table 1 Descriptive Characteristics of the Sample

	Autism[a]		Dev. Delay[b]		
Demographics	*M*	*SD*	*M*	*SD*	*p*
Chronological age	50.67	6.74	50.56	9.16	.968
Verbal mental age	22.72	12.03	28.02	9.66	.162
Nonverbal mental age	34.54	9.32	31.57	12.51	.430
SES	50.56	12.38	47.50	12.80	.478
Gender (M:F)	15:3		10:7		.109
ADI–R					
Social	20.00	5.42	7.38	3.61	<.001
Communication	13.61	3.71	5.13	3.61	<.001
Repetitive/stereotyped	4.44	2.15	1.69	1.49	<.001

Note: Dev. Delay = developmental delay. ADI–R = Autism Diagnostic Interview–Revised.
[a] $n = 18$.
[b] $n = 17$.

Table 3 Descriptive Characteristics of the Sample Matched Pairwise on Age and Nonverbal Ability ($n = 13$ pairs)

	Autism		Dev. Delay		
Demographics	*M*	*SD*	*M*	*SD*	*p*
Chronological age	50.62	6.19	50.73	7.66	.909
Verbal mental age	19.75	11.29	29.62	9.25	.002
Nonverbal mental age	32.12	8.80	32.48	10.18	.710
SES	49.15	13.33	49.00	13.82	.982
Gender (M:F)	11:2		7:6		.089
ADI–R					
Social	19.85	6.00	7.85	3.78	<.001
Communication	13.31	3.59	4.46	2.26	<.001
Repetitive/stereotyped	4.77	2.13	1.54	1.61	<.001

Note: Dev. Delay = developmental delay. ADI–R = Autism Diagnostic Interview–Revised.

using data from two subsets of these children. The first subset of children was matched pairwise on VMA and CA, yielding 13 matched pairs (see Table 2). Children in the second subset were matched pairwise on NVMA and CA, yielding 13 matched pairs (see Table 3). This NVMA subset of children was analyzed because the EF tasks used in this study had a strong spatial/nonverbal component.

Procedure

All children were seen individually by the principal investigator. The present report includes a subset of the tasks performed by these children; other tasks included imitation, attachment, and free play. The entire study required three 1–1½ hour sessions.

Table 2 Descriptive Characteristics of the Sample Matched Pairwise on Age and Verbal Ability ($n = 13$ pairs)

	Autism		Dev. Delay		
Demographics	*M*	*SD*	*M*	*SD*	*p*
Chronological age	50.31	7.48	51.04	9.48	.507
Verbal mental age	26.58	12.01	27.24	10.98	.474
Nonverbal mental age	37.36	8.95	31.71	14.19	.109
SES	48.77	13.35	45.19	12.11	.451
Gender (M:F)	11:2		8:5		.185
ADI–R					
Social	17.92	5.26	7.17	4.06	<.001
Communication	13.92	4.54	5.00	4.09	<.001
Repetitive/stereotyped	4.50	2.58	1.75	1.42	.002

Note: Dev. Delay = developmental delay. ADI–R = Autism Diagnostic Interview–Revised.

The EF tasks were given to all children in the following fixed order, with the first four on the first day and the rest on the second day: A not B, 3-Boxes Stationary, Object Retrieval, 6-Boxes Stationary, 3-Boxes Scrambled, A not B with Invisible Displacement, 6-Boxes Scrambled, and Spatial Reversal. The tasks were presented in a fixed sequence in order to ensure that children's interest and motivation were maintained by moving from easier to harder tasks and by varying the types of tasks given on a particular day. The object searched for was determined by what most interested each child (cars, dinosaurs, animals, cartoon characters, or food items), and was varied by child and within a session to maintain optimum motivation.

Measures and Scoring

All EF tasks included appropriate practice trials. Initial sides of hiding for A not B and A not B with Invisible Displacement were randomized, as was which side, on side-open trials, was open first in Object Retrieval. Initial positions of the boxes and scramble patterns for the boxes tasks also were randomized. In Spatial Reversal, objects were hidden in both locations on the first trial.

A not B. This is the standard A not B task (Piaget, 1954) with a variable delay used extensively in the developmental literature (Wellman, Cross, & Bartsch, 1986), and was administered in a manner similar to Diamond et al. (1997). The child watched as a desired object was hidden in one of two identical containers placed to the right and left of his or her midline. A delay was imposed during which the examiner ensured that the child was not fixating on the object location.

The child then chose the correct container to retrieve the object. The side of hiding (left or right container) remained the same until the child chose correctly on two consecutive trials, and then was reversed. All children began this task at a delay of 10 s. If performance was perfect (both correct at the first side of hiding and correct again when the side of hiding was switched) at this delay, the delay was increased. If the child made errors on the first side of hiding with a 10-s delay, the delay was reduced. Scoring began at the delay time at which the child committed the A not B error, that is, reached to the previously correct side when the object was hidden on the other side. The number of total trials given to a child varied based on performance because standard limits were imposed to insure that, although opportunities for A not B errors were adequate, the child did not have to endure a frustrating number of total trials.

The delay at which the child made the A not B error was scored (possible range 5–15 s). The pattern of errors also was examined across the three types of trials: reversals (the trial on which the side of hiding was first switched), trials following errors, and trials following correct responses.

