Original Article

autism

Autism
1–10

DOI: 10.1177/13623613231154310
journals.sagepub.com/home/aut
SAGE

# Associations between executive function and attention abilities and language and social communication skills in young autistic children

**Jill Howard[1*], Brianna Herold[1*], Samantha Major[1], Caroline Leahy[1], Kevin Ramseur , II[1], Lauren Franz[1], Megan Deaver[1], Saritha Vermeer[1], Kimberly LH Carpenter[1], Michael Murias[2], Wei Angel Huang[1] and Geraldine Dawson[1]**

**Abstract**

Although it has been found that autistic children exhibit delays in executive function abilities and atypical patterns of attention, less is known about the relationship between executive function and attention abilities and social and language skills in early childhood. In this study, 180 autistic children, age 2–8 years, participated in a study examining the relationship between executive function abilities, measured by the Behavior Rating Inventory of Executive Function, and assessments of sustained attention measured via eye-tracking and several language and social communication measures. Results revealed that children with higher caregiver-reported executive function skills, specifically, working memory and planning/organization abilities, demonstrated higher levels of caregiver-reported receptive-expressive social communication abilities measured via the Pervasive Developmental Disorder Behavior Inventory. Higher executive function abilities across all domains were associated with lower levels of social pragmatic problems. Children who were able to sustain their attention for a longer duration demonstrated higher expressive language abilities. These results suggest that executive function and attention skills may play an important role in multiple domains of functioning in autistic children. It will be useful to determine whether therapies that seek to improve executive function skills in autistic individuals also positively influence their social/communication and language abilities.

**Lay Abstract**

Executive functioning describes a set of cognitive processes that affect thinking and behavior. Past research has shown that autistic individuals often have delays in the acquisition of executive function abilities. Our study explored how differences in executive function and attention abilities relate to social abilities and communication/language in 180 young autistic children. Data were gathered via caregiver report (questionnaires/interviews) and an assessment of vocabulary skills. The ability to sustain attention to a dynamic video was measured via eye tracking. We found that children with higher levels of executive function skills demonstrated lower levels of social pragmatic problems, a measure of having difficulties in social contexts. Furthermore, children who were able to sustain their attention longer to the video displayed higher levels of expressive language. Our results emphasize the importance of executive function and attention skills across multiple areas of functioning in autistic children, in particular those that involve language and social communication.

**Keywords**

attention, autism spectrum disorder, executive function, eye-tracking, social communication

## Introduction

Autism is frequently associated with delays in adaptive behavior skills and language abilities, as well as lower levels of executive function (EF) skills, relative to chronological age-matched peers (Chen et al., 2016). From the perspective of an integrative model of prefrontal cortex functioning, EF refers to top-down cognitive processes

[1]Duke University, USA
[2]Northwestern University, USA
*These authors contributed equally and should be considered joint first authors.

**Corresponding author:**
Jill Howard, Duke Center for Autism and Brain Development, Duke University, 2608 Erwin Road, Suite 300, Durham, NC 27705, USA.
Email: jill.lorenzi@duke.edu

that are important for the regulation of thoughts and actions and allow for goal-directed behaviors (Miller & Cohen, 2001). EF skills include controlling impulses, actions, or responses (inhibition), flexibly switching between task sets (shifting), regulating emotions and emotional responses (emotional control), maintaining information (working memory), and using goal-directed actions (planning and organizing; Gioia et al., 2000; Rosenthal et al., 2013). While research has shown that autistic individuals often demonstrate delays in executive functioning (Demetriou et al., 2018), and there is emerging evidence suggesting that these delays are related to adaptive behavior (Gilotty et al., 2002; Pugliese et al., 2015), less is known about the associations between EF abilities and other aspects of functioning. Elucidating the relationship between executive dysfunction abilities and other domains of behavioral functioning in autism may ultimately help to guide therapeutic efforts. In this study, we sought to understand how EF and sustained attention are associated with social communication and language abilities in young autistic children.

The heterogeneity observed in autism may add to the complexity and challenges of understanding delays in EF, as the current literature reports mixed findings for autistic individuals of varying ages (Garon et al., 2018; Granader et al., 2014; Hill, 2004). Such EF delays have been observed in autistic children as early as the preschool years based on both parental report and specific task-based measures. For example, Garon et al. (2018) found significantly lower executive abilities in the domains of working memory, inhibition, and shifting in autistic preschoolers. In addition, autistic individuals of all ages have demonstrated lower performance on neurocognitive tests such as the Tower of London (Hill, 2004) and Wisconsin Card Sorting Task (WCST; Bennetto et al., 1996; Sergeant et al., 2002; Shu et al., 2001). Other studies have shown that autistic individuals demonstrate lower levels of mental and behavioral flexibility on cognitive tasks when compared to neurotypical individuals (Reed et al., 2013; van den Bergh et al., 2014).

Previous studies have shown associations between executive deficits and the presence of autism-related behaviors in the social and communication domains in a small sample of 35 children between the ages of 6 and 17 (Gilotty et al., 2002). EF abilities in domains related to behavioral regulation (i.e. inhibition, shifting, and emotional control) have been shown to be associated with level of social abilities in both autistic and neurotypical children, although the EF domains of initiation, working memory, planning, and organizing were found to be associated with social abilities only for autistic children (Leung et al., 2016). In addition, EF abilities in young autistic children have been found to be strongly associated with level of communication, play, and social abilities (Gilotty et al., 2002; Jarrold, 2003). Van Eylen et al. (2015) found that EF abilities were associated with level of autism-related behaviors, including restricted and repetitive behaviors and interests. Mosconi et al. (2009) demonstrated that inhibitory control abilities in autistic individuals were associated with the presence of higher-order repetitive behaviors (e.g. insistence on sameness). More research is needed to understand exactly how EF is linked to restricted and repetitive behaviors and social abilities.

