Executive function predicts school readiness in autistic and typical preschool children

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Abstract

Children's emerging executive functions (EF) have been shown to be critical for a whole range of other functions, including school readiness and later academic success. Here we examine for the first time whether individual differences in EF are uniquely associated with autistic children's readiness to learn in school, beyond general and developmental influences in age and ability. Thirty autistic and 30 typical preschool children matched on age and ability, were assessed on EF (working memory, inhibition, set-shifting) and school readiness measures. Autistic children performed significantly worse on school readiness measures and EF measures relative to typical children. Furthermore, individual differences in children's EF skills, especially in inhibitory control and working memory, were uniquely related to variation in their school readiness for both autistic and non-autistic children. The findings from this cross-sectional study provide further support for the potential role of EF in explaining the variability in autistic children's functional outcomes.

Keywords: autism, executive function, school readiness, academic achievement, outcomes

Entering school for the first time is an important transition for any child. The age at which this takes place varies in countries across the world but in England, the context of the current study, children begin formal education at age 5. Unlike home, childcare and most early learning environments, schools place increasing demands and expectations on children, not least the need to engage in formal, structured learning activities. Children will vary considerably in how ready they are to learn in these environments, including understanding key concepts like colours, letters, numbers and shape, and their social and emotional competence, which collectively have been termed "school readiness" (High, 2008). The extent to which children are prepared for this transition has a significant impact on their social and academic trajectories (Duncan et al., 2007; Friedman et al., 2007; Mashburn & Pianta, 2006; Moffitt et al., 2011; Snow, 2006). Understanding the potential sources of this variability across the full spectrum of typical and atypical development (Graham & Madigan, 2016) is therefore critical, particularly for children who are at risk of poor developmental outcomes.

Although ecological factors, including parenting, home-school partnership, teacher/peer-child relationships, are widely acknowledged to play a role in children's readiness to learn in school (Pianta & Rimm-Kaufman, 2006), much attention in both policy (e.g., Allen, 2011; Bennett & Tayler, 2006) and research (Blair & Raver, 2015) contexts has been paid to child-level factors. One key factor highlighted by researchers is children's emerging executive functions (EF), a set of higher-order processes that underpin goal-directed activity and enable individuals to respond flexibly to change, including inhibiting prepotent but maladaptive responses, cognitive flexibility and future-oriented (or 'working') memory (see Garon, Bryson, & Smith, 2008; Hughes, 2011; and Müller & Kerns, 2015, for reviews). This attention is unsurprising. It is well known that the prefrontal cortex, which partly mediates EF, shows a protracted developmental trajectory, with a particular boost precisely during the preschool period (Diamond, 2013). Furthermore, the transition to school itself relies on mastery of basic EF skills, including remembering and following instructions and representing the goal of the lesson (working memory), completing tasks independently and smoothly transitioning between tasks (cognitive flexibility), and staying on task (inhibitory control). EF, therefore, is held to play an important role in the acquisition of knowledge; the better children are at focusing and re-focusing their attention, holding information in mind and manipulating it and resisting distraction, the better placed children should be to acquire knowledge and skills in the classroom (Blair, 2002).

Several lines of evidence point towards the important role of EF in children's early school success. First, in one large survey of a national sample of teachers in the United States, 46% reported that more than half of the children in their classes showed problems adjusting with transition to kindergarten (Rimm-Kaufman, Pianta, & Cox, 2000). Teachers attributed children's difficulties not to limited knowledge of basic concepts, but to difficulties with following directions and controlling attention (see also, Heaviside, 1993) – thus endorsing a model of school readiness as executive control (Blair & Raver, 2015). Second, there is growing evidence for a substantial link both concurrently (Blair & Razza, 2007; Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Bull, Espy, Wiebe, Sheffield, & Nelson, 2011) and longitudinally (Clark, Pritchard, & Woodward, 2010; McClelland et al., 2007; Neuenschwander, Röthlisberger, Cimeli, & Roebers, 2012; Riggs, Blair, & Greenberg, 2004) between typical preschoolers' early EF and their school readiness, over and above general intellectual ability (though see Blair & Willoughby, 2013; and Müller & Kerns, 2015 call for more research needed to definitively determine the causal nature of this relationship). Third, several intervention studies have sought to foster learning in early childhood by "exercising" children's early-emerging EF skills (Bierman et al., 2008; Diamond, Barnett, Thomas, & Munro, 2007; Duncan et al., 2007). This research has demonstrated both that EF is malleable and can have significant positive effects on children's early academic success. Furthermore, studies focusing particularly on socially disadvantaged children, often with the weakest EFs, have consistently shown that they appear to benefit the most from intervention (Blair & Raver, 2014; Raver et al., 2011). Together, this evidence provides substantial support for the foundational role of EF in children's adjustment to, and readiness for, school (Blair & Raver, 2015; Ursache, Blair, & Raver, 2012).

