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Executive Function as a Predictor of Academic Achievement in School-Aged Children with ASD

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Abstract

The contributions of Executive Function (EF) to academic achievement in children with Autism Spectrum Disorder (ASD) are not well understood. Academic achievement and its association with EF is described in 32, 9-year-old children with ASD. EF at age 6 and 9, and academic achievement at age 9 were assessed as part of a larger longitudinal study. Better performance on a Spatial Reversal task but not A-not-B with Invisible Displacement at age 6 was associated with better math achievement at age 9. No relationship was found between these EF measures at age 6 and reading or spelling achievement at age 9. Future studies are needed to explore whether improving early EF skills can increase math achievement in children with ASD.

Keywords

set shifting; working memory; inhibition; math; academic achievement; autism

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Academic skills such as reading, writing, and problem solving prepare young people to function with independence as adults. Children with Autism Spectrum Disorder (ASD) are at high risk for academic difficulties and as a result may be less prepared than their typically developing peers for future adult responsibilities. Estimates suggest that the majority of children with ASD perform worse than expected in at least one academic area and are 5.5

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Compliance with Ethical Standards

Conflict of Interest
The authors declare that they have no conflict of interest.

Informed consent
Informed consent was obtained from all individuals included in the study.

times more likely to show a mathematics disability as compared to mathematical giftedness (Estes et al. 2011; Griswold et al. 2002; Jones et al. 2009; Oswald et al. 2016). Early math skills are one of the strongest predictors of later academic achievement (Duncan et al. 2007). Enhancing math skill development could be one path to improving overall academic success and increased math skills may lead to improved functional outcomes for children with ASD. However, relatively little is known about math achievement in children with ASD.

There is an emerging understanding of the factors that contribute to variability in academic achievement in individuals with ASD. (Ashburner et al. 2008; Estes et al. 2011; Mayes and Calhoun 2003). In typically developing students, IQ and academic achievement are highly correlated, but there are significant discrepancies between IQ and academic achievement in children with ASD, suggesting that factors in addition to IQ may be important to consider (Estes et al. 2011; Jones et al. 2009). In typically developing children and children with non-ASD neurobiological disorders, executive function (EF) plays an important role in the development of academic achievement (Bull and Scerif 2001; Clark et al. 2010; Engel de Abreu et al., 2014; Espy et al. 2004; McClelland et al. 2014; Passolunghi et al. 1999; Sjowall et al. 2017; St. Clair-Thompson and Gathercole 2006; Will et al. 2016). One aspect of EF, working memory (holding and manipulating information in the mind), has garnered the most attention in the academic achievement literature. Working memory is associated with a variety of mathematical skills from simple (e.g., counting) to more complex (e.g., word problems; Raghubar et al. 2010). There is also evidence that working memory is an important pre-arithmetic skill (De Smedt et al. 2008; Passolunghi et al. 2007). Children with math disability show weaker verbal and visual-spatial working memory in comparison to age-matched, average achieving children (Swanson and Jerman 2006). However, when numerical-based and non-numerical based verbal working memory tasks are compared, only numerical-based measures of verbal working memory demonstrate a relationship to math achievement (Passolunghi and Cornoldi 2008). It is therefore unclear which aspect is driving the relationship (i.e., numbers or verbal working memory). On the other hand, visual-spatial working memory has demonstrated a relationship with math achievement irrespective of the whether a number-based task is used (Bull et al. 2008; Bull and Scerif 2001; D'Amico and Guarnera 2005, McLean and Hitch 1999, St. Clair-Thompson and Gathercole 2006; van der Sluis et al. 2005).

Significantly less research has explored the relationship between other aspects of EF such as set shifting (switching between different tasks or adjusting to changed demands or priorities) and inhibition (suppressing behavior or distracting information), and math achievement. Most studies suggest that both inhibition and set shifting are related to math achievement (Blair and Razza 2007; Bull et al. 1999; Clark et al. 2010; St. Clair-Thompson and Gathercole 2006). For example, Clark et al. (2010) showed that children's performance on set shifting, inhibitory control, and general executive behavior measures during the preschool period accounted for substantial variability in children's early mathematical achievement at school. These associations persisted even after individual differences in general cognitive ability and reading achievement were taken into account. In another study, children with lower math skills had difficulties inhibiting learned strategies and switching to new strategies (Bull & Scerif 2001). Espy et al. (2004), found that working memory and inhibitory control predicted math skills but only inhibitory control accounted for unique variance in math skills after controlling for the other executive functions.