While research has begun to explore the relationship between language abilities and EF skills, further research is required to better understand the complex relationship and interaction. For example, social pragmatic skills are involved in engaging or interacting with others, including the ability to use language in various contexts (Matthews et al., 2018). The relationship between EF skills and pragmatic language is complex and potentiality bi-directional (Matthews et al., 2018). To date, research has focused on specific aspects of pragmatic language (e.g. irony, humor, metaphors, and idioms; Filipe et al., 2020). In addition, targeting pragmatic language abilities within interventions has been associated with improvements in EF skills (Friedman & Sterling, 2019). There may be more global implications of EF skills in pragmatic abilities including their use in social contexts. One study found that metacognitive domains of EF (i.e. child's ability to initiate, plan, organize, self-monitor, and sustain working memory) were significantly associated with social functioning for autistic children (Torske et al., 2018). Similarly, in another study, the metacognition scale was the strongest predictor of functional communication skills and the behavior regulation and inhibition scales were predictive of verbal conversation skills (Hutchison et al., 2020). In addition, a study comparing 15 autistic children (required to have an IQ of 80 or higher and met *DSM*-5 criteria for Autism) matched to 15 typically developing peers (based on age, non-verbal intelligence, and gender) indicated impairment in prosodic skills and EF skills for the autistic children as well as a bidirectional link between these skills even when controlling for confounding cognitive difficulties (Filipe et al., 2018). The current literature regarding EF skills and language skills indicate inconsistent findings and unclear relationships within the autism population.

EF skills have also been found to be related to social communication and social functioning. In a study of 77 autistic children and 55 typically developing peers, certain EF skills were found to be linked to social competencies (e.g. social knowledge and social inferencing) (Fong & Iarocci, 2020). In another study, EF skills in the areas of inhibition and working memory were found to be important in adaptive social functioning for elementary aged autistic children, and additionally, these factors were found to be related to engagement on the playground along with behavior with peers (Freeman et al., 2017). Friedman and Sterling (2019) note the complexity of disentangling the relationship between autism-related behaviors and EF

impairments as it remains unclear whether autism-related behaviors impact EF skills or vice versa.

Autism has also been shown to be associated with reduced ability to sustain attention to complex dynamic stimuli (Major et al., 2022). The ability to sustain attention develops during early childhood and provides a developmental foundation to the acquisition of EF skills (Fisher, 2019). Furthermore, impairments in sustained attention have been associated with autism and differences in functional brain maturation and activation for autistic individuals (Chien et al., 2014; Murphy et al., 2014). Several studies have used eye tracking (ET), which automatically tracks gaze, to measure how autistic children attend to complex dynamic stimuli (Falck-Ytter et al., 2013). Previous ET studies have demonstrated that, when shown a dynamic video containing social and nonsocial elements, autistic children have shorter look durations and spend less time overall attending to the stimuli compared to neurotypical children (Chawarska et al., 2012; Major et al., 2022). In this study, we explored the relationship between sustained attention abilities, measured via ET, and children's language and social abilities. We utilized several commonly used standardized caregiver-report measures that assessed social functioning and language ability, and a standardized clinician-administered assessment of expressive vocabulary in young autistic children. Our goal was to examine how executive dysfunction and attention are associated with other important aspects of behavioral functioning, which could help to inform future therapeutic efforts.

## Methods

### Participants

Participants were 180 autistic children (ages 2–8) who were enrolled in a clinical trial exploring the efficacy of umbilical cord blood (CB) for improving social abilities (ClinicalTrials.gov: NCT02847182; Dawson et al., 2020). One hundred seventy-six children (140 males; 17.6% Hispanic/Latino) ultimately met inclusion criteria for the clinical trial. Two pilot participants and two participants who were determined to be ineligible following randomization to treatment were excluded from the analysis. Behavioral and ET data for this study were collected at the baseline visit of the clinical trial before treatment was administered. Legal guardians provided informed consent prior to study procedures. The study was approved by the institutional review board. Full methodology for the clinical trial is available by Dawson et al., 2020.

Participants met criteria for a clinical diagnosis of autism spectrum disorder based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (*DSM*-5; American Psychiatric Association, 2013). Diagnoses were established by experienced assessors based on the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al., 2012) and the Autism Diagnostic Interview, Revised (ADI-R; Rutter et al., 2003). Cognitive/developmental ability was measured using the Mullen Scales of Early Learning (Mullen, 1995) or Differential Ability Scales, Second Edition (DAS-II; Elliot, 2007) depending on the participant's age; children up to the age of 4 completed the Mullen Scales of Early Learning.