Research on the EF-school readiness link has focused almost exclusively on the nature of this link in typically developing samples. Yet there is a substantial minority of children who follow atypical trajectories, some more pronounced than others. Knowledge of such links – either continuities *or* discontinuities – within atypically developing samples should serve to advance our understanding of typical development and indeed the fundamental variability that exists in capacities like EF and school readiness (see Jaswal, Akhtar, & Burack, 2016). The current study therefore examined the relationship between EF and school readiness in a group of children who are at increased likelihood for poor developmental outcomes, namely children on the autism spectrum.

Anecdotally, parents and teachers report that becoming accustomed to the new physical (built and sensory), social and academic environments can be particularly challenging and anxiety-provoking for their autistic [1] youngsters, especially given their core difficulties in social communication and social interaction and their preference for sameness (American Psychiatric Association, 2013). Despite these apparent problems in adjusting to school, there is strikingly little research either on autistic preschoolers' transition to formal education (see Forest, Horner, Lewis-Palmer, & Todd, 2004, for an exception) or on their school readiness. What we know from the also-limited literature on autistic children's academic achievement is that such achievement varies widely (e.g., Mayes & Calhoun, 2003; see Wong et al., 2014, for a review) with many children showing peaks and troughs on aspects of academic performance (reading, mathematics) that are incommensurate with their age and intellectual functioning (Estes, Rivera, Bryan, Cali, & Dawson, 2011; Jones et al., 2009). In a recent review, Keen, Webster, and Ridley (2016) found that, across 19 studies examining potential predictors of variation in autistic children's academic achievement,

[1] Identity-first language is the preferred language of many people on the autism spectrum (see Sinclair, 1999) and their parents (Kenny, Hattersley, et al., 2016). In this article, we use this term as well as person-first language to respect the wishes of all individuals on the spectrum.

the majority focused on intellectual functioning and language ability as predictor variables. Remarkably, no study examined children's EF as a possible source of the variation in their academic outcomes and nor was it highlighted by Keen et al. (2016) as a potential avenue for future research.

The absence of research examining the potential role of EF in autistic children's academic outcomes is surprising, especially given that executive difficulties are well established in autism. Such difficulties, which typically manifest as perseverative responses (i.e., getting "stuck" performing the same action) and difficulties switching flexibly between response sets (Hill, 2004; Kenworthy, Yerys, Anthony, & Wallace, 2008; Leung & Zakzanis, 2014), were once thought to play a primary role in the development of autistic features (Damasio & Maurer, 1978; Ozonoff, Pennington, & Rogers, 1991; Pennington & Ozonoff, 1996), but this causal hypothesis is now controversial (Geurts, Corbett, & Solomon, 2009; Happé, Ronald, & Plomin, 2006; Yerys, Hepburn, Pennington, & Rogers, 2007). More recently, researchers have proposed that the association between EF and functional outcomes in developmental conditions might be direct or indirect: people with strong EF abilities may be better able to compensate for atypicalities across development (Halperin & Schulz, 2006; Johnson, 2012).

Consistent with this proposal, there is accumulating evidence of the important contribution of early individual differences in EF in shaping autistic children's developmental trajectories. Variation in autistic children's EF correlates with their autistic features, including repetitive behaviours (Mosconi et al., 2009; Pellicano, 2013; Turner, 1997) and social competence (Berger, Aerts, Spaendonck, Cools, & Teunisse, 2003; Griffith, Pennington, Wehner, & Rogers, 1999; Munson, Faja, Meltzoff, Abbott, & Dawson, 2008; Pellicano, 2013). Two long-term follow-up studies have reported evidence for associations between autistic individuals' early EF and their adaptive functions measured over 10 years later (Kenny, Cribb, & Pellicano, 2016; Szatmari, Bartolucci, Bremner, Bond, & Rich, 1989). There is also evidence of an asymmetric relationship between EF and another key cognitive ability that shows significant growth during the preschool period, theory of mind (ToM): Pellicano (2010a) showed that autistic children's early EF skills were predictive of ToM three years later, independent of age, language ability, nonverbal intelligence and early ToM skills, but that early ToM skills were not predictive of later EF – a finding that is consistent with longitudinal studies of the EF-ToM relation in typical children (Carlson, Mandell, & Williams, 2004; Carlson, Moses, & Claxton, 2004; Devine & Hughes, 2014; Hughes, 1998c). Finally, one recent study has demonstrated that EF measured in cognitively able autistic children at age 3 significantly predicted their pre-symbolic and symbolic play skills at age 6 (Faja et al., 2016). Yet there were no predictive relations in the opposite direction: early play skills did not predict children's emerging EF. Together, these findings provide compelling grounds for suggesting that one source of the heterogeneity in autistic individual's functional outcomes are individual differences in emerging EF (Pellicano, 2012).