Despite quite extensive literature on the relationship between EF and math skills in typically developing children and children with math difficulties, relatively little is known about EF and math in children with ASD. One study investigating predictors of academic achievement in high-IQ children with ASD found that working memory was associated with math skills but also to reading and written language (Assouline et al. 2011). Another study found no relationship with working memory and math achievement after IQ and test anxiety were accounted for (Oswald et al. 2016). The only other study addressing EF and math achievement in ASD found that attentional shifting was related to math achievement (May et al. 2013). EF may also contribute to other areas of academic achievement in ASD but the literature on EF and other academic skills in children with ASD is quite limited. In one study, verbal working memory was shown to relate to reading and writing (Assouline et al. 2011). However, attention shifting did not predict reading in a different study (May et al. 2013). In typically developing children working memory, inhibitory control, and attention shifting have shown a relationship to reading (Blair and Razza, 2007, Kieffer et al. 2013, St. Clair Thompson and Gathercole 2006). We are not aware of previous research on EF and spelling.

The overall aim in the present study was to examine the longitudinal and cross sectional relationship between EF and math achievement in children with ASD. We specifically sought to 1) identify early EF skills that would predict later math achievement, 2) determine whether EF was uniquely associated with math achievement above and beyond general cognitive abilities, 3) determine to what extent EF skills were specific to math versus academic achievement in the domains of reading and spelling.

Methods

Participants

Thirty-two children were recruited from a larger, longitudinal study of neurobiology and development in autism and developmental disabilities at the University of Washington. To be included in the academic achievement study and establish that the academic achievement battery was appropriate to administer, children were required to demonstrate a Full Scale Intelligence Quotient (FSIQ) of 70 and a Verbal Intelligence Quotient (VIQ) of 69 or above at age 9. Participants were approximately 9.46 years of age ($M = 113.56$ months, $SD = 4.80$, range =109 to 127 months) at the time of the academic achievement assessment. Participants met research criteria for ASD by direct assessment when first enrolled in the study, between 3–4 years of age, using the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al. 2003) and the Autism Diagnostic Observation Schedule-Generic, the version available at the time of enrollment (ADOS-G; Lord et al. 2003). The ADI-R, a parent interview, and the ADOS-G, a semi-structured play observation, are both standardized measures used to diagnose autism spectrum disorders. Different modules of the ADOS are used and depend on the current language level of the child. Each child was administered the module that was appropriate for their language level at study entry. Family history, medical records, and clinical observations were also considered when making a clinical best estimate based on

DSM-IV criteria (the diagnostic criteria in use at the time of the study). Exclusionary criteria included a history of significant sensory or motor impairment, serious traumatic brain injury, major physical anomalies, genetic disorders associated with ASD (e.g., Fragile X), or presence of a known neurological disorder. Data reported for the current study were obtained when participating children were aged 6 and 9. Fifty six percent of the sample were Caucasian males, 28% were non-Caucasian males, and 16% were Caucasian females. Mothers were on average highly educated, with only 6% reporting no college, 19% reporting some college, and 65% reporting college completion (maternal education was missing for 3 participants). At age 9, 24 children were in regular education classrooms, 2 children spent part of the day in a special education classroom and part of the day in a regular education classrooms, 2 children were in mixed regular education/special education classrooms, 1 child was in special education classroom, and 1 was home-schooled.

Procedures

EF was assessed at age 6 and 9, and intellectual ability and academic achievement was assessed at age 9 across 2–3 sessions. A licensed clinical psychologist or clinical psychology doctoral students under the supervision of a licensed clinical psychologist conducted assessments at the University of Washington.