Other inclusion criteria based on the clinical trial were (1) negative genetic testing, (2) qualified CB unit with a minimum banked total nucleated cell dose of $\geqslant 2.5 \times 10^7$ cells/kg or ⩾4/6 human leukocyte antigen-matched allogeneic unrelated CB unit, (3) stable on medications for ⩾2 months, (4) ability to travel to study site twice, (5) English speaking, and (6) normal absolute lymphocyte count (⩾1500/mL). Exclusion criteria included (1) known diagnosis of depression, bipolar disorder, schizophrenia, obsessive compulsive disorder, or Tourette syndrome (as reported by caregivers and via review of medical records); (2) known genetic syndrome or pathogenic mutation or copy number variation associated with autism; (3) known central nervous system (CNS) infection and/or HIV positivity; (4) known metabolic disorder, mitochondrial dysfunction, seizure disorder, primary immunodeficiency disorder, autoimmune cytopenias, active or prior malignancy treated with chemotherapy, significant sensory impairment, or impaired renal or liver function; (5) current or prior cell therapy, use of intravenous (IV) immunoglobulin or other anti-inflammatory medication (except nonsteroidal anti-inflammatory drugs), and/or immunosuppressive therapy; and (6) child unlikely to be able to complete assessments due to current language level, estimating a standard score ⩾60 on the Expressive One-Word Picture Vocabulary Test, Fourth Edition (determined during extensive screening process prior to child being enrolled in the study, including review of medical records, previous cognitive/language testing, and videos of the child in their home or school environment). Demographic characteristics of participants are presented in Table 1.

### Measures

The measures listed below were selected in order to capture a broad picture of the child's EF, attention, language, and social abilities.

*Executive functioning.* The Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000) or BRIEF-Preschool (BRIEF-P; if participant was under age 5; Gioia et al., 2003) assessed a child's executive functioning skills via caregiver report, comprised of five domains: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize. Higher scores on these scales indicate greater dysfunction.

**Table 1.** Characteristics of sample.

| *N* = 176 (140 males and 36 females) | | | |
|---|---|---|---|
| Characteristics | Mean | Range | Standard deviation |
| Age (months) | 64.86 | 27–95 | 19.52 |
| Full Scale Ratio IQ | 70.77 | 23–133 | 20.58 |
| ADOS-2 Comparison Score | 8.02 | 2–10 | 1.63 |
| EOWPVT-4 Standard Score | 77.91 | 55–117 | 18.54 |
| VABS-3 Communication Standard Score | 65.59 | 20–100 | 17.99 |
| VABS-3 Socialization Standard Score | 63.02 | 34–102 | 13.98 |
| Ethnicity | *n* (%) | | |
| Hispanic | 31 (17.6) | | |
| Non-Hispanic | 145 (82.4) | | |
| Race | *n* (%) | | |
| Non-white | 29 (16.5) | | |
| White | 147 (83.5) | | |
| Total pre-tax household income ($) | *n* (%) | | |
| <50,000 | 10 (5.7) | | |
| 50,000–99,999 | 31 (17.6) | | |
| 100,000–149,999 | 45 (25.6) | | |
| 150,000–199,999 | 30 (17.0) | | |
| 200,000+ | 56 (31.8) | | |
| Unknown | 4 (2.3) | | |

IQ: Intelligence Quotient; ADOS-2: Autism Diagnostic Observation Schedule, Second Edition; EOWPVT-4: Expressive One-Word Picture Vocabulary Test, Fourth Edition; VABS-3: Vineland Adaptive Behavior Scales, Third Edition.
Of the original 180 participants involved in the clinical trial, two pilot participants and two participants who were determined to be ineligible following randomization to treatment were excluded ($n = 176$).

*Language abilities.* Two measures of language abilities were used. The Vineland Adaptive Behavior Scales, Third Edition (VABS-3; Sparrow et al., 2016), is a clinician-administered caregiver interview assessing adaptive behavior skills. The VABS-3 Communication domain is an assessment of both receptive and expressive language skills. The second measure assessed expressive language abilities with the Expressive One-Word Picture Vocabulary Test, Fourth Edition (EOWPVT-4; Martin & Brownell, 2011). The EOWPVT-4 is a clinician-administered assessment measuring an individual's ability to name the object, action, or concept when presented with a picture.

*Social communication abilities.* Two measures of social/social communication abilities were used. The first was the Socialization domain of the VABS-3, which assesses interpersonal relationships, play and leisure skills, and social coping abilities. The second was Social Pragmatic Problems and the Receptive/Expressive Social Communication Abilities Composite (which is a composite of Social Approach Behaviors, Expressive Language, and Learning/Memory/Receptive Language) from the Pervasive Developmental Disorders Behavior Inventory (PDDBI; Cohen & Sudhalter, 2005), which is a caregiver-completed questionnaire assessing autism-related behaviors in several domains. Higher scores on the Social Pragmatic Problems subscale indicate greater dysfunction, whereas higher scores on the Receptive/Expressive Social Communication Abilities Composite indicate increasing levels of competence.

*Attention.* Participants watched a 3 minute video of dynamic audiovisual stimuli, which portrayed an actress filmed in a setting containing four toys and a table with ingredients for making sandwiches (Chawarska et al., 2012). During the movie, the actress engaged in child-directed speech, made sandwiches, and displayed joint attention bids toward toys. Throughout the video, toys became activated with noise and movement.

While the children watched the video, EF data were collected in a dimly lit room on a Tobii TX300 eye-tracker (Tobii® Technology, 2014). The stimulus was built and presented with Tobii Studio Version 3.2.2 using binocular, remote EF on a 23-inch TFT monitor with a 120 Hz refresh rate, 16:9 (1920 × 1080 pixel) aspect ratio, and a 65 cm participant eye-to-monitor distance. Children either sat alone in a chair, or in their caregiver's lap. In the event that the child sat in a caregiver's lap, measures were taken to block the caregiver's eyes. A 5-point calibration preceded the experiment for all participants, and 5-point validation and calibration quality were assessed through a manufacturer-defined 5-point validation.

