ARE EXECUTIVE CONTROL FUNCTIONS RELATED TO AUTISM SYMPTOMS IN HIGH-FUNCTIONING CHILDREN?

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Background: Linking autism symptoms to cognitive abilities can expand phenotypic descriptions and facilitate investigations into the etiology and treatment of this multiplex disorder. Executive dysfunction is one of several potential cognitive phenotypes in autism.

Method: Archival clinical data on 89 children diagnosed with Autism Spectrum Disorders and administered a large neuropsychological battery were evaluated for relationships between executive functioning and autism symptoms.

Results: Significant relationships between both laboratory tasks and behavior rating scales of executive functions and autism symptoms were identified. Multiple regression analyses revealed that measures of semantic fluency, divided auditory attention, and behavioral regulation were significantly correlated with autism symptoms, even after accounting for the variance from correlated “nuisance variables,” such as vocabulary and age.

Conclusions: Executive dysfunction is related to all three clusters of behavioral symptoms in Autism Spectrum Disorders.

Keywords: Autism; Executive control; Asperger Syndrome; Communication; Social; Repetitive behavior; Fluency; Attention.

Executive dysfunction is a consistent, well-documented finding in school-age children with Autism Spectrum Disorders (ASDs; see reviews: Hill, 2004; Pennington & Ozonoff, 1996; Sergeant, Geurts, & Oosterlaan, 2002). Although it has not been demonstrated as a causal factor in ASDs (Dawson, Meltzhoff, Osterling, & Rinaldi, 1998; Dawson et al., 2002; Griffith, Pennington, Wehner, & Rogers, 1999; Liss et al., 2001; Yerys, Hepburn, Pennington, & Rogers, 2007), it may be related to some of the behaviors that define this complex, multi-determined group of disorders (Happé, Ronald, & Plomin, 2006). The present study investigates this possibility.

Developmental disorders, such as ASDs, attention deficit/hyperactivity disorder (ADHD), and dyslexia, are behaviorally defined but commonly associated with brain
abnormalities (for review, see: Giedd, Shaw, Wallace, Gogtay, & Lenroot, 2006). Definition of specific neurodevelopmental disorders at the behavioral and biological levels has been hampered by problems of variability, comorbidity, age-related differences, and widely ranging severity. Frith (2001) and Pennington (2002) argue for the utility of identifying specific cognitive deficits in developmental disorders that may arise from brain abnormalities and drive behavioral symptoms. Exploring cognitive correlates of behavioral symptoms in neurodevelopmental disorders offers several possible advantages. Cognitive profiles may supplement behavioral phenotypes, or even represent intermediate phenotypes, and provide important data in the search for genetic etiologies (Gottesman & Gould, 2003). Cognitive phenotypes can also inform intervention by proposing possible antecedents to behavior problems (Fisher & Happé, 2005; Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006).

Like other neurodevelopmental disorders, ASDs are defined by behaviors, such as poor eye contact, limited imaginative play, repetitive movements, and restricted interests. Multiple genes are implicated (Folstein & Rosen-Sheidley, 2001) in this highly heritable disorder. Happé et al. (2006) use evidence from a population-based sample of twins to argue that the behavioral signs of autism do not stem from a unitary deficit. Instead, the triad of impairments (social, communication, and repetitive behaviors) in autism represents a dissociable set of primarily genetically driven factors. If so, the pursuit of specific cognitive phenotypes that may relate to the discrete impairments in autism could increase power to detect genetic effects (Payton, 2006). There are a number of candidates for cognitive phenotypes in autism, including language (Kjelgaard & Tager-Flusberg, 2001), theory of mind (Baron-Cohen, 1995), executive function (EF), and central coherence (Happé & Frith, 2006). This paper investigates possible linkages between EF and autism symptoms.

EF is a cognitive domain related to self-regulation and the orchestration of other cognitive functions in order to achieve a goal. Findings of executive dysfunction are robust in school-age children with ASDs (for reviews see Hill, 2004; Kenworthy, Yerys, Anthony, & Wallace, 2008; Pennington & Ozonoff, 1996; Sergeant et al., 2002), who show specific impairment with tasks that require set-shifting and other aspects of mental flexibility (Gioia, Isquith, Kenworthy, & Barton, 2002; Hughes, Russell, & Robbins, 1994; Rumsey & Hamburger, 1988). In addition, numerous studies have highlighted the inability of children with ASD to plan and organize response patterns on tasks such as the Tower of London and the Rey-Osterrieth Complex Figure (Hughes et al., 1994; Kenworthy et al., 2005; Ozonoff, Pennington, & Rogers, 1991).