The current study

No study, however, has examined the potential role of EF in autistic children's academic outcomes. Here, we investigated this possibility by focusing specifically on autistic children's school readiness. Cognitively able autistic and typical preschoolers, all aged between 3 and 5 years and of similar intellectual ability, completed a battery of tasks related to school readiness, which assessed their understanding of basic concepts, as well as their social understanding and phonemic awareness. Since there are no studies investigating school readiness in autistic children, our first aim was to examine between-group differences on these measures.

Children also completed three developmentally-appropriate EF tasks, each targeting one key component of EF, including spatial working memory, inhibition and cognitive flexibility – all emphasised in models of preschool EF (Garon et al., 2008; Wiebe, Espy, & Charak, 2008). Correlational and regression analyses were used to address our second aim, that is, to examine whether individual differences in EF scores are related to individual differences in school readiness scores in autistic and typical children, independent of general and developmental differences in age and intellectual ability.

Identifying firm predictions with regard to the nature of the EF-school readiness link in autistic pre-schoolers was not straightforward. While research investigating the relationship between EF and other functions (e.g., ToM) has generally yielded similarities between autistic and typical children (e.g., ToM; Pellicano, 2007, 2010a), other key relationships, particularly between EF and language ability, have not been forthcoming (e.g,. see Joseph, McGrath, & Tager-Flusberg, 2005; Pellicano, 2010b; Wallace, Silvers, Martin, & Kenworthy, 2009; Williams, Bowler, & Jarrold, 2012), suggesting that verbal skills may not influence the emergence of EF in autism as they do in typical development (Fuhs & Day, 2011; Hughes, 1998a, 1998b; Hughes & Ensor, 2009). Notwithstanding, similarities and differences in the EF-school readiness relationship between typical and atypically developing samples should be equally informative – and serve both to understand better EF in autism *and* the spectrum of possibilities for researchers within the field of typical development (Jaswal et al., 2016).

Method

Participants

Sixty preschool children participated. Thirty autistic children (27 boys) were recruited from community contacts in London. All had received an independent clinical diagnosis according to ICD-10 (World Health Organization, 1993) or DSM-IV criteria (American Psychiatric Association, 2000) and met cut-off for autism spectrum disorder (score of 15) on the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) and the Autism Diagnostic Observation Schedule – Generic (Lord et al., 2000). Twenty-six children attended mainstream preschool provision (21 were receiving additional support), while the four youngest were not attending school. According to parents, 17 children were of White background, 6 of Black African background, 3 of Black Caribbean background and 6 of mixed backgrounds. Only one child was reported to be taking medication (for asthma).

Table 1. *Descriptive statistics and group differences for developmental, school readiness and executive function variables for autistic (n=30) and typical (n=30) children.*

	Group		
	Autistic children M (SD) Range	**Typical children** M (SD) Range	p value
Developmental Variables			
Age (in months)	53.26 (12.20) 36.11 – 71.97	53.02 (10.50) 35.72 – 71.41	.94
Verbal IQ[a]	96.53 (15.52) 72 – 124	101.87 (11.01) 71 – 121	.13
Performance IQ[a]	101.63 (14.97) 70 – 144	102.33 (12.63) 75 – 123	.84
SCQ[b]	24.63 (5.90) 15 – 33	.37 (.85) 0 – 4	<.001**
School Readiness			
BSRA-R[c] School Readiness Composite	113.50 (18.02) 74 – 144	124.20 (12.43) 97 – 142	.006*
BBCS-R[d] Self-Social Awareness subtest	7.07 (3.42) 0 – 15	13.57 (2.87) 7 – 18	<.001**
Sound Deletion – no. trials correct (out of 12)	2.27 (3.02) 0 – 9	4.43 (2.98) 0 – 10	.007*
Executive Function			
DCCS[e] task – no. trials correct in post-switch and border conditions (out of 18)	4.66 (5.86)[e] 0 – 18	12.20 (5.09) 1 – 18	<.001**
Corsi Blocks task – no. Backwards trials correct	1.87 (1.50) 0 – 9	5.60 (2.71) 0 – 10	<.001**
Less is More task – proportion of optimal selections	.42 (.36) 0 – 1	.72 (.27) .08 – 1	.001**

Notes: [a] Children's intellectual functioning was measured using the Wechsler Preschool and Primary Scale of Intelligence – 3rd Edition (WPPSI-III; Wechsler, 2003), standard scores reported here; [b] SCQ: Social Communication Questionnaire (Rutter et al., 2003), scores out of 39; [c] BSRA-R = Bracken School Readiness Assessment - Revised (Bracken, 1998), standard scores reported here; [d] BBCS-R = Bracken Basic Concept Scale – Revised, [e]DCCS = Dimensional Change Card Sort task (Zelazo, 2006); n=29; * p < .05; ** p < .005.