The ET variable of interest was the proportion of total viewing time (% Looking) during the entire video which has been shown to be reduced in autistic children in previous studies (Chawarska et al., 2012). The purpose of this

specific task is to use common social situations to exogenously recruit attention; the amount of time the child spends observing a complex dynamic scene containing both social and nonsocial elements is hypothesized to reflect the ability to sustain attention to complex dynamic environments in the real world. The % Looking variable was calculated by dividing the total time viewing the media by the total video presentation (i.e. no segmenting of the video occurred). The media region was defined as the entire video frame.

$$\text{Percent looking} = \frac{\text{Time looking on media (seconds)}}{\text{Total media presentation time}}$$

The Tobii I-VT Fixation Filter was applied to the data

> to fill in data where valid data is missing. For example, this is to prevent a fixation in which a few samples are missing as being interpreted as two separate fixations. Such loss of valid data can occur due to temporary reflections in the participant's eyes or glasses, etc. In these cases, the data loss is limited to a short period of time, typically less than 50 ms. Data can also be lost due to legitimate reasons such as the participant blinking or looking away. These kinds of data losses usually result in data gaps longer than 100 ms. (Tobii Studio User's Manual Version 3.4.5; Komogortsev et al., 2010)

Sixteen participants (9%) were excluded due to noncompliance and calibration failures, resulting in a final sample size of $n = 160$ for ET analyses.

### Analytic strategy

Multiple linear regression models were used to determine whether executive functioning (five BRIEF subscales) was related to the social communication and language variables, while controlling for age, sex, and non-verbal developmental quotient (which was derived from either the Mullen Scales of Early Learning or DAS-II depending upon the participant's age). Linear regression was also used to determine the relationship between attention measured via ET (proportion of total viewing time during the entire video) and the social communication and language variables, while controlling for age, sex, and non-verbal developmental quotient. The % looking variable was multiplied by 100 to make the regression coefficient more interpretable. Statistical analyses were run using R 4.2.1.

We hypothesized that higher levels of EF and attention abilities would be related to higher levels of social communication and language skills.

### Community involvement

The Duke Center for Autism and Brain Development, where this research was conducted, has a Community Engagement Board that includes two autistic persons and two parents of autistic children, and provides input and feedback on studies conducted at the Center. The study received assistance from an intern who is on the autism spectrum, who is recognized in the acknowledgements section.

## Results

Multiple linear regression models estimating executive functioning and sustained attention as a function of PDDBI (Social Pragmatic Problems), VABS-3 (Communication and Socialization domains), and EOWPVT-4 (expressive vocabulary raw score), when controlling for age, sex, and intelligence, are presented in Table 2.

For BRIEF Inhibition, when controlling for the variables noted above, the predictors explained 38% of the variance. Problems with inhibition were positively associated with social pragmatic problems ($\beta = 0.52$, $p < 0.001$), as predicted. Conversely, problems with inhibition were also associated with higher socialization skills ($\beta = 0.16$, $p = 0.04$), which was not in the expected direction.

For BRIEF Shifting, when controlling for the variables noted above, the predictors explained 21% of the variance. Problems with shifting were associated with higher levels of social pragmatic problems ($\beta = 0.40$, $p < 0.001$), which was in the expected direction. No other significant predictors emerged.

For BRIEF Emotional Control, when controlling for the variables noted above, the predictors explained 21% of the variance. Problems with emotional control were associated with higher social pragmatic problems ($\beta = 0.47$, $p < 0.001$), which was in the expected direction. No other significant predictors emerged.

For BRIEF Working Memory, when controlling for the variables noted above, the predictors explained 29% of the variance. Several behavioral domains were associated with working memory. Specifically, problems with working memory were associated with higher social pragmatic problems ($\beta = 0.41$, $p < 0.001$), which was in the expected direction. Problems with working memory were associated with lower receptive expressive social communication abilities ($\beta = -0.37$, $p = 0.03$) and communication skills ($\beta = -0.20$, $p = 0.03$), which were in the expected direction. However, problems with working memory were also associated with higher socialization skills ($\beta = 0.26$, $p = 0.003$), which was not in the expected direction.

For BRIEF Plan/Organize, when controlling for the variables noted above, the predictors explained 32% of the variance. Problems with planning/organizing were associated with higher social pragmatic problems ($\beta = 0.48$, $p < 0.001$), which was in the expected direction. Problems with planning/organizing were also associated with lower receptive expressive social communication abilities ($\beta = -0.75$, $p < 0.001$), which was in the expected direction. However, problems with planning/organizing were also associated with higher socialization skills ($\beta = 0.26$, $p = 0.008$), which was not in the expected direction.