The extensive literature on EF and theory of mind (TOM), which can be considered a proxy for social abilities, provides evidence for a link between social symptoms and EF in ASD. For example, Pellicano (2007) found correlations between TOM and EF independent of age and ability level in young children with ASD, supporting the identification of EF as an important factor in the advancement of TOM. Joseph and Tager-Flusberg (2004) demonstrated a similar relationship among school-age children with ASD. They report a positive relationship between performance on a task requiring working memory and inhibitory control and TOM, which was independent of language and nonverbal ability. In an intervention study, Fisher and Happé (2005) found that EF training contributed to improvements in TOM and postulated an indirect “trickle-down” effect of EF training on TOM performance. Taking a much more concrete approach to social abilities, we have previously linked parent-reported EF deficits to weak adaptive social skills (Gilotty, Kenworthy, Sirian, Black, & Wagner, 2002).
Other investigations have explored the link between EF and autism symptoms directly. Several previous investigations have targeted the repetitive, inflexible behaviors/interests component of the ASD symptom triad. Lopez, Lincoln, Ozonoff, and Lai (2005) investigated the association between repetitive behaviors and multiple measures of EF in a sample of adults with ASD. They documented a significant relationship between cognitive flexibility and repetitive behaviors as measured by the Autism Diagnostic Interview (ADI; Le Couteur et al., 1989) and the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 1999). South, Ozonoff, and McMahon (2007) also found an association between cognitive flexibility and repetitive behaviors in a group of children between 10 and 19 years of age.

Taking a more expansive view of possible EF-autism symptom correlates, Bishop and Norbury (2005a, b) failed to find a relationship between inhibition and any of the three components of the autism triad but did find a link between fluency performance and communication symptoms in autism. Power to reject the null hypothesis may have been limited in the inhibition study by small sample size (14 children with ASD). Joseph and Tager-Flusberg (2004) investigated the relationship between ADOS symptom scores and three aspects of EF: working memory, combined working memory and inhibition, and tower task performance. Significant EF-autism symptom correlations were noted. The relationship between social abilities and EF measures became nonsignificant when verbal ability was partialled out of the correlation, however. Many children had language impairments (mean naming standard score = 78), which, combined with the limited opportunity to document repetitive behaviors during the ADOS, may have limited power to detect relationships in this investigation. In summary, conflicting results presented in previous investigations of the relationship between EF and autism symptoms may reflect limits in sample size, and the scope of symptoms and EFs assessed, as well as the confounding influence of language impairments.

The present study investigates the relationships between EF and autism symptoms by using data from an archival clinical sample of children with ASD. We explore the relationship between a broad range of EF-related tasks tapping attention, fluency, flexibility, inhibition, planning and working memory, and comprehensive measures of ASD symptoms in a relatively large sample of high-functioning children with ASD. As argued in Hill and Bird (2006), use of a high-functioning sample reduces the chances of misattributing general cognitive and language impairments to executive dysfunction. Because EF is a broadly defined construct that may be unitary or a set of discrete, fractionable functions (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Gioia, Isquith, Guy, & Kenworthy, 2000), this study samples performance on a wide range of purported tasks of EF, some tapping multiple EF-related abilities (e.g., the Tower of London; Unterrainer & Owen, 2006) and others that tap more specific abilities, such as inhibition. Because many standard laboratory measures of EF lack ecological validity, making EF hard to capture outside of realistic, “true to life” settings (Bernstein & Weber, 1990; Hill & Bird, 2006), a measure of everyday EF as reported by parents and teachers was also included. In order to be inclusive regarding autism symptoms, scores from the ADI and ADOS were combined to create composite measures of autism symptomatology based on both parent report and clinician observation (Lopez et al., 2005). Although other investigators have used the ADI or ADOS as individual measures of symptoms, we are persuaded by the arguments of Lopez et al. and others that the ADI and ADOS measure different aspects of ASD symptomatology and that combining them gives a more comprehensive and valid overall measure of autism symptoms (see also Risi et al., 2006).
Correlations and regression analyses were used to test the hypothesis that EF performance explains a unique portion of variance in autism symptoms independent of verbal and nonverbal abilities. Based on previous findings, we hypothesized that a composite autism symptom measure would be significantly related to parent and teacher reports of executive dysfunction in everyday settings. We also hypothesized that because the tower task taps multiple EF domains and has been consistently impaired in ASD groups in the past, it too would be related to autism symptoms. We further hypothesized that category (semantic) fluency would be negatively correlated specifically with communication symptoms based on earlier findings (Bishop and Norbury, 2005b) and a presumed relationship between verbal fluency and verbal communication in autism. Although our measure of flexibility, the TEA-Ch Creature Counting test, has not to our knowledge been previously explored in ASD, we hypothesized that it, like other previously investigated measures of flexibility, would be significantly related to repetitive behavior/circumscribed interest symptoms. Regarding measures of sustained auditory and divided auditory attention and autism symptoms, we had no formal hypothesis, because this is a relatively understudied domain of EF in ASD. These tasks offer a primary benefit of increased ecological validity, and, based on anecdotal clinical experience, we considered it important to explore the relationship between social symptoms and the ability to attend to multiple auditory inputs simultaneously.