Measures

Intellectual ability and academic achievement—The Differential Ability Scales (DAS; Elliot 1990b) is normed for children aged 2 years, 6 months to 17 years, 11 months. The School Age Core was administered at age 9 and included six subtests that provide three composite scores and one score reflecting general intellectual ability: Verbal Ability (VA), Nonverbal Ability (NVA), Spatial Ability (SA), and General Conceptual Ability (GCA). The Nonverbal Ability and Spatial Ability cluster scores were used in the current study. The DAS Achievement Tests, administered at age 9, are comprised of three subtests yielding standard scores: Basic Number Skills (BNS) which assess a child's ability to name and recognize numbers, and to perform a range of mathematical operations, Spelling (SP) which assessing a child's knowledge and recall of correct spelling, and Word Reading (WR) which assesses recognition of individual, printed words without contextual cues. DAS Standard Scores have a mean of 100 and standard deviation of 15.

Executive Function—Executive function (EF) was assessed using the A-not-B with Invisible Displacement (A-not-B ID) task at age 6 and the Spatial Reversal (SR) task at age 6 and 9. These tasks assess working memory, inhibition of prepotent responses, and set shifting and have been validated as EF measures (see Espy et al. 1999 and Espy et al. 2001). These measures were specifically chosen for the current study because they have been used in other studies of children with ASD and may be better suited for children with neurodevelopmental disorders (Griffith et al. 1999).

In the A-not-B ID task (Diamond et al. 1997), a green box with an open side facing the child was presented at the center of the table and, while the child watched, a toy was hidden inside. A cover was then draped over the opening of the box, obscuring the toy inside but not the box. With the child watching, the box was slid either to the right or left of the child. A screen was then placed between the box and child for 5 s. During the delay, the examiner placed an identical, empty box on the opposite side of the table. After the delay, the screen was lifted and the child was encouraged to find the toy. The side of hiding was reversed after the child reached correctly on two consecutive trials. The task was discontinued after 14 trials or 3 reversal trials. Percent of correctly completed trials was calculated.

The SR task (Kaufmann et al. 1990) began with a practice trial. During the practice trial, the examiner said, "I am hiding a {*toy name*}," as a toy was placed under one of two identical cups to the right and left of the child but hidden from the child's view behind a screen. The screen was raised and the child was encouraged to find the toy. If a child chose incorrectly during a trial, the child was not allowed to obtain the object and the examiner simply said, "Let's try again," with no additional feedback. The hiding side was reversed after every set of four consecutive correct trials for a total of 20 trials. Percent of correctly completed trials was calculated.

Results

Descriptive Statistics

The means, standard deviations, minimum and maximum scores for each measure are displayed in Table 1. Eight participants obtained the maximum possible score of 100% on the A-not-B ID and no one obtained the lowest possible score at age 6. The A-not-B ID was not given at age 9. No one obtained the maximum or minimum score on the SR task at age 6 or age 9. All variables were examined for Skewness and Kurtosis and fell within the acceptable range (i.e., +/− 2). No statistically significantly correlations were found between age 6 SR and age 6 A-not-B ID (r=−0.02) or age 6 SR and age 9 SR (r=0.35) or age 6 A-not-B ID and age 9 SR (r=−0.08).

Regression Analysis

Linear regression analyses were conducted to assess the relationship between EF at age 6 (SR and A-not-B ID) and 9 (SR) and all three academic achievement variables (BNS, WR, SP). Cognitive measures (NVA and SA) were entered as control variables given their moderate to strong correlations with the outcome variables. Given the relatively small sample size, we used bootstrap regression with 1,000 repetitions of re-sampling with replacement to estimate regression coefficients, standard errors, and significance values. Results are presented in Table 2 and Table 3.