**Table 2.** Multiple linear regression models (estimates and 95% confidence interval) examining relationships between executive functioning and sustained attention and language and social abilities while controlling for age, sex, and IQ.

| | BRIEF domains | | | | | |
|---|---|---|---|---|---|---|
| | Inhibition | Shifting | Emotional control | Working memory | Planning/organizing | Percent looking at video via eye-tracking |
| (Intercept) | 59.83*** [41.01, 78.65] | 48.53*** [28.01, 69.05] | 40.06*** [16.96, 63.15] | 78.88*** [57.21, 100.55] | 71.76*** [48.01, 95.50] | 64.06*** [34.84, 93.29] |
| EOWPVT-4 Raw Score | 0.10 [−0.02, 0.21] | 0.07 [−0.06, 0.20] | 0.03 [−0.11, 0.18] | 0.08 [−0.05, 0.22] | 0.08 [−0.07, 0.23] | 0.22* [0.05, 0.40] |
| VABS-3 Communication | −0.10 [−0.26, 0.05] | 0.01 [−0.16, 0.17] | 0.04 [−0.14, 0.23] | −0.20* [−0.37, −0.02] | −0.11 [−0.30, 0.08] | −0.01 [−0.25, 0.23] |
| VABS-3 Socialization | 0.16* [0.01, 0.31] | −0.03 [−0.20, 0.14] | 0.01 [−0.18, 0.19] | 0.26** [0.09, 0.44] | 0.26** [0.07, 0.46] | 0.06 [−0.17, 0.29] |
| PDDBI Social Pragmatic Problems | 0.52*** [0.39, 0.65] | 0.40*** [0.26, 0.55] | 0.47*** [0.31, 0.64] | 0.41*** [0.26, 0.56] | 0.48*** [0.31, 0.65] | −0.05 [−0.25, 0.16] |
| PDDBI Receptive Expressive Social Communication Abilities | −0.17 [−0.45, 0.11] | −0.06 [−0.37, 0.24] | −0.01 [−0.35, 0.34] | −0.37* [−0.69, −0.04] | −0.75*** [−1.10, −0.39] | 0.32 [−0.14, 0.78] |
| Age | −0.26*** [−0.39, −0.13] | 0.00 [−0.14, 0.14] | −0.10 [−0.26, 0.06] | −0.17* [−0.32, −0.02] | −0.13 [−0.30, 0.03] | −0.04 [−0.24, 0.16] |
| Sex | 2.15 [−1.54, 5.85] | 3.30 [−0.73, 7.34] | 4.59* [0.05, 9.13] | −0.58 [−4.84, 3.68] | −0.09 [−4.75, 4.58] | −4.68 [−10.35, 0.98] |
| Non-verbal IQ | −0.05 [−0.16, 0.06] | −0.10 [−0.22, 0.02] | −0.08 [−0.21, 0.06] | −0.04 [−0.17, 0.09] | 0.09 [−0.05, 0.22] | −0.05 [−0.22, 0.12] |
| *N* | 176 | 176 | 176 | 176 | 175 | 160 |
| $R^2$ | 0.38 | 0.21 | 0.21 | 0.29 | 0.32 | 0.23 |

BRIEF: Behavior Rating Inventory of Executive Function; EOWPVT-4: Expressive One-Word Picture Vocabulary Test, Fourth Edition; PDDBI: Pervasive Developmental Disorder Behavior Inventory; VABS-3: Vineland Adaptive Behavior Scales, Third Edition.
***Regression coefficient is significant at the 0.001 level (2-tailed). **Regression coefficient is significant at the 0.01 level (2-tailed). *Regression coefficient is significant at the 0.05 level (2-tailed).

For sustained attention via ET, when controlling for the variables noted above, the predictors explained 23% of the variance. Higher levels of sustained attention were associated with higher expressive vocabulary skills (total word count), such that children who had better expressive vocabulary skills were more likely to be able to maintain attention to the complex, dynamic stimuli ($\beta = 0.22$, $p = 0.013$). For every one-unit increase in EOWPVT-4 total word count, attention via ET (% Looking) increased by 0.22 percentage points. No other significant associations were found.

## Discussion

We examined the relationships between EF abilities and sustained attention and children's language and social communication abilities. We found that children who had higher levels of working memory and planning/organizing skills had higher receptive-expressive social communication abilities. Furthermore, across all domains of EF, higher EF skills were associated with lower levels of social pragmatic problems. No significant association between EF skills and expressive vocabulary was found. Unexpectedly, higher EF abilities were associated with lower socialization skills as measured by the Vineland Adaptive Behavior Scales, Third Edition (VABS-3). This domain reflects developmental adaptive skills in the areas of interpersonal relationships and play. Additional research will need to further examine this finding. Based on the ET task, we found that children who were able to maintain attention longer to a complex, dynamic video involving people, toys, and sounds displayed higher levels of expressive language ability. The potential for children's attention skills to contribute to language and other skill domains should continue to be examined, especially using alternative tasks that directly target executive functioning domains, such as cued task switching (Zheng & Church, 2021), saccadic tasks (Tao et al., 2020), and gap overlap tasks (Chernenok et al., 2019).

We found that stronger working memory and planning/organizing skills were associated with higher levels of receptive-expressive social communication abilities. A modest relationship was found in a previous study between EF skills and language, especially receptive language (Weismer et al., 2018). The association between working memory/planning/organizing and language skills could reflect the ability to retain information in short-term memory and the ability to plan and organize thoughts which could contribute to the development of communication abilities.

We found that stronger skills in all five EF domains were correlated with lower levels of social pragmatic problems. This was arguably the most robust finding across our analyses on the whole, as it emerged in all of the EF models. In contrast to the VABS-3 Socialization domain which was negatively associated with EF skills, the Social Pragmatic Problems subscale on the Pervasive Developmental Disorders-Behavior Inventory assesses specific difficulties in reacting to the approaches of others, understanding social conventions, or initiating social interactions with others. As such, it reflects the specific challenges that autistic children typically display in social situations, rather than the acquisition of normative social skills. Previous research has similarly found working memory to be associated with pragmatic judgment skills in young autistic children (Akbar et al., 2013). This finding is particularly relevant, given the role of social pragmatic skills in social relationships. While our study involved children with a wide range of cognitive ability, the association between EF and pragmatic social abilities has also been found in autistic individuals who do not have intellectual disability (Filipe et al., 2020).