METHOD

Participants

Participants included a clinically referred sample of 89 children (n = 74 [83%] male) with an autism spectrum diagnosis (autism n = 34; Asperger Syndrome n = 32; pervasive developmental disorder, not otherwise specified n = 23) evaluated by a multidisciplinary team at the Center for Autism Spectrum Disorders (C ASD) at Children’s National Medical Center in the Washington, D.C., metropolitan area. Each child received a comprehensive multidisciplinary evaluation that included a detailed medical and developmental history, an extensive neuropsychological battery, as well as administration of the Autism Diagnostic Interview (ADI; Le Couteur et al., 1989) or the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) and the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1999) by a trained, research reliable clinician. All diagnoses were based on expert clinical impression using Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition (DSM-IV; American Psychiatric Association, 1994) criteria and results from the ADI/ADI-R, ADOS and developmental history. In addition to meeting DSM diagnostic criteria by clinical impression, all participants also met criteria for an ASD on the ADOS and/or ADI/ADI-R according to criteria established by the National Institutes of Health Collaborative Programs for Excellence in Autism (CPEA; see Lainhart et al., 2006). Because the ADI and ADOS do not have an algorithm for Asperger Syndrome, Lainhart and colleagues developed criteria that include an individual in the broad autism spectrum if they: meet the ADI cutoff for autism in the social domain and at least one other domain or meet the ADOS cutoff for the combined social and communication score. In order to include the full autism spectrum, these criteria are relatively inclusive and were used in this study in addition to the criteria that all subjects meet DSM criteria for ASD in the judgment of a team of clinicians experienced with the assessment and diagnosis of individuals with ASD. All participants also had an IQ scaled score of 5 (i.e., standard
score of 75) or higher on either the Wechsler Vocabulary or Block Design subtests. Demographic and sample characteristics are presented in Table 1.

**Measures**

**Socioeconomic status.** Socioeconomic status (SES) was based on the four-factor Hollingshead Index of Social Position (Hollingshead, 1975), which utilizes marital status, gender, education, and occupation to compute a household SES score. Lower SES scores reflect greater SES status.

**Diagnostic measures.** The Autism Diagnostic Interview (ADI or ADI-R; Le Couteur et al., 1989; Lord et al.1994) is a detailed parent or caregiver interview of developmental history and autism symptoms. Scores are aggregated into symptom clusters that correspond to *DSM-IV* criteria for a diagnosis of autism. The Autism Diagnostic Observation Schedule (ADOS; Lord et al. 1999) is a structured play and conversational interview that includes a series of social presses and other opportunities to elicit symptoms of an ASD.

ADI and ADOS scores were aggregated into a composite score for each symptom domain (communication, reciprocal social interaction, and restricted and repetitive behaviors). This was done by first converting domain raw scores of the ADI and ADOS into standardized *z*-scores and then taking the mean of the ADI and ADOS *z*-scores to create composite scores. This approach was taken to make the contribution of ADOS and ADI scores comparable. Using raw scores in this calculation would have overrepresented the ADI in the composite because ADI algorithm totals include more items, and thus more possible points, than the ADOS algorithm totals. Unstandardized raw scores are presented in Table 1 for the ADOS and ADI/ADI-R.