This task taps a child's ability to maintain the desired object's location and a retrieval plan over the delay, and to inhibit the prepotent response to reach to the previously correct side after the side of hiding switches. Perseverations to the previously correct response greatly increase following ablation of the dorsolateral prefrontal cortex in both adult and infant monkeys (Diamond & Goldman-Rakic, 1989).

Object retrieval from transparent boxes. This task was given as per Diamond (1991) and Diamond and Goldman-Rakic (1985). A desired object was placed inside a transparent box that was open on one side. The child was then allowed to retrieve the object without delay. The open side of the box varied (top, front, left, right), as did the side through which the child saw the object. Trials were designed to move from easiest (object seen through the open side of the box) to hardest (object seen only through a closed side of the box). The accuracy of the child's reach (as per Diamond, 1991) on trials during which the child sees the object through a closed side of the box was scored (scale 0–4).

This task requires children to relate the box opening and the desired object over a spatial separation as well as inhibit the prepotent response (here the response most closely linked to the reward) to reach directly in their line of sight to retrieve the object. Monkeys with lesions to the prefrontal cortex demonstrate deficits on this task (Diamond & Goldman-Rakic, 1985).

A not B with invisible displacement. This task was used by Diamond et al. (1997) and is loosely based on Piaget's (1954) tasks that follow A not B in his object permanence sequence. Children watched as a desired object was hidden in one container at their midline. That container was then moved to the right or left of midline. The examiner did not move the container until the child's eyes were focused on it and followed its movement. A delay of 5 s was imposed (screen down), during which a second identical container silently was placed on the opposite side. The child then chose the correct container in order to retrieve the object. As in the A not B task described earlier, the side to which the container moved after the object was hidden remained the same until the child chose correctly on two consecutive trials at that side; then the side of hiding was reversed.

The percent correct reaches for the total number of trials for each child was scored. The pattern of errors also was examined across the three types of trials: reversal trials, trials following errors, and trials following correct responses.

This task required the child to draw an inference that the desired object was still in the container after the container was moved, maintain that information over a delay, and then use it to inhibit a reach to the previously correct side. The neural basis of this task has not been investigated using lesion studies; however, it is strongly suspected to be tied to the frontal cortex of the brain due to its similarity to the basic A not B task that has been validated using lesion methods.

Spatial reversal. This task (Kaufman, Leckman, & Ort, 1989) was given as described in McEvoy et al. (1993). In the first trial, a desired object was hidden in both of two identical containers placed to the right and left of midline behind a screen, so that the child *could not see* the side of hiding. The child was allowed to choose a container, with no delay. Objects then continued to be hidden behind the screen in the container on the side the child first picked until the child made four consecutive correct reaches. At that point, the side of hiding was switched without warning. Twenty-three trials were given to each child.

Scores from this task included the number of correct responses (scale 0–20) and the number of sets of four correct reaches (0–5). Errors included failures to maintain set, perseverative responses scored by the criteria used in McEvoy et al. (1993) and by more conservative criteria. The more conservative criteria attempt to take into account the confounding of chance and incorrect responses by scoring as perseverative only those responses that repeat an immediately preceding incorrect response.

This task builds up a prepotent response (by keeping the side of hiding the same for four consecutive correct reaches), and then makes the children change their response pattern when the previous response is no longer successful in getting the desired object (children must inhibit the prepotent response). Frontally lesioned monkeys have been shown to perform poorly on a version of this task, scoring most poorly when the side of hiding changed, thus requiring set-shifting (Goldman & Rosvold, 1970).

Boxes tasks. These tasks, developed by Petrides (1995) for use with monkeys and expanded by Diamond et al. (1997) are based on the self-ordered pointing tasks used with adults (Passingham, 1985; Petrides & Milner, 1982). There were four boxes tasks in this study: 3-Boxes Stationary, 3-Boxes Scrambled, 6-Boxes Stationary, and 6-Boxes Scrambled. Each box in these tasks was decorated with a different-colored abstract shape. While the child was watching, a desired object was placed in each box and all lids closed. A 5 s (for 3-Boxes) or a 10 s (for 6-Boxes) delay was imposed (a screen was lowered to hide the boxes from the child's sight), after which the child was allowed to open one of the boxes and retrieve an object. The lid on that box was closed and another delay imposed. The child was again allowed to open one of the boxes. This continued until the child had retrieved all objects (3 or 6) or had made five consecutive errors. In the scrambled conditions, the position of the boxes was scrambled in a random sequence during the delay, such that a full box did not always cycle into the location to which the child just reached. This variation made perseverating to location detrimental to performance, rather than a helpful strategy.

These tasks were given an efficiency ratio score (number of rewards retrieved/number of total reaches in the task; scale 0–1). The number of reaches needed to obtain all rewards also was scored. Error analyses included the number of reaches prior to making the first error, and the maximum consecutive reaches to the same box. For the scrambled conditions only, the maximum consecutive reaches to the same location also were scored because in this condition, unlike the stationary boxes, the boxes changed location.

These tasks require maintaining over a delay which boxes one has opened and updating this memory after each trial, while inhibiting a reach to a previously correct box or location. Although it is possible to keep a simple placekeeper in mind to guide reaching when the boxes are stationary, scrambling requires the maintenance of more specific information regarding the particular visual appearance of boxes one has already emptied. There is evidence of degraded performance on similar tasks by monkeys with dorsolateral prefrontal cortex lesions (Petrides, 1995). These tasks also are similar to self-ordered pointing tasks on which humans with frontal lesions are impaired (Passingham, 1985; Petrides & Milner, 1982) and to spatial working memory tasks on which patients with Parkinson's disease are impaired (Owen et al., 1992).