Thirty typical children (20 boys) also participated, recruited from local nurseries. All typical children scored well below the threshold for autism on the SCQ. All but the youngest child was attending mainstream provision, none were taking medication, and 21 children were of White background, 5 of Black African background and 4 of mixed backgrounds.

There were no significant group differences on chronological age, $F(1,59)=.007$, $p=.94$, Verbal IQ, $F(1,59)=2.36$, $p=.13$, or Performance IQ, $F(1,59)=.04$, $p=.84$, as measured by the Wechsler Preschool and Primary Scales of Intelligence – 3rd edition (WPPSI-III; Wechsler, 2003) (see Table 1). There were significant group differences with regard to gender, with more girls in the typical than the autistic group, $\chi^2 = 4.81$, $p=.03$[2]. All children were considered cognitively able, achieving IQ scores of 70 or above.

Six additional children were assessed but excluded either for not meeting the autism threshold on the SCQ and ADOS-G (n=2 autistic children) or for not obtaining a Verbal IQ score of 70 or above (n=2 autistic children; n=2 typical children).

Measures

Verbal and nonverbal abilities. The Vocabulary and Word Reasoning subtests from the WPPSI-III (WPPSI-III; Wechsler, 2003) were used to index children's verbal ability and Matrix Reasoning and Picture Concepts indexed non-verbal ability. Standard scores (M=100; SD=15) were derived for Verbal IQ and Performance IQ (see Table 1) but raw scores were used in correlational and regression analyses since such scores have not been adjusted for age and therefore reflect children's ability.

School Readiness. Children's understanding of foundational concepts was measured using the *Bracken School Readiness Assessment – Revised* (BSRA-R), one element of the Bracken Basic Concepts Scale – Revised (BBCS-R: Bracken, 1998), a developmentally-sensitive measure designed for children aged 2.5-7 years with excellent reliability and validity (Panter & Bracken, 2009). The 6 core subtests of the BRSA-R were administered, measuring children's receptive understanding of colours, letters, numbers, sizes, comparisons and shapes. Children received a score of '1' for each

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[2] Gender was not correlated with any EF or school readiness variable within either group of children (lowest p value = .28) and so differences on any of these variables are unlikely to be attributable to gender.

correct answer. Raw scores across subtests were summed and, following (Bracken, 1998), were converted to age-adjusted standard scores to yield a School Readiness Composite score (M=100; SD=15).

Children's social awareness was measured using the Self-/Social Awareness subscale from the BBCS-R. This includes 38 items on understanding of emotions and of social terms related to kinship, gender, relative ages and social appropriateness. Children received a score of '1' for each correct answer. Scores were summed and converted to age-adjusted scaled scores (M=10; SD=3).

Following tables in (Bracken, 1998), children's rate of conceptual development was classified for both the School Readiness Composite and the Self-/Social Awareness subscale, into very advanced, advanced, average, delayed and very delayed. Standard scores were used to examine group differences but raw scores were used in correlational and regression analyses.

The *Sound Deletion subtest* of the York Assessment of Reading for Comprehension (YARC; Snowling et al., 2009) assessed one component of phonological awareness, sound deletion. In this test, the child hears a word (and also sees a picture of the word) and is required to repeat the word, but to delete single phonemes from it (e.g., "Say boat without the [t]"). Children received two teaching followed by 12 test items. Children scored 1 point for each correct answer. Scores were summed to yield a total sound deletion score (maximum score=12). Higher scores indicate better phonemic awareness.

Executive function. The *Dimensional Change Card Sort (DCCS) task* measured children's set-shifting ability (Zelazo et al., 2003). Following Zelazo (2006), children were initially shown two model cards (red rabbit, blue star) and the experimenter demonstrated how to sort a card by labelling it with the relevant dimension and saying the pre-switch rules, "If it's blue/a rabbit, it goes here, but if it's red/a star it goes here." Feedback was then given on the child's attempt to sort the next (randomly-selected) card. Next, in the pre-switch condition (6 trials) the experimenter selected each card at random, placed it on a clear sorting box, labelled it by the relevant dimension and repeated the pre-switch rules. On each trial, children were asked, "Where does this card go in the (colour/shape) game?" After 6 trials of sorting by one dimension, the rule switched to sorting the cards by the alternate dimension. If the child scored at least 5 out of 6 in the pre-switch condition, s/he then moved onto the post-switch condition, completing a further 6 trials sorting by the alternate dimension. No specific feedback was given.