**General cognitive ability.** General cognitive ability was assessed using one of three Wechsler Intelligence scales, the Wechsler Intelligence Scale for Children – 3rd Edition (Wechsler, 1991), Wechsler Intelligence Scale for Children – 4th Edition (Wechsler, 2003), or the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). In order to create comparable cross-test measures, verbal ability was estimated using the

### Table 1  Participant Characteristics.

<table>
<thead>
<tr>
<th></th>
<th><em>N</em></th>
<th><em>M</em></th>
<th><em>SD</em></th>
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<td>11–44</td>
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<td>1–19</td>
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<td>2–14</td>
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<td>1.65</td>
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</table>

*a*Based on Wechsler Vocabulary scores reported in scaled format (*M* = 10, *SD* = 3).

*b*Based on Wechsler Block Design scores reported in scaled format (*M* = 10, *SD* = 3).
Vocabulary subtest and nonverbal ability was estimated using the Block Design subtest. Vocabulary and Block Design performance is presented as norm-referenced scaled scores \((M = 10; SD = 3)\).

**Executive function measures.** All executive functioning measures are presented as age-corrected, norm-referenced standard scores calculated using the reference tables provided for each instrument.

*Behavior Rating Inventory of Executive Functions (BRIEF; Gioia et al., 2000).* The BRIEF is an informant report inventory of executive functioning in everyday situations. It yields eight scales that are collapsed into two broad indices: the Behavioral Regulation Index (BRI) and the Metacognition Index (MCI). BRI and MCI \(T\)-scores \((M = 50; SD = 10)\) from both parent and teacher report were standardized into \(z\)-scores and then aggregated to create composite scores for the BRI and MCI. Higher scores indicate greater impairment; \(T\)-scores \(\geq 65\) indicate clinically significant symptoms.

*Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999).* The TEA-Ch is a standardized assessment battery of various aspects of attention and EFs in children including sustained attention, divided attention, working memory/flexibility, and response inhibition. TEA-Ch subtests are reported as scaled scores \((M = 10; SD = 3)\). Four TEA-Ch subtests were used:

1. **Score!** is a measure of auditory sustained attention. It requires respondents to count the number of beeps heard on a tape.
2. **Score-DT** assesses divided attention and working memory. It combines the sustained-attention demand from Score! with an additional auditory component. Respondents count the sounds while listening for an animal name spoken during a concurrent audio news broadcast.
3. **Creature Counting** is a measure of flexibility (or switching) and working memory that requires respondents to alternate between counting forward and counting backward while following a path of targets.
4. **Walk-Don’t Walk** is a measure of sustained attention and prepotent response inhibition. Respondents must attend to two auditory stimuli (i.e., beeps and beeps plus crashing noise); the former prompts respondents to mark the corresponding tile of a path, while the latter cues them to stop marking on the corresponding tile of the path. To receive credit, the child must correctly mark the number of beeps heard. The temporal interval between the auditory stimuli decreases as the task proceeds.

*Tower of London-Drexel (TOL-DX) (Culbertson & Zillmer, 2000).* TOL-DX measures multiple EFs such as planning, inhibition, and working memory. It requires the subject to work step-by-step to copy a pattern of beads on pegs using the least number of moves possible. The total-moves score was analyzed as an omnibus measure of EF. Results are reported as standard scores \((M = 100; SD = 15)\).

**Semantic fluency.** Semantic Fluency taps language organization by asking the subject to orally name as many words as possible that belong to a certain category (e.g., foods or animals). Two versions of this task were given: NEPSY®: A Developmental Neuropsychological Evaluation (NEPSY; Korkman, Kirk, & Kemp, 1998) or the Delis-Kaplan
Executive Functioning System (D-KEFS; Delis, Kaplan, & Kramer, 2001), depending on the age of the child. Results are reported as scaled scores ($M = 10; SD = 3$).

**Data Analytic Plan**

All data were first examined for outliers and to determine that statistical assumptions of parametric tests were not violated. Data were analyzed initially using bivariate correlations between possible nuisance variables (age, Vocabulary, and Block Design scores) and both EF measures and composite autism symptom domains. Statistically related nuisance variables were included in subsequent analyses. Because this is a clinical dataset and not all data points were available for all subjects, using statistical significance levels to identify meaningfully related variables was deemed inappropriate. Instead, a medium effect size or larger, corresponding to an $r \geq .24$ by Cohen’s standards (Cohen, 1977), was used as entry criterion into subsequent analyses. Scatter plots between related predictor and outcome variables were composed to examine the distribution of scores for problems that might affect primary results, such as a bimodal distribution and/or outliers.