Early social communication scales. An abbreviated version of this semistructured play session (Mundy et al., 1996) was used to measure three types of nonverbal social/communication skills: Joint Attention (sharing attention with another person around an object or event), Social Interaction (interactions with others including turn-taking), and Behavior Regulation (requests and directing others' behavior). Several different toys and interactions were presented in a structured manner in order to elicit responses from the children. These included running wind-up toys across the table, providing turn-taking opportunities, raising interactional opportunities with tickle and balloon games, and giving a variety of commands and opportunities to follow an examiner's point. This interaction was videotaped for later scoring. The frequency of the three types of behaviors was scored from videotape. Composite scores were calculated based on Mundy et al.

Results

Preliminary Analyses

Prior to any inferential statistics, the distribution of the data points for all variables was examined for skew, kurtosis, and significant outliers. Only Object Retrieval was found to exhibit ceiling effects; no variables were at floor. All continuous dependent variables, except initiating joint attention from the ESCS, were determined to meet the normality assumption, allowing t tests to be run. Variables with categorical distributions were examined using chi-square analyses.

The power to detect group differences of the magnitude (.98; *mean d*) found in previous studies of EFs in autism (Pennington & Ozonoff, 1996) at the $p = .05$ level was .82 for the current study (Cohen, 1977). Replicating all task analyses on the two subsets of children matched pairwise in addition to the already large number of total planned comparisons raised the probability of finding significant differences by chance alone above the .05 level. Given the planned nature of the comparisons, however, analyses proceeded, albeit cautiously.

Analyses to Examine Group Differences on Executive Function Tasks

The first hypothesis examined by this experiment was that the children with autism would perform less well than the matched control group on average and, in fact, that most children with autism would perform less well than the controls' mean, thus demonstrating a pervasive EF deficit. Each task was analyzed both for overall performance (e.g., number correct and efficiency ratios), as well as for specific errors (e.g., number of perseverations and errors on reversal trials). All variables, mean scores, and significance values for the groupwise matched groups are presented in Table 4.

There was only one significant difference between the autism and developmental delay groups that were matched groupwise. Children with autism had *fewer* failures to maintain set in the Spatial Reversal task, $t(33) = -3.23$, $p = .003$. Once the children with autism began a set of four correct trials, they were more likely to complete the set and less likely to make an error after three correct. Analyses of the pairwise matched groups also demonstrated the control group's difficulty maintaining set on Spatial Reversal; for VMA matched pairs, $t(12) = -2.14$, $p = .054$, and for NVMA, $t(12) = -3.72$, $p = .003$.

There was a trend across all three groups for the children with autism to perform *better* (have higher efficiency ratios) on the 3-Boxes Scrambled task:

Table 4 Performance of the Groups on the Executive Function Tasks

	Autism		Developmental Delay		
Measures and Variables	*M*	*SD*	*M*	*SD*	*p*
A not B					
Delay (5–15 s)	12.56	2.45	13.00	2.29	.584
% Wrong reversal trials	55.50	22.60	62.42	26.40	.528
% Wrong following errors	24.29	19.90	31.62	30.60	.527
% Wrong following correct	11.37	8.50	13.14	17.20	.772
A not B-Invisible Displacement					
% Correct	48.23	18.73	57.48	23.21	.254
% Wrong reversal trials	82.67	26.99	63.08	42.83	.154
% Wrong following errors	55.71	40.47	46.59	39.19	.552
% Wrong following correct	19.81	24.00	24.07	25.76	.655
Spatial Reversal					
No. correct (scale = 0–20)	15.28	2.72	15.44	1.80	.840
Sets of four (scale = 0–5)	2.78	1.26	2.19	1.01	.138
Failures to maintain set	.11	.32	.69	.68	.003
Perseverations—original	6.53	2.24	6.21	1.78	.666
Perseverations—conservative	2.12	2.47	1.93	1.79	.808
3-Boxes Stationary					
Efficiency ratio	.82	.21	.80	.26	.838
Reaches to open all 3	3.89	1.23	3.60	.91	.457
Reaches to first error (1 versus 2)	6 versus 3		4 versus 4		.486
Reaches to same box/location	.89	1.18	1.12	1.50	.618
3-Boxes Scrambled					
Efficiency ratio	.70	.21	.58	.19	.075
Reaches to open all 3	4.61	1.24	5.13	1.25	.239
Reaches to first error (1 versus 2)	4 versus 9		4 versus 12		.730
Reaches to same box	1.94	1.70	1.88	1.32	.905
Reaches to same location	1.44	1.25	2.06	1.35	.170
6-Boxes Stationary					
Efficiency ratio	.63	.27	.56	.25	.411
Reaches to open all 6	8.00	2.28	8.67	2.45	.537
Reaches to first error	2.21	1.31	2.73	1.22	.280
Reaches to same box/location	1.67	1.19	1.53	1.23	.739
6-Boxes Scrambled					
Efficiency ratio	.58	.17	.55	.10	.614
Reaches to open all 6	10.07	2.37	10.18	1.28	.882
Reaches to first error	2.47	1.09	2.93	1.09	.218
Reaches to same box	1.65	1.33	1.67	1.26	.965
Reaches to same location	3.18	1.62	3.20	1.55	.965
Object Retrieval					
Quality of reaches	Ceiling		Ceiling		

$t(33) = 1.84$, $p = .075$ for the groupwise matched groups, $t(12) = 2.07$, $p = .060$ for the VMA matched groups, and $t(12) = 1.98$, $p = .072$ for the NVMA matched groups.