Age 6 EF and age-9 cognitive abilities predicted a significant amount of variance in age-9 BNS; F(4, 25)=15.63, p< .000; R^2=.71. Age-6 SR contributed 9% unique variance in age-9 BNS, controlling for cognitive abilities and age-6 A-not-B ID. Age-6 A-not-B ID did not uniquely contribute to variance in age-9 BNS after controlling for the other co-variates in the model. Age-6 EF and age-9 cognitive abilities did not predict significant variance in age-9 SP (F(4, 25)=.10, p=.982) or age-9 WR (F(4, 25)=1.38, p=.269). In the final model (see Table 3), age-9 EF did not uniquely predict age-9 BNS, although the overall model including cognitive abilities was significant (F(3,25)=15.13, p<.000, R^2=.65). WR and SP were included as co-variates in the models with BNS as the dependent variable to test whether

BNS was associated with EF above-and-beyond these other academic skills; however, the overall results did not change.

Discussion

We found that better EF as measured by a spatial reversal at age 6 was related to higher math achievement, but not to spelling or word reading, at age 9 in school-aged children with ASD. EF accounted for unique variance in math achievement over and above the contributions of IQ. However, contrary to our expectations, EF at age 9 was not concurrently related to math achievement and a second measure of EF at age 6, A-not-B ID, was not related to math achievement at age 9. This study replicates and extends previous findings in typically developing children to school-aged children with ASD by demonstrating that early EF skills are related to later math achievement (Alloway and Alloway 2010; Clark et al. 2010, Bull et al. 2008).

These findings also indicate that, for children with ASD, a relationship may exist between specific EF skills, such as set shifting, and math achievement. We assessed EF at age 6 using two different tasks measuring visual-spatial working memory, response inhibition, and set shifting (SR and A-not-B ID); however, only the SR task at age 6 explained significant, unique variance in math achievement at age 9. Although the SR and A-not-B ID task both rely on visual-spatial working memory, the SR task may be more dependent on set shifting or cognitively flexibility (Espy et al. 1999). In order to perform well on the SR task, the child is required to learn the hiding rule and then learn a new rule when the side of hiding is switched. On the A-not-B ID task, the child watches the toy being hidden and then displaced; therefore performance on this task is less reliant on rule learning. Thus, one possible interpretation of our findings is that SR is related to BNS because it requires more cognitive flexibility than the A-not-B ID task.

Interestingly, SR at age 9 did not predict math achievement at age 9. This is consistent with Oswald et al. (2016) but is in contrast to Assouline et al. (2011). One important difference is that Assouline et al. (2011) included only children with ASD and very high IQs (over 120 FSIQ) whereas we included children with a broader IQ range (70 to 134). The type of EF assessed also differed. Assouline et al. (2011) used tasks typically associated with verbal working memory whereas our tasks assessed visual-spatial working memory and set shifting. Developmental effects on these EF and academic skills may be quite profound and needs to be considered when comparing findings among different samples. For example, De Smedt et al. (2008) found that in typically developing children visual-spatial working memory was associated with first grade math, but not second grade math and that verbal working memory was associated with second grade math but not first grade math. McKenzie et al. (2003) reported younger children (mean age 6.91 years) with no known learning difficulties utilized visual-spatial working memory when solving addition problems whereas older children (approximately 8.94 years) with no known learning difficulties used a mixed strategy, relying primarily on verbal working memory and only utilized visual-spatial working memory as needed. Moreover, there is evidence that different EFs are recruited when solving different types of math problems (Geary, Hoard, Byrd-Craven, Nugent, and Numtee, 2007; Kyttala, Aunio, Lehto, Van Luit, and Hautamaki, 2003; also see Raghubar et al., 2010 for review). Our study focused on mathematical computation whereas Assouline et al. (2011) measured computation speed and applied math in addition to mathematical computation.

Several limitations of the current study are important to note. The EF tasks used in the present study are typically used for younger, preschool-aged children and, particularly the A-not-B ID task might not have been sufficiently challenging. We saw ceiling effects on that measure in a subgroup of children, and future studies of this age group may require more advanced EF tasks. Furthermore, the EF tasks in this study are not normed, limiting any conclusions about EF impairment relative to same-aged peers. The use of basic academic achievement measures such as mathematical computation and single word reading provides only a limited picture of academic achievement. A more broad-based academic achievement test assessing a wider range of academic skills, such as applied math or reading comprehension could help further characterize the relationship between EF and academic achievement.