To understand the unique contribution of each EF measure, multiple regression models were calculated with each autism symptom composite score as the outcome variable and EF scores as predictors. Laboratory and informant report measures were analyzed in separate regression models because of the qualitative differences in source and type of data. Stepwise regressions, entering predictor variables (EF variables correlated at $\geq .24$ with autism symptom scores) at step 1, and nuisance variables at step 2 were conducted. This strategy was selected first to examine the relationship between EF and autism symptoms and then to examine how that relationship changed with the addition of covariates. When there was just one predictor, both the covariates and the predictor were entered in the same step since entering a single predictor in step 1 would be redundant with bivariate correlations.

**RESULTS**

**Preliminary Results and Descriptive Statistics**

Inspection of predictor and outcome variables did not reveal any problems with skewness, kurtosis, outliers, or the presence of a bimodal distribution. The frequency distribution of scores revealed no floor or ceiling effects with one exception: 8 subjects, or 20% of the sample, performed at the floor on the tower task. Inspection of scatter plots of tower scores and autism symptom scores indicated that those subjects with low scores had autism symptom scores that were evenly distributed above and below the mean for this sample, however. In addition, $t$-tests comparing the 8 subjects at the floor of tower measure to the remaining sample revealed no differences between those at the floor and the rest of the sample on any of the three symptom domains. As shown in Table 2, despite having scored in the average range on the Wechsler Vocabulary and Block Design subtests, scores on laboratory measures of EF tended to be in the low average range. The lowest scores were on measures of sustained attention (TEA-Ch Score!), response inhibition (TEA-Ch Walk Don’t Walk), and when multiple EFs were assessed simultaneously (TOL-DX). Similarly, mean scores on both the parent and teacher report of problems in behavior regulation and metacognition were in the clinically significant range ($t \geq 65$).
As shown in Table 3, Vocabulary was significantly negatively related to autism communication symptoms and negatively related to restricted and repetitive behaviors. With regard to laboratory measures of EF, Score DT and Category Fluency were negatively correlated with communication and reciprocal social interaction symptoms and Walk Don’t Walk was negatively correlated with restricted and repetitive behaviors. The BRIEF BRI was related to all three autism symptom domains and BRIEF MCI was related to reciprocal social interaction symptoms.

**Primary Analyses**

**Communication symptoms.** Two multiple regressions were conducted with communication symptoms as the outcome variable, one with laboratory measures of EF and one with informant report measures of EF. In the first regression, Score DT and Category Fluency were entered in step 1 and Vocabulary as a covariate entered in step 2. Results shown in Table 4 indicated that better performance on Category Fluency was associated with fewer
autism communication symptoms after accounting for variance from Score DT and Vocabulary. Score DT and Vocabulary did not contribute meaningfully to the model. The second regression investigated the informant report measure. Both the BRIEF BRI and Vocabulary were entered in the same step. Results indicated that informant report of problems with behavior regulation was associated with more communication symptoms (Table 4). Higher Vocabulary scores were associated with fewer communication symptoms in this model.

**Reciprocal social interaction symptoms.** Following the same model as described above, two multiple regressions were conducted with social symptoms as the outcome variable. In the first regression, Score DT and Category Fluency were entered in step 1 and age at testing was entered in step 2. As shown in Table 5, significant results indicated that better performance on both Score DT and Category Fluency was associated with fewer social symptoms. Entering age in the model did not influence the results. In the second regression both the BRIEF BRI and BRIEF MCI were included in the model and age was entered at step 2. This model was also significant indicating that BRIEF MCI and BRIEF BRI are related to autism social symptoms (Table 5). A review of the T-scores related to each variable indicated that, after accounting for shared variance, neither was significant although BRI approached significance. The ΔF score at step 2 was not significant indicating that age at testing did not contribute to the model.

**Restricted and repetitive behaviors.** Table 6 displays the results of two multiple regressions conducted with restricted and repetitive behaviors as the outcome variable. In the first regression, both Walk Don’t Walk and age at testing were entered in the same step. In contrast to the correlations described above, after accounting for variance explained by age, Walk Don’t Walk no longer accounts for significant variance in restricted and repetitive behaviors. In the second regression, both the BRIEF BRI and age at testing were entered in the same step. Results indicated that both BRIEF BRI and age were significantly related to restricted and repetitive behaviors such that children with greater behavior regulation problems exhibit more restricted and repetitive behaviors. In both models, results indicate older children exhibit fewer restricted and repetitive behaviors.