There were two additional variables that exhibited significant differences in the pairwise analyses, but not in the groupwise. Children with autism had significantly *fewer* maximum number of reaches to the same location in the 3-Boxes Scrambled task than did control children in both the VMA and NVMA matched pairs analyses, $t(12) = -2.14$, $p = .053$, $t(12) = -2.65$, $p = .021$, respectively. This difference suggests that the children in the control group were more perseverative than children in the autism group. In fact, on this task they were perseverating to a misleading cue, the location, when instead the appearance of the box must be used to guide correct responding in the scrambled conditions. On the 6-Boxes Scrambled task, only the VMA matched pairs analysis on efficiency ratio was significant, with the children with autism performing *better* than the control group, $t(12) = 2.55$, $p = .026$.

Aside from these few significant differences and trends favoring the group with autism, the mean performances of the two groups were virtually identical. The one exception to this was the A not B with Invisible Displacement task, in which the children in Dawson et al. (1998) performed poorly. Although the children with autism appeared to perform more poorly in this task in the present study, the variance was quite large for both groups, and the mean differences were not significant. It is important to note that the number of significant differences found here could have been achieved by chance alone, and that all the significant differences indicated that the children with autism were performing *better* than the children in the control group.

Analyses to Examine Group Differences on ESCS Variables

When these variables were examined for normality in each group, it was determined that Initiating Joint Attention exhibited significant skew; therefore, all analyses were performed using its square root. The other three variables showed a normal distribution. Commensurate with previous findings, the children with autism performed more poorly on Initiating Joint Attention, $t(31) = -3.04$, $p = .005$, Responding to Joint Attention, $t(31) = -2.46$, $p = .02$, and Social Interaction, $t(31) = -3.66$, $p = .001$. There were no group differences in the Behavior Regulation scores (see Figure 1).

Analyses to Examine the Relation between Spatial Reversal and ESCS

The McEvoy et al. (1993) study demonstrated a significant correlation between perseverations on the Spatial Reversal task and joint attention behaviors and social interaction behaviors from the ESCS when their groups were combined. These analyses also were performed on the current data set, combining the autism and control groups. Pearson correlations between McEvoy et al.'s scoring of perseverative responses on the Spatial Reversal task and Initiating Joint Attention demonstrated trends toward significance, as did Spatial Reversal and Responding to Joint Attention. When the more conservative scoring of perseverations on the Spatial Reversal task was analyzed, these two correlations were significant, $r(28) = -.43$, $p = .017$ and $r(28) = -.41$, $p = .027$, respectively. Neither manner of scoring perseverations on Spatial Reversal was significantly correlated with Social Interaction or Behavior Regulation.

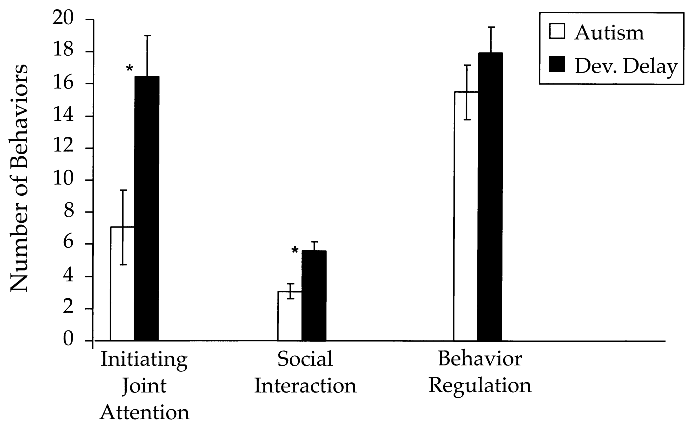

Figure 1 Number of behaviors in each category of the ESCS by group. * $p < .01$.

Contribution of Mental Age and Chronological Age to EF Tasks

The contribution of mental age and chronological age to performance on the EF tasks was examined in two ways. First, both groups' performances on the seven tasks used by Diamond et al. (1997) were compared to the performance of the typically developing children in that study. Second, performance on all eight EF tasks in the present study was analyzed in relation to chronological age and to verbal/nonverbal intelligence (MA/CA ratio quotients).

The recent work using seven of the EF tasks (all except Spatial Reversal) by Diamond et al. (1997) afforded the opportunity to compare the performance of the two groups studied here with performance by developmentally typical children. One important limitation to the conclusions drawn from these comparisons should be noted. In the Diamond et al. study, tasks were given only to children within the recommended age ranges (e.g., A not B given only to infants 8 to 12 months old), restricting the number and types of comparisons possible between that study and the present one in that all tasks were administered to all children.