Children who passed the post-switch condition (≥5 out of 6 correct) moved on to the more difficult, borders condition. Children received 12 similar cards, half of which included a black border, and asked to sort to one dimension (e.g., shape) for cards with borders and sort to the other dimension (e.g., colour) for cards without borders. Children were reminded of this rule before each card sort. A score of at least 9 out of 12 trials correct was considered a 'pass'.

The order of presentation of dimensions (colour, shape) was counterbalanced across children. Children scored 1 point for each card sorted correctly. The dependent variable of interest was the total number of correct post-switch and borders responses (maximum score=18). Higher scores reflect better cognitive flexibility.

The *Corsi Blocks task* (Corsi, 1973; Milner, 1971) measured children's spatial working memory. It consists of nine identical blocks positioned on a wooden board in a particular configuration. In the initial Forwards version, children were told: "Look at this board. It has nine blocks on it. I am going to tap 2 blocks, one after the other. Watch carefully, because I want you to copy what I do. Try to tap the blocks in exactly the same order as I did." There were 7 problem sets, which progressively increased in length, with 5 trials per set. If a child failed four or more trials within a set, testing ceased. In the second, Backwards condition, children were told to watch the sequence carefully, then tap the sequence backwards. Two practice trials were given. Test trials were then presented following the same procedure as the Forwards condition. Sequence length increased after 5 trials until either a maximum of 7-block sequences, or until the child was unable to recall the backward sequence on 4 of the 5 trials.

One point was given for each successfully replicated sequence. The total number of trials on which the child correctly recalled the sequence of blocks was calculated for each condition separately (maximum score=35). Higher scores on the Backwards condition reflect better spatial working memory, that is, children's ability to hold information (a spatial sequence) online and manipulate it (reverse the order).

The *Less is More task* (Carlson, Davis, & Leach, 2005) is a reverse-reward measure of inhibition in which children must point to a smaller amount of treats to receive a larger amount for themselves, inhibiting the natural tendency to point to the desired (larger) amount. First, the experimenter established the child's preferred treat (e.g., fruit-flavoured sweets or chocolate sweets) and presented them on two clear trays, one showing a five-sweet array and the other a two-sweet array. The child was asked which array they preferred.

Next, the experimenter introduced the child to a "greedy" puppet, "Dolly". The child and Dolly were each given a clear plastic cup and the child was told that each time s/he points to a tray, the sweets on that tray go into Dolly's cup and the sweets on the other tray go into his/her cup. The child completed one practice trial in which the child was asked to "point to a tray" when a five-sweet and two-sweet array were presented on trays equidistant from the child. Each child then completed 12 test trials on which children received no explicit feedback. Children scored 1 point for selecting the smaller array. The number of test trials on which the child made an optimal selection (i.e., chose the smaller array) was summed (maximum score=12). Higher scores reflect better inhibition skills.

General procedure

Children were seen individually in a quiet room at home or school for 15-20 minutes on up to 4 separate occasions. The WPPSI-III subtests were administered first followed by the BRSA-R, Sound Deletion, and executive measures. Ethical approval for this study was granted by the University's Research Ethics Committee and parents provided informed written consent prior to their child's participation.

Results

This section begins with analyses of between-group differences for the school readiness and EF tasks, which address the first aim of our study. Prior to analyses, scores on each task were converted to z scores using the typical group as the normative standard ([score - $M_{typical}$]/$SD_{typical}$). All subsequent analyses were performed using the z scores for each variable (see Table 1 for the untransformed means and standard deviations).

Next, we examine individual differences between school readiness and EF variables and developmental variables (age, verbal ability and nonverbal ability), followed by an analysis of the coherence of each construct (school readiness, EF) within each group separately. We then report the results of correlational analyses between school readiness and EF variables.

Finally, we examine the results of hierarchical regression analyses, which addresses the second aim of our study: to determine the unique relationships, if any, between EF and school readiness in autistic and typical children.

Group differences

School readiness. Table 1 shows children's mean performance on the School Readiness Composite of the BRSA-R. Compared to typical children of similar age and ability, autistic children performed significantly worse on the School Readiness Composite score, $F(1,58)=7.16$, $p=.01$, $\eta_p^2=.11$ (see Table 1). This group difference is despite the fact that autistic children's absolute scores are relatively high, almost 1 SD above the population mean – higher than expected given their intellectual ability (VIQ and PIQ scores). Analyses of group differences on each individual subtest revealed that autistic children performed significantly worse than typical children on 4 of the 6 subtests, including Colours, $F(1,58)=4.28$, $p=.04$, $\eta_p^2=.07$, Sizes, $F(1,58)=17.26$, $p<.001$, $\eta_p^2=.23$, Comparisons, $F(1,58)=20.87$, $p<.001$, $\eta_p^2=.26$, and Shapes, $F(1,58)=6.52$, $p=.01$, $\eta_p^2=.10$. No significant differences were found on the Letters and Numbers subtests (both ps>.28).