Future studies are needed to replicate these findings in a larger, independent sample children with ASD and extended to include an age and IQ-matched control group. Future studies should also include measures of EF accessing verbal and auditory modalities to increase our understanding of the relationship of specific types of EF to math and other academic skills. Children with a broader range of nonverbal ability should be included in future studies. We have observed minimally verbal children with ASD can develop academic skills such as basic math, reading, and spelling. Understanding academic achievement in these individuals with ASD is critical and requires non-standardized testing. These results may be less generalizable to females given that only 16% of the sample was female.

These findings highlight the potential importance of early cognitive flexibility with respect to later math skills in children with ASD. Our findings are consistent with emerging evidence suggesting that strong early EF skills can allow children to catch up to their peers in math (Ribner et al. 2017), and previous studies suggesting that math skills are related to academic achievement in other domains (Duncan et al. 2007). This has implications for practitioners and teachers who may want to consider implementing and developing programs to improve EF in children with ASD. Intervention and educational programming specifically aimed at increasing cognitive flexibility may lead to positive downstream effects and pathways to better academic outcomes for children with ASD.

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Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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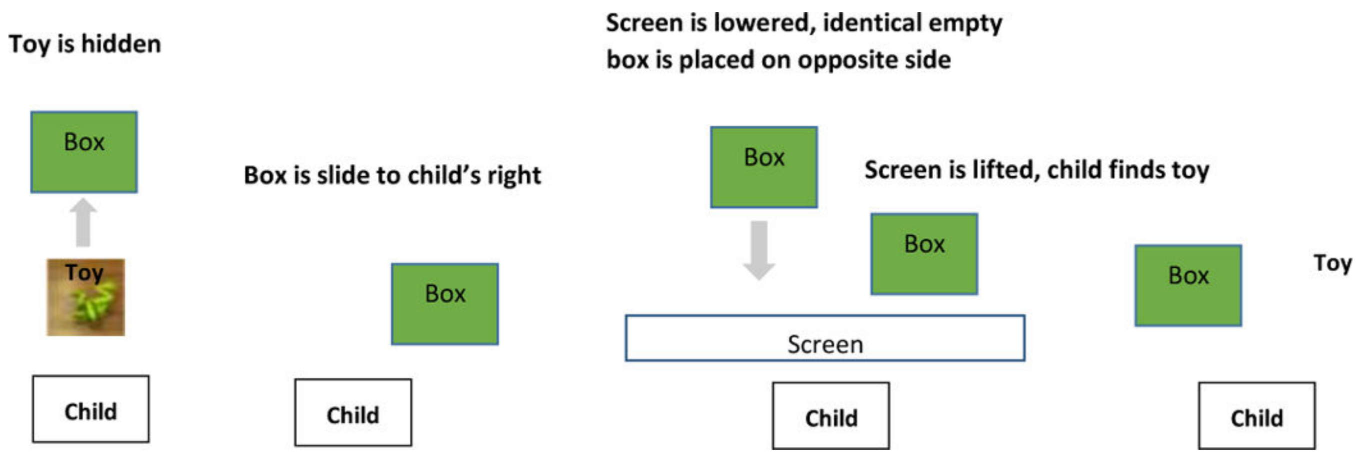