Taken together, our results indicate that EF and attention abilities are associated with important domains of behavioral functioning related to language and social abilities. Thus, developing therapies that can improve EF and attention skills could potentially have a positive influence on quality of life. In particular, the ability to regulate behavior is an important skill and has been shown in other studies to be associated with adaptive functioning (Pugliese et al., 2015) and social abilities (Leung et al., 2016). In studies of neurotypical children, early EF skills are predictive of a preschooler's later school readiness (McClelland et al., 2007) and math and reading skills (Bull & Scerif, 2001). Higher levels of EF skills have also been linked to higher quality of life (de Vries & Geurts, 2015).

A strength of our study was the use of a large, well-characterized sample of young autistic children and validated and standardized measures to assess behavior. A limitation was the use of solely caregiver-report measures for the evaluation of EF. Furthermore, while some co-occurring conditions were part of the exclusion criteria for this study, we did not conduct a comprehensive assessment in order to evaluate the presence of commonly co-occurring psychological conditions, such as attention-deficit/hyperactivity disorder. Future directions could assess the influence of co-occurring diagnoses.

In light of our findings that EF and attention abilities are related to aspects of social and language functioning, further research studying the role of EF and attention in autism and how to improve EF and attention skills in real-world settings could ultimately improve functional skills in autistic individuals. It will be important to determine whether targeting specific EF and/or attention skills helps to build social communication abilities in different environments (i.e. school, family, and peer interactions) for individuals on the autism spectrum.

## Acknowledgements

The authors thank the Marcus Foundation and NICHD for their financial support, the children who participated and their families, and the staff members who contributed to the study. They also thank Raghav Swaminathan for his assistance with study procedures during data collection.

## Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: G.D. is on the Scientific Advisory Boards of Janssen Research and Development, Akili Interactive, Inc, LabCorp, Inc, Roche Pharmaceutical Company, Zynerba, and Tris Pharma, and is a consultant to Apple, Gerson Lehrman Group, and Guidepoint Global, Inc. G.D. has stock interests in Neuvana, Inc. G.D. has two patents: 10912801B2 and 11158403B1. G.D. has developed technology, data, and/or products that have been licensed to Cryocell, Inc. and G.D. and Duke University have benefited financially. G.D. and K.L.H.C. helped develop technology for early screening for autism. The technology has been licensed and G.D., K.L.H.C., and Duke University have benefited financially. J.H. reports personal fees from Roche. For the remaining authors none were declared.

## Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Funding for this work was generously provided by the Marcus Foundation and NICHD P50 HD093074 award.

## ORCID iDs

Jill Howard https://orcid.org/0000-0003-2668-5194
Samantha Major https://orcid.org/0000-0001-5969-1721
Kevin Ramseur https://orcid.org/0000-0003-0134-430X
Lauren Franz https://orcid.org/0000-0003-4434-7500
Kimberly LH Carpenter https://orcid.org/0000-0002-3838-798X

## References

Akbar, M., Loomis, R., & Paul, R. (2013). The interplay of language on executive functions in children with ASD. *Research in Autism Spectrum Disorders*, *7*(3), 494–501. https://doi.org/10.1016/j.rasd.2012.09.001

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Publishing.

Bennetto, L., Pennington, B. F., & Rogers, S. J. (1996). Intact and impaired memory functions in autism. *Child Development*, *67*(4), 1816–1835. https://doi.org/10.2307/1131734

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology*, *19*(3), 273–293. https://doi.org/10.1207/S15326942DN1903_3

Chawarska, K., Macari, S., & Shic, F. (2012). Context modulates attention to social scenes in toddlers with autism. *Journal of Child Psychology and Psychiatry*, *53*(8), 903–913. https://doi.org/10.1111/j.1469-7610.2012.02538.x

Chen, S.-F., Chien, Y.-L., Wu, C.-T., Shang, C.-Y., Wu, Y.-Y., & Gau, S. S. (2016). Deficits in executive functions among youths with autism spectrum disorders: An age-stratified analysis. *Psychological Medicine*, *46*(8), 1625–1638. https://doi.org/10.1017/S0033291715002238

Chernenok, M., Burris, J. L., Owen, E., & Rivera, S. M. (2019). Impaired attention orienting in young children with Fragile X syndrome. *Frontiers in Psychology*, *10*. https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01567

Chien, Y.-L., Gau, S. S.-F., Chiu, Y.-N., Tsai, W.-C., Shang, C.-Y., & Wu, Y.-Y. (2014). Impaired sustained attention, focused attention, and vigilance in youths with autistic disorder and Asperger's disorder. *Research in Autism Spectrum Disorders*, *8*(7), 881–889. https://doi.org/10.1016/j.rasd.2014.04.006

Cohen, I. L., & Sudhalter, V. (2005). *The PDD behavior inventory*. Psychological Assessment Resources, Inc.