**Table 5** Laboratory and Parent Report Measures of EF Predict Social Symptoms.

<table>
<thead>
<tr>
<th>Variables in equation</th>
<th>$F$</th>
<th>$R^2$</th>
<th>$\beta$</th>
<th>$t$</th>
<th>$p^*$</th>
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<td>Step 2. Model Summary</td>
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$^aF$ indicates $F$-value at step 1; $\Delta F$ indicates change in $F$ from step 1 to step 2.

$^bR$ indicates $R^2$ at step 1; $\Delta R^2$ indicates change in $R^2$ from step 1 to step 2.

$^c$Bold indicates $p < .05$.

**Table 6** Age and Parent Report Measures of EF Predict Restricted/Repetitive Symptoms.

<table>
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<th>$\beta$</th>
<th>$t$</th>
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$^a$Bold indicates $p < .05$.

**DISCUSSION**

In this investigation we documented several associations between autism symptoms and executive control functions. Multiple regression analyses revealed that measures of semantic fluency, divided auditory attention, and behavioral regulation were significantly correlated with autism symptoms, even after accounting for the variance from correlated “nuisance variables,” such as vocabulary and age. Our first finding was that, consistent with our prediction, better performance on semantic fluency was associated with fewer autism communication symptoms, even after accounting for vocabulary, suggesting that, in this sample, as reported previously, verbal fluency is related to the presentation of communication symptoms.

Many previous investigators document verbal fluency deficits in individuals with ASD and their relatives (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Hughes, Plumet, & Leboyer, 1999; Kleinans, Akshoomoff, & Delis, 2005; Verte, Geurts, Roeyers,
Oosterlaan, & Sergeant, 2005). Bishop and Norbury (2005a) reported a linkage between fluency and autism-related communication symptoms. They argued that pragmatic language deficits in autism may reflect deficits in generativity as well as social difficulties. Indeed, both on fluency tasks and in conversation, individuals with ASD struggle to generate words that are relevant to a context or topic. Such difficulty could be reflected in ADI andADOS items that assess an individual’s capacity to engage in reciprocal conversations, as well as a tendency to rely on scripted or stereotypic speech, whether it be used appropriately, such as when using a rote script to ask for help, or inappropriately, such as when reciting lines from a favorite book or movie out of context. An alternative, or complimentary, hypothesis is that the structural language deficits associated with high-functioning autism and, in some cases, pervasive developmental disorder, not otherwise specified adversely affect verbal fluency performance.

We also found that the Behavior Regulation Index (BRI) of the Behavior Rating Inventory of Executive Function (BRIEF) predicted ASD-restricted and repetitive behavior symptoms. The BRI is comprised of three subdomains that tap behaviors related to inhibition, flexibility, and emotional control. Thus, like South et al. (2007), Lopez et al. (2005), and Turner (1997), we link flexibility to autism-related restricted and repetitive behavior symptoms. Both our findings and those of Lopez et al. conflict with Turner’s hypothesis (1997) that generativity also plays a role in restricted and repetitive symptoms in autism, however, as we found no link between fluency and restricted and repetitive behavior symptoms.

Our third, and perhaps most significant, finding associates both semantic fluency and auditory divided attention abilities with ASD social symptoms, a linkage that has not been previously described. Indeed, Ozonoff et al. (2004) as well as Joseph and Tager-Flusberg (2004) failed to find an association between EF and ASD social symptoms. This discrepancy may be explained by the different measures of EF employed in each of these studies. Our data are consistent with these investigations in finding no significant association of performance on a tower or inhibition task with social symptoms. It is also possible that differences in age (Ozonoff’s sample included adults) and sample size (Joseph’s sample was somewhat smaller than ours) contributed to discrepant findings in these studies. One other study (Bishop & Norbury, 2005a) found a trend toward significant correlations between social autism symptoms and ideational fluency in a mixed group that included a subset of children with ASD.