Figure 1.
A-not-B ID task

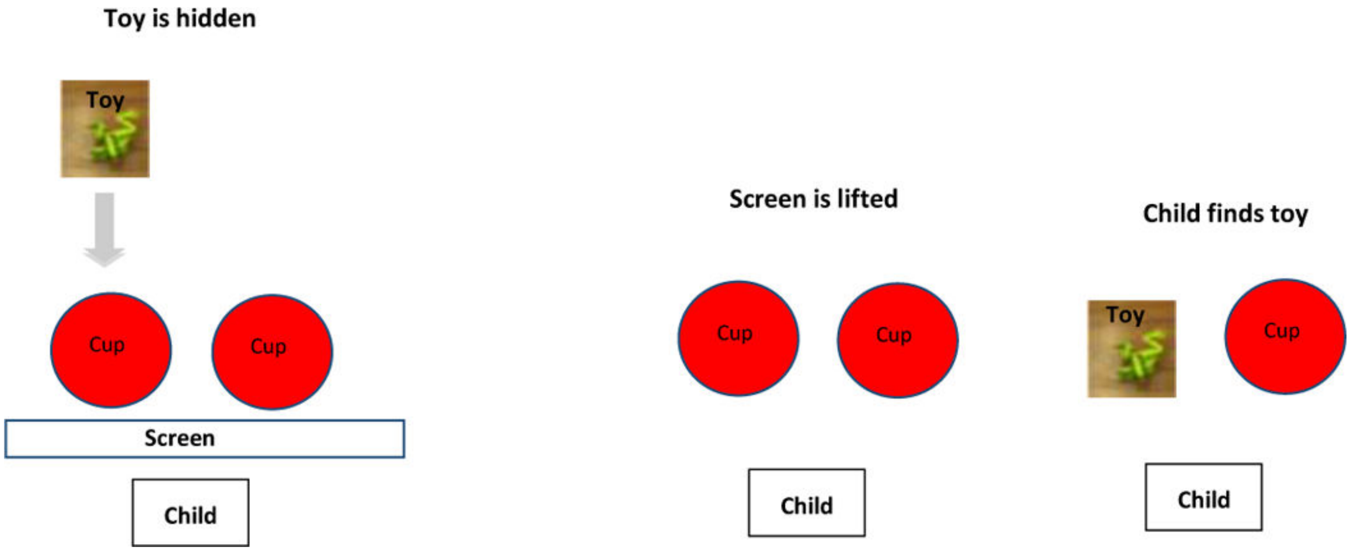

Figure 2.
Spatial reversal task

Table 1

Descriptive statistics for executive function performance at age 6 and academic achievement at age 9

Variable	Mean	SD	Min Score	Max Score
6 years				
SR Correct	72.83	7.15	60.00	85.00
A-not-B ID Correct	84.90	14.46	42.86	100.00
9 years				
DAS Nonverbal Ability Composite Score	99.19	17.36	70.00	152.00
DAS Spatial Ability Composite Score	102.55	11.81	76.00	122.00
SR Correct	67.82	9.58	50.00	80.00
DAS Basic Number Skills	91.61	18.98	59.00	125.00
DAS Spelling	97.52	19.21	55.00	126.00
DAS Word Reading	99.23	14.28	70.00	124.00

Table 2

Regression analysis of EF at age 6 and academic achievement at age 9

	B	SE	Beta	t	p-value	Unique R^2
Basic Number Skills Age 9						
DAS Nonverbal Ability Composite age 9	.66	.14	.60	4.79	.00	.26
DAS Spatial Ability Composite age 9	.66	.23	.38	2.85	.01	.09
SR Correct Age 6	.79	.30	.29	2.60	.01	.08
A-not-B ID Correct Age 6	.12	.15	.09	.79	.44	.01
Spelling Age 9						
DAS Nonverbal Ability Composite age 9	.04	.26	.04	.15	.88	0.00
DAS Spatial Ability Composite age 9	.11	.44	.06	.26	.80	0.00
SR Correct Age 6	.15	.57	.06	.27	.79	0.00
A-not-B ID Correct Age 6	.14	.27	.11	.52	.52	0.01
Word Reading Age 9						
DAS Nonverbal Ability Composite age 9	.30	.18	.36	1.70	.10	0.10
DAS Spatial Ability Composite age 9	.11	.30	.09	.38	.70	0.00
SR Correct Age 6	.32	.39	.16	.81	.42	0.02
A-not-B ID Correct Age 6	.16	.19	.16	.86	.40	0.02

Table 3

Regression analysis of concurrent EF and math achievement at age 9

	B	SE	Beta	t	p-value	Unique R^2
Basic Number Skills Age 9						
DAS Nonverbal Ability Composite Age 9	0.72	0.14	0.67	5.10	0.00	0.37
DAS Spatial Ability Composite age 9	0.42	0.22	0.25	1.91	0.07	0.05
SR Correct Age 9	0.06	0.24	0.03	0.23	0.82	0.00