When qualitative comparisons were made with the typical performance on these tasks as found by Diamond et al. (1997), it was determined that, across most tasks with available comparison data, both groups of children in the current study performed less well than expected based on their mental ages, and therefore also less well than their CA, while still making the patterns of errors expected. This included A not B, A not B with Invisible Displacement, and 3-Boxes Scrambled. For example, on A not B with Invisible Displacement, typically developing children are able to succeed on around half of the reversal trials by 30 months of age (Diamond et al.), whereas the two groups in the current study are succeeding on only 17%–37% of these trials, despite having mental ages around 30 months.

The major variable from each of the EF tasks (excluding Object Retrieval) was analyzed in relation to CA and to verbal and nonverbal intelligence using Pearson correlations (see Table 5). Because the correlation structures were similar across groups, the two groups (autism and controls) were combined for this analysis. None of the EF variables correlated significantly with CA. The two stationary boxes tasks (3- and 6-Boxes) and Spatial Reversal were correlated with verbal and nonverbal intelligence. A not B with Invisible Displacement percent wrong on reversal trials was significantly correlated only with verbal Ratio IQ, as were the number of maximum reaches to empty boxes on the two scrambled boxes tasks. The high correlations of these tasks with the Ratio IQs suggests that overall cognitive ability, rather than group differences may be accounting for a significant portion of the variance in these tasks.

Table 5 Correlation of EF Variables with Nonverbal and Verbal Ratio Intelligence Quotients (RQ)

EF Measures and Variables	Nonverbal RQ	Verbal RQ
A not B		
Delay	.24	.09
% Wrong reversal trials	−.17	−.08
A not B–Invisible Displacement		
% Correct	.10	.20
% Wrong reversal trials	−.19	−.39*
Spatial Reversal		
No. correct	.31	.34*
Perseverations—conservative	−.62**	−.56**
3-Boxes Stationary		
Efficiency ratio	.56**	.49*
Reaches to same box/location	−.50**	−.41*
3-Boxes Scrambled		
Efficiency ratio	.04	−.22
Reaches to same box	.28	.40*
6-Boxes Stationary		
Efficiency ratio	.52**	.45**
Reaches to same box/location	−.06	−.23
6-Boxes Scrambled		
Efficiency ratio	−.08	.09
Reaches to same box	−.28	−.38*

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

Discussion

In summary, analyses comparing group performance on each of the eight EF tasks did not support the hypothesis that children with autism would perform significantly worse than controls. The few group differences that were significant indicated that the children with autism performed *better* than children in the control group. Furthermore, it appears that both groups may be performing below mental age expectations on tasks that allowed those comparisons to be made, and that performance on several EF tasks in both groups was significantly correlated with verbal and nonverbal ability. These results suggest that these tasks are sensitive to developmental differences, and that performance on EF tasks lags behind MA level in groups with developmental disorders, rather than being specific to autism.

In contrast, the children with autism did initiate fewer joint attention and social interaction behaviors, as found in previous studies. In addition, children across the groups who made more perseverative errors on Spatial Reversal demonstrated fewer joint attention behaviors, replicating the McEvoy et al. (1993) results. Unlike that study, however, there was not a significant correlation of perseverations with social interaction.

The first study appears to have ruled out early EF deficits in autism. The second study was designed to examine the possibility that young children with autism develop EDF as they grow older, rather than this deficit being present from the start. This second study also explored the relation between EF and joint attention over time, to further elucidate the correlation between these two variables.

STUDY 2

This second study examined a subgroup of the children from the first study who were given Spatial Reversal at two time points, approximately 1 year apart. Their performance then was compared across time. It was hypothesized that the children with autism would perform worse than controls at both time points. The correlations between EF and joint attention also were compared across time, to explore the hypothesis that early deficits in EF would correlate strongly with later joint attention deficits, rather than early joint attention deficits predicting later EDF.

Method

Participants

Thirteen children with autism and 11 children with developmental delays from the previous experiment were included in this study. Children were matched groupwise at both time points on chronological age and on verbal and nonverbal mental ages (see Table 6).

Procedure

Children who participated in the Wehner and Rogers study (1994) were given Spatial Reversal in that study, and again about a year later as part of Study 1, the study presented above. Children from Study 1 who did not participate in Wehner and Rogers were first given Spatial Reversal during Study 1 and then again 1 year later in order to obtain the longitudinal information.

Measures

Spatial Reversal and the ESCS were given as described in Study 1.

Table 6 Descriptive Characteristics of Longitudinal Sample at Times 1 and 2

	Autism[a]		Dev. Delay[b]		
Demographics	*M*	*SD*	*M*	*SD*	*p*
Chronological age					
Time 1	39.77	8.35	44.45	7.74	.171
Time 2	55.12	8.60	58.64	6.69	.282
Verbal mental age					
Time 1	19.48	8.70	24.68	9.06	.166
Time 2	29.25	11.84	30.65	9.53	.756
Non-verbal mental age					
Time 1	27.31	8.93	26.20	9.68	.774
Time 2	38.12	8.62	34.09	12.47	.361
SES	51.85	12.52	48.86	12.46	.566
Gender (M:F)	10:3		7:4		.476
ADI–R					
Social	19.23	5.83	6.73	3.04	$< .001$
Communication	13.85	4.36	4.55	2.94	$< .001$
Repetitive/ stereotyped	4.69	2.43	1.27	1.35	$< .001$

Note: Dev. Delay = developmental delay. ADI–R = Autism Diagnostic Interview–Revised.
[a] $n = 13$.
[b] $n = 11$.