As expected, autistic children also obtained significantly lower scores than typical children on the Self-/Social Awareness Scale of the BRSA-R (see Table 1), $F(1,29)=63.46$, $p<.001$, $\eta_p^2=52$. Following Bracken (1998), we classified children's scores into 5 levels of functioning on both the

School Readiness Composite and the Self-/Social Awareness Scale. Figure 1 shows the number of children falling in each normative classification level. There were significant associations between level of functioning and group for both the School Readiness Composite, $\chi^2(3)=9.81$, $p=.02$ (Figure 1A), and the Self-/Social Awareness subscale, $\chi^2(4)=28.25$, $p<.001$ (Figure 1B), with more typical children falling in the Very Advanced and Advanced classifications than autistic children.

We also found significant group differences on the Sound Deletion test, $F(1,58)=7.84$, $p=.007$, $\eta_p^2=.12$. Autistic children had greater difficulty deleting single phonemes of words than typical children.

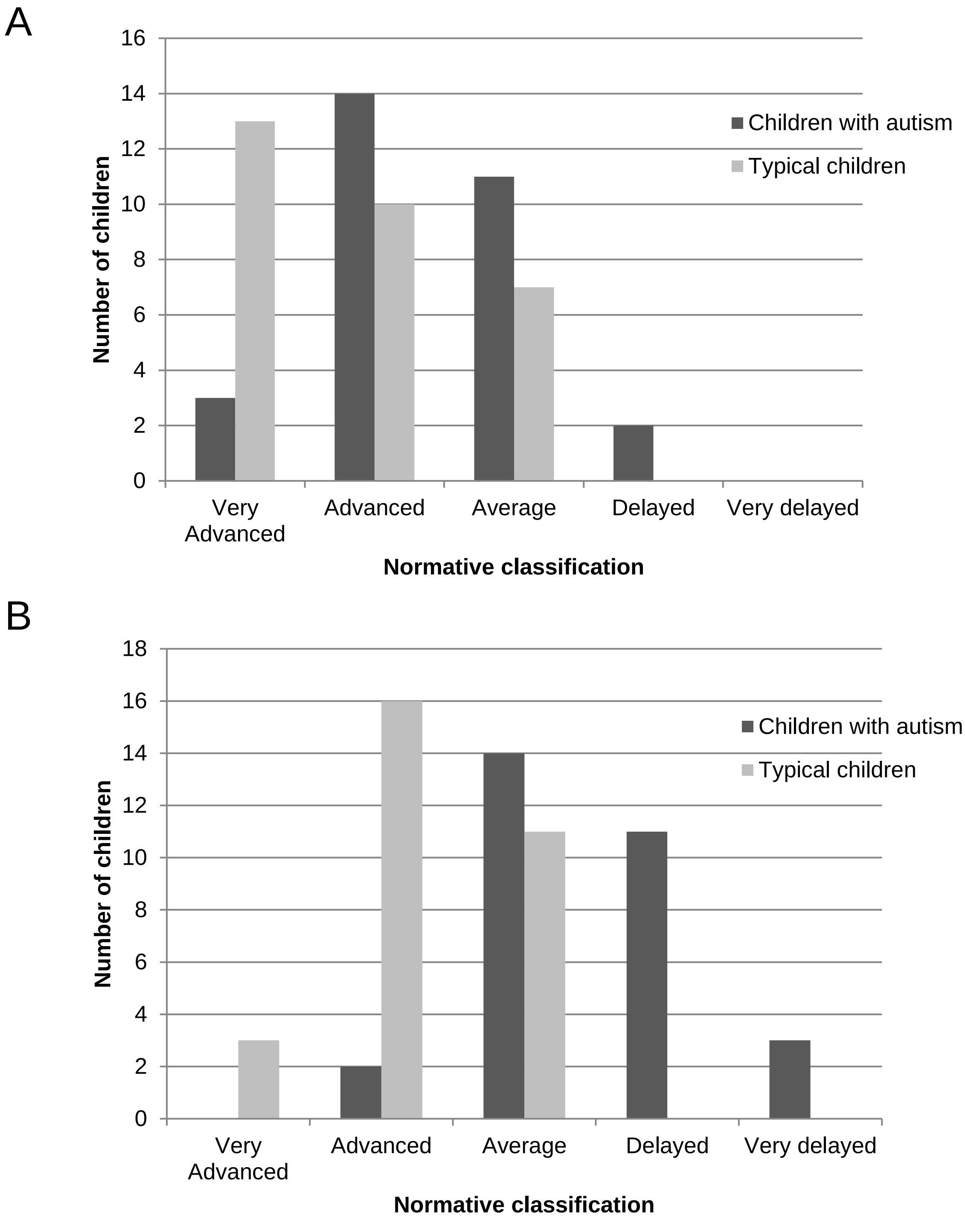

Figure 1. Figure showing the number of autistic (n=30) and typical (n=30) children falling into the normative classification levels according to their scores on the Bracken Basic Concepts Scale - Revised (A) School Readiness Composite and (B) the Self-/Social Awareness subscale.

Executive function. On the DCCS task, all typical children and all but one autistic child reached criterion on the pre-switch phase. Examination of children's performance in the post-switch and borders conditions, however, showed that autistic children scored significantly fewer trials correct than typical children, $F(1,57)=27.92$, $p<.001$, $\eta_p^2=.33$. When categorized into those who passed the post-switch condition (scoring at least 5 out of 6 trials correct) and those who did not, there were significantly more autistic children who failed to switch their cognitive set (n=20) than typical children (n=7), $\chi^2(1)=12.37$, $p<.001$. Of the children who completed the border condition (autistic: n=9; typical: n=24), 2 autistic children passed (i.e., scored at least 9 out of 12 trials correct) compared to 13 typical children. This difference, however, was not significant, $\chi^2(1)=2.69$, $p=.10$.

On the Backwards condition of the Corsi Blocks task, we found that autistic children scored significantly fewer trials correct than typical children, $F(1,58)=30.72$, $p<.001$, $\eta_p^2=.35$, suggestive of poorer spatial working memory skills (see Table 1).