Dawson, G., Sun, J. M., Baker, J., Carpenter, K., Compton, S., Deaver, M., Franz, L., Heilbron, N., Herold, B., Horrigan, J., Howard, J., Kosinski, A., Major, S., Murias, M., Page, K., Prasad, V. K., Sabatos-DeVito, M., Sanfilippo, F., Sikich, L., & Kurtzberg, J. (2020). A phase II randomized clinical trial of the safety and efficacy of intravenous umbilical cord blood infusion for treatment of children with autism spectrum disorder. *The Journal of Pediatrics*, *222*, 164–173. e5. https://doi.org/10.1016/j.jpeds.2020.03.011

Demetriou, A., Makris, N., Kazi, S., Spanoudis, G., & Shayer, M. (2018). The developmental trinity of mind: Cognizance, executive control, and reasoning. *Wires Cognitive Science*, *9*(4), Article e1461. https://doi.org/10.1002/wcs.1461

de Vries, M., & Geurts, H. (2015). Influence of autism traits and executive functioning on quality of life in children with an autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *45*(9), 2734–2743. https://doi.org/10.1007/s10803-015-2438-1

Elliot, C. D. (2007). *Differential Ability Scales* (2nd ed.). Harcourt Assessment, Inc.

Falck-Ytter, T., Bolte, S., & Gredeback, G. (2013). Eye tracking in early autism research. *Journal of Neurodevelopmental Disorders*, *5*(1). http://link.gale.com/apps/doc/A534526055/AONE?u=duke_perkins&sid=zotero&xid=0f06dabc

Filipe, M. G., Frota, S., & Vicente, S. G. (2018). Executive Functions and Prosodic Abilities in Children With High-Functioning Autism. *Frontiers in Psychology*, *9*, Article 359. https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00359

Filipe, M. G., Veloso, A., Frota, S., & Vicente, S. G. (2020). Executive functions and pragmatics in children with high-functioning autism. *Reading and Writing*, *33*(4), 859–875. https://doi.org/10.1007/s11145-019-09975-2

Fisher, A. V. (2019). Selective sustained attention: A developmental foundation for cognition. *Current Opinion in Psychology*, *29*, 248–253. https://doi.org/10.1016/j.copsyc.2019.06.002

Fong, V. C., & Iarocci, G. (2020). The Role of Executive Functioning in Predicting Social Competence in Children with and without Autism Spectrum Disorder. *Autism Research*, *13*(11), 1856–1866. https://doi.org/10.1002/aur.2350

Freeman, L. M., Locke, J., Rotheram-Fuller, E., & Mandell, D. (2017). Brief report: Examining executive and social

functioning in elementary-aged children with autism. *Journal of Autism and Developmental Disorders*, *47*(6), 1890–1895. https://doi.org/10.1007/s10803-017-3079-3

Friedman, L., & Sterling, A. (2019). A review of language, executive function, and intervention in autism spectrum disorder. *Seminars in Speech and Language*, *40*(04), 291–304. https://doi.org/10.1055/s-0039-1692964

Garon, N., Smith, I. M., & Bryson, S. E. (2018). Early executive dysfunction in ASD: Simple versus complex skills. *Autism Research*, *11*(2), 318–330. https://doi.org/10.1002/aur.1893

Gilotty, L., Kenworthy, L., Sirian, L., Black, D. O., & Wagner, A. E. (2002). Adaptive skills and executive function in autism spectrum disorders. *Child Neuropsychology*, *8*(4), 241–248. https://doi.org/10.1076/chin.8.4.241.13504

Gioia, G. A., Espy, K. A., & Isquith, P. K. (2003). *BRIEF-P: Behavior rating inventory of executive function-preschool version*. Psychological Assessment Resources, Inc.

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). *BRIEF: Behavior rating inventory of executive function*. Psychological Assessment Resources, Inc.

Granader, Y., Wallace, G. L., Hardy, K. K., Yerys, B. E., Lawson, R. A., Rosenthal, M., Wills, M. C., Dixon, E., Pandey, J., Penna, R., Schultz, R. T., & Kenworthy, L. (2014). Characterizing the factor structure of parent reported executive function in autism spectrum disorders: The impact of cognitive inflexibility. *Journal of Autism and Developmental Disorders*, *44*(12), 3056–3062. https://doi.org/10.1007/s10803-014-2169-8

Hill, E. L. (2004). Evaluating the theory of executive dysfunction in autism. *Developmental Review*, *24*(2), 189–233. https://doi.org/10.1016/j.dr.2004.01.001

Hutchison, S. M., Müller, U., & Iarocci, G. (2020). Parent reports of executive function associated with functional communication and conversational skills among school age children with and without autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *50*(6), 2019–2029. https://doi.org/10.1007/s10803-019-03958-6

Jarrold, C. (2003). A review of research into pretend play in autism. *Autism*, *7*(4), 379–390. https://doi.org/10.1177/1362361303007004004

Komogortsev, O. V., Gobert, D. V., Jayarathna, S., Koh, D.-H., & Gowda, S. (2010). Standardization of automated analyses of oculomotor fixation and saccadic behaviors. *IEEE Transactions on Biomedical Engineering*, *57*(11), 2635–2645. https://doi.org/10.1109/TBME.2010.2057429

Leung, R. C., Vogan, V. M., Powell, T. L., Anagnostou, E., & Taylor, M. J. (2016). The role of executive functions in social impairment in autism spectrum disorder. *Child Neuropsychology*, *22*(3), 336–344. https://doi.org/10.1080/09297049.2015.1005066

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. L. (2012). *Autism diagnostic observation schedule-2nd edition (ADOS-2)* (2nd ed.). Western Psychological Services.