Results

EF Performance across Time by Group

Each variable from the Spatial Reversal task was subjected to a 2 × 2 mixed-model analysis of variance (ANOVA), with group being the between-subjects factor and time point being the within-subject factor. There were no significant main effects of group or time, nor were there any interaction effects. There were trends, however, in the data for the control group to commit fewer perseverative errors over time, whereas the autism group remained the same (see Figure 2).

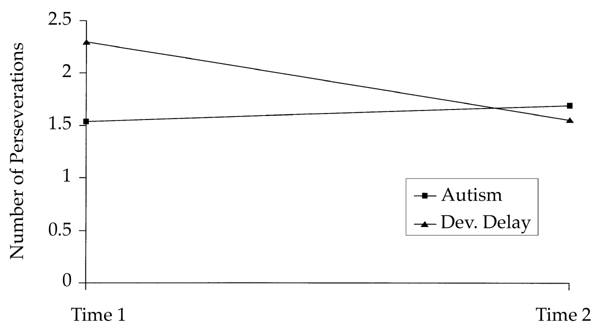

Figure 2 Performance across time on Spatial Reversal perseveration errors by group.

Correlations within Task and Group across Time

For each group, the relation between children's performance at time 1 and time 2 on the Spatial Reversal task was examined. For the control group, correlations between time 1 and time 2 performance ranged from $r(9) = .37$ to $r(9) = .56$, whereas the autism group's correlations ranged from $r(11) = .02$ to $r(11) = .16$. None of the correlations were significant. Although the correlations were higher for the control group, when the difference between correlations by group were examined using Fisher's z test, there were no significant differences.

For each group, the relation between children's performance on the ESCS task across time also was examined. For both the autism and the control groups, correlations between time 1 and time 2 performance were equally low for Behavior Regulation, $r(11) = .17$ and $r(9) = -.25$, Responding to Joint Attention, $r(11) = .24$ and $r(9) = .05$, and Social Interaction, $r(11) = .29$ and $r(9) = .22$. For the autism group, however, the correlation for Initiating Joint Attention was high and statistically significant, $r(11) = .65$, $p = .016$, whereas the correlation for the control group was very low, $r(9) = .02$. A Fisher's z test indicated that these two correlations were significantly different at $p < .05$, using a one-tailed test.

Correlations between Tasks across Time

The number correct and the revised perseveration variable from Spatial Reversal were examined in relation to the Initiating Joint Attention variable from the ESCS across time separately for each group (see Table 7). For the autism group, the number correct from Spatial Reversal at time 1 was significantly correlated with Initiating Joint Attention at time 2, $r(11) = .63$, $p = .02$; there also was a trend for perseverations at time 1 to be negatively correlated with Initiating Joint Attention at time 2, $r(11) = -.50$, $p = .083$; that is, the more perseverative children were, the fewer acts of joint attention they performed. In contrast, the correlations of Initiating Joint Attention at time 1 with number correct and perseverations at time 2 were not significant. The difference between the correlations was not significant, however; for the autism group, the variables from Spatial Reversal did not predict joint attention statistically differently than joint attention predicted the Spatial Reversal variables.

For the control group, neither the correlations nor any of the differences between them were significant. Finally, the differences between the two groups' correlations were examined using a Fisher's z test, and found to not be significant.

Table 7 Cross-Time Correlations between Spatial Reversal and Joint Attention

Tasks Being Correlated	Autism	Dev. Delay
Spatial Reversal, Time 1 → Joint Attention, Time 2		
Correct T1 → joint attention T2	.63*	.23
Perseverations T1 → joint attention T2	$-.50^{+}$	.20
Joint Attention, Time 1 → Spatial Reversal, Time 2		
Joint attention T1 → correct T2	.25	.07
Joint attention T1 → perseverations T2	−.27	.05

Note: Dev. Delay = developmental delay.
$^{*}p < .05$; $^{+}p < .10$.

Discussion

Neither group's performance on Spatial Reversal changed significantly over time, suggesting that young children with autism do not exhibit an autism-specific deficit on this task at very young ages (40 months) or at slightly older ages (55 months). The trend for children in the control group to perform fewer perseverative errors with time might suggest that the deficit appears autism-specific at later ages due to an improvement in the executive functioning of young children with developmental delay. If this were the case, it would support the results from Study 1 that EDF is not the critical deficit in autism, or is not the lone critical deficit. There must be something else that differentiates the early development of these two groups of children.

Although the differences were, for the most part, not statistically significant, there was a trend in the data for the control group to have higher correlations across time for the Spatial Reversal variables, and the autism group to have higher correlations across time for the ESCS initiating joint attention variable. Thus the stability within task appears to vary by task and group.

Although the results are inconclusive, the trend appears to be for the EF variables to predict joint attention over time better than joint attention predicts EF in the autism group. This does not appear to be the case in the control group.