On the Less is More task, all children said that the puppet would get the treats they pointed to following feedback, indicating their comprehension of the rule. Analysis of the proportion of trials on which children made an optimal selection showed a significant group difference, $F(1,58)=13.20$, $p=.001$, $\eta_p^2=.18$. Autistic children were more likely to choose the larger array of sweets than typical children (see Table 1 for scores). Typical children performed significantly above chance (.50), $p<.001$, but children with autism did not, $p=.20$, suggesting that, as a group, autistic children show difficulties with conflict inhibition.

Correlational analyses

Effects of age, verbal ability and nonverbal ability. Initial correlational analyses between children's performance on school readiness and developmental variables (age and ability) (see Table 2) showed significant inter-correlations between School Readiness Composite performance and age for both autistic, $r(29)=.43$, $p=.02$, and typical children, $r(29)=.59$, $p=.001$, and verbal ability for typical children, $r(29)=.35$, $p=.05$. No other correlations were significant (all ps>.17). Correlations between developmental variables and Self-Social Awareness, Sound Deletion and EF variables followed a similar pattern (see Table 2).

Table 2. *Pearson correlations for developmental (age and ability), school readiness and executive function variables in autistic and typical children separately.*

		Chronological Age	**Verbal ability[a]**	**Nonverbal ability[b]**
Autistic	School Readiness	.43*	.23	.14
	Self-/Social	.62**	.17	.20
	Sound Deletion	.56**	.23	.10
	DCCS	.65**	.28	.41*
	Corsi Blocks	.37*	-.04	.20
	Less is More	.72**	.21	.28
Typical	School Readiness	.60**	.36*	.29
	Self-/Social	.49**	.59**	.27
	Sound Deletion	.55**	.25	.09
	DCCS	.51**	.08	.08
	Corsi Blocks	.48**	.22	.03
	Less is More	.50**	.20	.03

Notes. [a] as indexed by raw (ability) VIQ scores on the WPPSI-III (Wechsler, 2002); [b] as indexed by raw (ability) PIQ scores on the WPPSI-III (Wechsler, 2002); * Significant at the 0.05 level (2-tailed); ** Significant at the 0.01 level (2-tailed).

Coherence. Table 3 presents a correlation matrix of associations between individual task scores on school readiness and EF measures. In general, significant associations emerged between scores on tasks used to assess each domain, suggestive of good convergent validity for each construct. There were strong positive relationships between measures of school readiness, including the School Readiness Composite, Self-/Social Awareness and Sound Deletion scores, for children with and without autism. Most EF variables were significantly interrelated in the autistic and typically developing groups (see Table 3).