To our knowledge, ours is the first investigation of the relationship between auditory divided attention (as measured by the TEA-Ch Score! DT task) and autism symptoms. This task requires a child to simultaneously listen to a news broadcast for an animal name and to count beeps, thus requiring dual attention and working memory in order to hold the animal name, number of beeps counted, and rules of the task in mind. It is not unreasonable that this ability to divide attention and working memory between two stimuli has implications for social reciprocity and social interaction generally. Interacting with another person, particularly another child, requires adept “on-line” processing and integration of multiple stimuli, such as facial expression, body language, and intonation (Klin, Jones, Schultz, & Volkmar, 2003).

It is noteworthy that the EF measures on which participants scored most poorly did not show the strongest relationship to symptoms of autism. We found low EF scores on measures of response inhibition, sustained attention, and omnibus EF, but measures of divided attention and semantic fluency, both with mean scores in the average range, were significantly associated with autism social and communication symptoms. In this sample,
EF performance covaries with autism symptoms most on tasks that are intact for the group as a whole, indicating the importance of considering the heterogeneity within ASD samples, as well as between ASD and other disorders. Mundy, Henderson, Inge, and Coman (2007) argue for a modifier model in autism that addresses heterogeneity in ASD by considering variables that may not be specific to autism but can alter expression of the disorder in significant ways, such as increasing social impairment. Our data is more consistent with identification of divided attention and fluency as possible modifier variables than as intermediate phenotypes in autism.

It is also important to note that, as has been reported elsewhere, many of the EF laboratory measures used in this investigation were not related to autism symptoms, even when performance on the measure was impaired. For example, performance on the tower was impaired in this study when compared to normative data (see Table 2), but not related to autism symptoms. Poor performance on the tower in ASD may reflect factors that are not related to symptom expression. On the other hand, failure to find relationships could reflect limitations in standard laboratory EF tasks such as the tower. Tower tasks are reported to have weak test-retest reliability (Bishop, Aamodt-Leeper, Creswell, McGurk, & Skuse, 2001; Lemay, Bedard, Rouleau, & Tremblay, 2004); although Culbertson and Zillmer (2000) report moderate to high test-retest reliability on the Tower of London-DX move score, which was used in this investigation.

In addition, Hill and Bird (2006) criticize standard measures of EF that fail to capture deficits in high-functioning individuals with ASD for their lack of ecological validity. The BRIEF and the Test of Everyday Attention for Children Score! DT subtest, both used in this study, are designed for increased ecological validity. By virtue of their reliance on everyday activities, however, they tap multiple abilities (e.g., language, processing/motor output speed) and may fail to isolate discrete EFs. This confound may be unavoidable in the EF domain. Bernstein and Waber (2007) argue that what we call EF relies not on functional modules but on functional neural networks that develop in the context of experience. This observation appears particularly relevant to autism, which has defied modular explanation at the genetic, neuroanatomical, neurofunctional, and behavioral levels and is increasingly understood as a disorder of distributed networks in the brain (Muller, 2007). At the same time, it is important to acknowledge that reification of “executive functions” may be premature, or even misguided, as we attempt to capture an illusive construct that is not easilyparsed into discrete components.

Several limitations must be acknowledged in this study. Reliance on archival clinical data prevented comprehensive assessment of all subjects using the same metrics, thus reducing power to detect potentially meaningful relationships. Nor were the strict controls provided in an experimental setting, such as random task order, imposed. Because there is no control group, we cannot know whether these EF-autism-symptom links are specific to ASD or predictive in a wider population. Indeed, future research may address this question by attempting to link EF with subclinical traits associated with autism in typical controls, and children with other developmental disorders, such as ADHD and language impairment. In addition, the EF abilities identified here as predictive of autism symptoms shared verbal mediation. Although we limited our sample to high-functioning children with ASD and, when appropriate, covared the influence of an expressive vocabulary formulation task (a proxy for language ability), we may not have controlled adequately for these shared verbal demands. Finally, the restriction of our sample to high-functioning children limits the relevance of these findings to lower-functioning children with ASD.
EXECUTIVE CONTROL FUNCTIONS AND AUTISM SYMPTOMS

This study contributes to the scientific literature by expanding the question of EF’s role in autism beyond repetitive behaviors to social and communication symptoms. Although EF was originally conceptualized to account for rigidity, perseveration, and other nonsocial deficits in ASD, this study indicates that some aspects of executive dysfunction may exacerbate symptoms in all three components of the triad of impairment. In the search for intervention targets, ameliorating executive dysfunction may serve to improve not only nonsocial deficits (as originally conceptualized) but also social and communication difficulties.

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