GENERAL DISCUSSION

These two studies tested the executive dysfunction (EDF) theory of autism in a younger group of children than those in whom a deficit in this cognitive realm had been found previously. Contrary to the predictions made by this theory, there were very few significant differences in either level or pattern of performance between the children with autism and matched clinical controls on the eight executive function (EF) tasks. The few significant differences found between the groups on individual measures were such that the children with autism performed *better* than controls. Four explanations for the earlier null results from the Spatial Reversal task (Wehner & Rogers, 1994) were presented above, and addressed in these two studies. First, the current null results do not appear to be due to large developmental variation within the groups, as a narrow range of ages (only 21 months, half that in Wehner and Rogers) was included. Second, results were null across eight different tasks, not just Spatial Reversal. Third, all tasks were subjected to careful error analyses. On none of the variables from the eight tasks did the children with autism perform significantly worse than controls. Finally, in Study 2, there was no evidence that the children with autism were growing into an executive deficit over time; rather, the trends indicated that the children without autism may have been growing out of a deficit. This pattern may lead to a difference between the two groups' performance by the time the children are 5½ years old, as were the children in Dawson et al. (1998) and in McEvoy et al. (1993). The finding of different developmental trajectories for the two groups on Spatial Reversal also raises the issue of other processes occurring in the children with autism that makes their behavior different and also may eventually influence their performance on EF tasks. Thus, the current results do not support an early autism-specific executive deficit (at least on the EF dimensions tested here), and consequently such a deficit is unlikely to cause the triad of behavioral symptoms found in autism.

It is important to note that the null results do *not* appear to be due to confounding subject or task factors. Participants were carefully diagnosed using the Autism Diagnostic Interview–Revised (ADI-R), a widely used and well validated instrument designed for research purposes (Lord et al., 1994). These children appear to be a representative group of children with autism in terms of their degree of autistic symptomology as indicated on the ADI-R, as well as their level of cognitive impairment, with just over three quarters of the group having verbal ratio IQs in the mental retardation range (Bailey, Phillips, & Rutter, 1996). These children also showed the autism-typical pattern of performance on the ESCS. Because the children in both groups were identified at a young age, they were participating in early intervention programs. In the area from which all the children were drawn, there is a strong early intervention program for children with autism focusing on imitation, language, and social relatedness training. The possibility that this program was "treating" early EDF remains an open question. There were not enough children in each subgroup when the autism group was divided into treatment subgroups to address this issue adequately.

Although the children were at first matched only in a groupwise manner, two pairwise matched groups were also generated. A nonverbal mental age pairwise matched group was included to control for the potential effects of nonverbal ability on these nonverbal EF tasks in addition to the usual verbal mental age pairwise matching. *None* of the three matching schemes produced results in the predicted direction.

Task factors were also carefully considered for potential confounds. The children in these studies learned the tasks without verbal instruction and were motivated to obtain the hidden objects, demonstrating the same error profiles produced by typical children in other studies. As with any task, the reliability and validity of the EF tasks must be considered. The reliability of scores on EF tasks (including those presented here) over time, or at a single time point, has rarely been studied, especially in special populations. The validity of these tasks appears to be good, based on both theoretical and empirical evidence. The eight tasks used in these studies were chosen based on their requiring skills believed to be executive in nature: set-shifting, maintaining and manipulating information on-line, and inhibiting prepotent responses. Tasks also were chosen because performance on them was disrupted in either prefrontal lesion studies of nonhuman primates or human studies of children with disorders that disrupt frontal functioning (Diamond et al., 1997). Thus, although the validity of the EF tasks used in these studies appears to be good, the reliability of the scores from them remains an open question.

Given the lack of confounding factors in these two studies, the null results raise serious questions about the EDF hypothesis of autism. Perhaps the critical deficit(s) in autism is in another realm, not EFs. The autism-specific deficits found in the current pair of studies were in the areas of joint attention and social interaction. The deficit in the area of joint attention is one of the most robust early deficits found in autism (see Mundy & Sigman, 1989, for a review). Joint attention, however, is a behavior, not a cognitive construct. Several constructs have been posited to underlie joint attention behaviors: affective processes or motivation, knowledge about self and others' intentions, the ability to make connections between one's own and others' behaviors, and the ability to shift attention or working memory (Mundy & Sigman, 1989; Tomasello, 1995). Although the McEvoy et al. (1993) finding of a significant correlation between executive functions and joint attention was replicated in this study, both at one time point and across time for the autism group, the lack of autism-specific deficits in shifting attention and working memory in the current studies makes the last, EF, hypothesis unlikely. The hypothesis that understanding intentions underlies joint attention behaviors has been developed in part to provide a bridge from joint attention to theory of mind (a later-developing area of cognition with which people with autism have difficulty). Recent work, however, has suggested that children with autism may not have difficulty with tasks tapping their understanding of others' intentions (Carpenter, 1997). Povenelli and Eddy's (1996) work also suggests that performing joint attention behaviors and understanding intentions may not be connected, such that it is possible to have one without the other. Although these findings need to be tested further, they question the hypothesis that a lack of understanding intentions is driving joint attention deficits, and that joint attention deficits are an early manifestation of theory of mind deficits. It also is unlikely that basic connections between one's own and others' behaviors are disrupted in autism due to their good performance on the Behavior Regulation subscale of the ESCS. Thus, this leaves disturbances in affective processes and/or in more basic cognitive processes that could underlie the symptom triad in autism; neither of these possibilities has been adequately tested.

The EDF explanation of autism has been well studied and supported by a variety of studies, and there are at least two further explanations of the current null results to be considered. First, the effects of general cognitive ability on EF skills must be considered, and second, the term EF covers a broad array of skills that require further specification and study.