Major, S., Isaev, D., Grapel, J., Calnan, T., Tenenbaum, E., Carpenter, K., Franz, L., Howard, J., Vermeer, S., Sapiro, G., Murias, M., & Dawson, G. (2022). Shorter average look durations to dynamic social stimuli are associated with higher levels of autism symptoms in young autistic children. *Autism: The International Journal of Research and Practice*, *26*(6), 1451–1459. https://doi.org/10.1177/13623613211056427

Martin, N. A., & Brownell, R. (2011). *Expressive one-word picture vocabulary test (EOWPVT-4)* (4th ed.). ATP Assessments.

Matthews, D., Biney, H., & Abbot-Smith, K. (2018). Individual differences in children's pragmatic ability: A review of associations with formal language, social cognition, and executive functions. *Language Learning and Development*, *14*(3), 186–223. https://doi.org/10.1080/15475441.2018.1455584

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*(4), 947–959. https://doi.org/10.1037/0012-1649.43.4.947

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*, 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Mosconi, M. W., Kay, M., D'Cruz, A.-M., Seidenfeld, A., Guter, S., Stanford, L. D., & Sweeney, J. A. (2009). Impaired inhibitory control is associated with higher-order repetitive behaviors in autism spectrum disorders. *Psychological Medicine*, *39*(9), 1559–1566. https://doi.org/10.1017/S0033291708004984

Mullen, E. M. (1995). *Mullen scales of early learning*. American Guidance Service Inc.

Murphy, C. M., Christakou, A., Daly, E. M., Ecker, C., Giampietro, V., Brammer, M., Smith, A. B., Johnston, P., Robertson, D. M., Murphy, D. G., & Rubia, K. (2014). Abnormal functional activation and maturation of fronto-striato-temporal and cerebellar regions during sustained attention in autism spectrum disorder. *American Journal of Psychiatry*, *171*(10), 1107–1116. https://doi.org/10.1176/appi.ajp.2014.12030352

Pugliese, C. E., Anthony, L., Strang, J. F., Dudley, K., Wallace, G. L., & Kenworthy, L. (2015). Increasing adaptive behavior skill deficits from childhood to adolescence in autism spectrum disorder: Role of executive function. *Journal of Autism and Developmental Disorders*, *45*(6), 1579–1587. https://doi.org/10.1007/s10803-014-2309-1

Reed, P., Watts, H., & Truzoli, R. (2013). Flexibility in young people with autism spectrum disorders on a card sort task. *Autism*, *17*(2), 162–171. https://doi.org/10.1177/1362361311409599

Rosenthal, M., Wallace, G. L., Lawson, R., Wills, M. C., Dixon, E., Yerys, B. E., & Kenworthy, L. (2013). Impairments in real-world executive function increase from childhood to adolescence in autism spectrum disorders. *Neuropsychology*, *27*(1), 13–18. https://doi.org/10.1037/a0031299

Rutter, M., LeCouteur, A., & Lord, C. (2003). *Autism diagnostic interview—Revised*. Western Psychological Services.

Sergeant, J. A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research*, *130*(1), 3–28. https://doi.org/10.1016/S0166-4328(01)00430-2

Shu, B.-C., Lung, F.-W., Tien, A. Y., & Chen, B.-C. (2001). Executive function deficits in non-retarded autistic children. *Autism*, *5*(2), 165–174. https://doi.org/10.1177/1362361301005002006

Sparrow, S. S., Cicchetti, D. V., & Saulnier, C. A. (2016). *Vineland Adaptive Behavior Scales* (3rd ed.). NCS Pearson.

Tao, L., Wang, Q., Liu, D., Wang, J., Zhu, Z., & Feng, L. (2020). Eye tracking metrics to screen and assess cognitive impairment in patients with neurological disorders. *Neurological Sciences*, *41*(7), 1697–1704. https://doi.org/10.1007/s10072-020-04310-y

Torske, T., Nærland, T., Øie, M. G., Stenberg, N., & Andreassen, O. A. (2018). Metacognitive aspects of executive function are highly associated with social functioning on parent-rated measures in children with autism spectrum disorder. *Frontiers in Behavioral Neuroscience*, *11*, Article 258. http://doi.org/10.3389/fnbeh.2017.00258

van den Bergh, S. F. W. M., Scheeren, A. M., Begeer, S., Koot, H. M., & Geurts, H. M. (2014). Age related differences of executive functioning problems in everyday life of children and adolescents in the autism spectrum. *Journal of Autism and Developmental Disorders*, *44*(8), 1959–1971. https://doi.org/10.1007/s10803-014-2071-4

Van Eylen, L., Boets, B., Steyaert, J., Wagemans, J., & Noens, I. (2015). Executive functioning in autism spectrum disorders: Influence of task and sample characteristics and relation to symptom severity. *European Child & Adolescent Psychiatry*, 24(11), 1399–1417. https://doi.org/10.1007/s00787-015-0689-1

Weismer, S. E., Kaushanskaya, M., Larson, C., Mathée, J., & Bolt, D. (2018). Executive function skills in school-age children with autism spectrum disorder: Association with language abilities. *Journal of Speech, Language, and Hearing Research*, *61*(11), 2641–2658. https://doi.org/10.1044/2018_JSLHR-L-RSAUT-18-0026

Zheng, A., & Church, J. A. (2021). A developmental eye tracking investigation of cued task switching performance. *Child Development*, *92*(4), 1652–1672. https://doi.org/10.1111/cdev.13478