The first alternative explanation suggests that IQ level may affect EF findings differentially. When children with both autism and retardation are studied, the children in the control groups also have retardation (a significant neurological impairment in its own right), whereas people with autism without retardation are often compared to typically developing people or people with specific learning disorders (such as dyslexia) that are not as likely to effect multiple brain processes. The available work does suggest a relation between variations in normal intelligence and EF (Duncan, 1995). The effect of intellectual level can been seen when the results of two recent studies on working memory in autism are compared. Bennetto et al. (1996) found a working memory deficit in people with autism (FSIQ = 89) compared to people with learning disorders. Russell et al. (1996) found no such deficit on similar tasks in people with autism (VRQ = 55) compared to matched controls, although the people with autism performed less well than typically developing verbal ability controls. Turner (1997) also recently found that people with autism but no retardation had deficits on a self-ordered search task in comparison to matched controls, whereas a group with retardation did not in comparison with their matched controls. Thus it appears that in other studies, groups with mental retardation were equally impaired whether or not they had autism, whereas higher IQ people with autism were differentially impaired.

In the first study presented here, children in *both* groups appeared to perform less well than the typically developing children in the Diamond et al. (1997) study on tasks for which the mental age comparisons could be made, suggesting that there may in fact be EDF in *both* groups of children. Performance on many of the eight EF tasks across the two groups also correlated with the children's cognitive abilities (as measured by ratio IQs). Little systematic work exists on EF across mental retardation syndromes (see Pennington & Bennetto, 1998, for a review of the existing literature), and until EFs in retardation syndromes are better understood, it will be difficult to determine the direction of these effects. Finding EF deficits of the same type and severity in both autism and other retardation syndromes means that EDF cannot be the factor that makes autism different from other disorders.

The second explanation for the results presented here could, in fact, adequately explain the results while not contradicting the EF hypothesis of autism. Recent work refining the skills encompassed under the broad term "executive functions" has indicated at least four different dimensions: "inhibition," "cognitive flexibility" or "set-shifting," "working memory," and "planning." Pennington (1997) provides empirical evidence for these four dimensions both from a factor analysis of performance on traditional EF tasks in a normative sample, as well as from comparisons of severity and profile differences across three groups of abnormally developing populations.

Work in this area has progressed to the point that some discrimination can be made regarding which dimensions are and are not areas of autism-specific deficits. When compared to appropriate controls, older groups of people with autism have been shown to have deficits in verbal working memory (Bennetto et al., 1996; but see Russell et al., 1996), in using arbitrary rules to guide their behavior (Biro, 1997), in cognitive flexibility or set-shifting (for a review of WCST studies see Ozonoff, 1995b; for the spatial reversal task see McEvoy et al., 1993; for two different tasks that more specifically manipulate this dimension see Hughes, Russell, & Robbins, 1994, and Ozonoff, Strayer, McMahon, & Filloux, 1994; but see

Minshew et al., 1992), and in planning (Hughes et al., 1994; Ozonoff et al., 1991). Two additional realms of EF have been hypothesized to be specific areas of deficit in autism: the generation of novel thoughts and actions (Jarrold, Boucher, & Smith, 1996; Turner, 1995), and action-monitoring (Russell & Jarrold, in press). In contrast, there do not appear to be autism-specific deficits in inhibition (Hughes & Russell, 1993; Ozonoff & Strayer, 1997; Ozonoff et al., 1994).

Examination indicates that the eight EF tasks in this study require many of the dimensions discussed above. All tasks very clearly require both the inhibition of a prepotent response, and spatial or object working memory (both the maintenance of information over a delay and the manipulation of that information), whereas three tasks also required set-shifting, and four required action monitoring. Planning of the type seen on the Tower of Hanoi (manipulating multiple moves in mind and then moving away from the goal/prepotent in order to attain it) appears unlikely to have been tapped by these tasks. Because of the age and ability level of the children in this study, tasks were specifically chosen so that they did not require any verbal skills, and therefore none specifically required verbal working memory. The generation of completely novel actions also was not tapped. Russell, Jarrold, and Hood (1999) have stated that arbitrary rules are task rules that have no apparent connection of the means to the end product. The tasks used in the current study all relied on the children paying attention to changing relevant information, but the means-ends connection was always apparent, that is, open container to reveal desired object. Thus, this study indicates that the following dimensions of EF are not likely to be the primary cognitive deficit in autism: inhibition of prepotent response, cognitive flexibility or set-shifting, spatial and object working memory, and action monitoring. The present study cannot speak to verbal working memory, planning, generativity, or understanding arbitrary rules. This study also does not speak to the combination of any of the skills tapped here with untapped skills (e.g., when an arbitrary rule competes with a prepotent response as in Biro, 1997), nor does it speak to performance when the level of skills required are increased (e.g., Roberts and Pennington, 1996, hypothesize that planning occurs in the interaction of the inhibition of a very strong prepotent response, manipulation of multiple moves in mind, and maintenance of rules on line).

Future research is required to examine the performance of young children with autism on other EF dimensions, especially "planning," verbal working memory (to the extent possible), generativity, and understanding arbitrary rules. Methods of examining separate EFs on tasks manipulating only one specific skill will be invaluable to this effort. Efforts should also be made to study each individual skill in combination with others and in varying doses. Clarifying the impact of EDF across mental retardation syndromes and across cognitive levels within autism will aid this effort to further define the skills that make up "executive function" and their relation to normal and abnormal cognitive functioning.

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