Table 3. *Pearson correlation coefficients between school readiness and executive function variables in children with autism (n=30) and typical children (n=30).*

		Self-/Social Awareness	Sound Deletion	DCCS task	Corsi Blocks Backwards	Less is More
Autistic	School Readiness	.65**	.51**	.47*	.41*	.50*
	Self-/Social	-	.60**	.74**	.38*	.67**

	Sound Deletion		-	.45*	.30	.55**
	DCCS			-	.54**	.67**
	Corsi Blocks				-	.38*
	Less is More					-
Typical	School Readiness	.72**	.64**	.54**	.60**	.46**
	Self-/Social	-	.62**	.56**	.63**	.55**
	Sound Deletion		-	.43*	.61**	.64**
	DCCS			-	.21	.61**
	Corsi Blocks				-	.50**
	Less is More					-

Note: [e]DCCS = Dimensional Change Card Sort task (Zelazo, 2006)

Relationships between school readiness and EF. Table 3 also shows the correlation coefficients between school readiness and EF variables, all of which were significant and generally of high magnitude in both groups of children. Higher school readiness scores (for the BRSA School Readiness Composite, the Self-/Social subscale and the Sound Deletion scores) were related to higher scores on all EF tasks.

Regression analysis. A hierarchical regression analysis was performed to determine the extent to which EF skills uniquely predicted children's school readiness. Including all children in the same model increased statistical power and allowed us to test for an interaction between group and EF variables. Given that the construct of school readiness encompasses academic and socioemotional skills and that we wanted to minimize the number of regression analyses performed, we created a robust, overall school readiness score. We did this by standardizing the individual school readiness variables (the BRSA-R School Composite, the Self-/Social subscale and the Sound Deletion scores) and averaging them. This overall school readiness score was used as the dependent variable in the hierarchical regression model.

Since school readiness was significantly related to age and ability, individual differences in these variables were accounted for by entering age, ability (verbal and performance raw) scores and group in the first step of the regression model. The additional contribution of EF variables was then tested by entering them stepwise into the regression equation, as well as the interaction terms for each variable.

When age, verbal ability, nonverbal ability and group were entered simultaneously as predictors of children's overall school readiness, these variables accounted for 58% of the variance, $F(4,54)=20.90$, $p<.001$. Children's scores on the DCCS task, the Corsi Blocks Backwards condition and the Less is More task were then entered stepwise into the model, along with their respective interaction terms. Performance on the Less is More task and the Corsi Blocks Backwards condition uniquely explained an additional 7% [$F(1,53)=11.47$, $p=.001$], and 4% [$F(1,52)=7.70$, $p=.008$] of the variance in children's school readiness scores, respectively. The positive beta values (Table 4) suggest that better inhibition skills and better spatial working memory predicted better school readiness, over and above that already accounted for by age and verbal ability. The final model was significant, $F(6,52)=22.17$, $p<.001$, $R^2=.69$. None of the interaction terms were significant (all ps>.28) suggesting that autistic children showed a similar pattern of relations among their EF and school readiness skills as typical children.

Table 4. *Summary of hierarchical regression analyses predicting overall school readiness (final model)*

Variable	***B***	***SE B***	***ß***	R^2 or ΔR^2
Step 1				.58**
Age	.02	.01	.24*	
Verbal ability[a]	.04	.02	.19*	
Nonverbal ability[b]	.001	.03	-.03	
Group	-.73	.22	-.32**	
Step 2				.11*
Corsi Blocks Backwards	.28	.10	.34**	
Less is More task	.28	.10	.28**	

Notes. [a]Indexed by WPPSI-III raw verbal scores; [b]Indexed by WPPSI-III raw performance scores; *Significant at $p < .05$; **Significant at $p < .01$.

Discussion

In the current study, cognitively able autistic preschool children demonstrated significantly lower school readiness than typical children – for basic concepts such as colour, shape, size etc., social competence and phonemic awareness. Furthermore, individual differences in children's EF were uniquely related to their school readiness scores, independent of age and verbal ability, for autistic *and* typical children. Specifically, children with better spatial working memory and inhibition skills showed better early learning skills. Our findings with typical children replicate existing research supporting an EF-school readiness link (see Blair & Raver, 2015, for review) and extend that work to show that a similar foundational link also exists in preschool children on the autism spectrum.

To our knowledge, this is the first study to examine autistic preschoolers' school readiness. We measured this construct in part by using the standardised Bracken School Readiness Assessment (Bracken, 1998). Both typical and autistic children performed well on the School Readiness Composite Score – in fact, their scaled scores were such that they generally performed much better than expected given their intellectual ability. The BSRA-R has not been standardized with a UK population, making it possible that this discrepancy arose either from the use of US norms with British children or differences in the pre-school learning experiences of our samples and the standardization sample. This is a potential limitation of this study. Notwithstanding, autistic children performed significantly worse than typical children of similar age, verbal and nonverbal ability on all school readiness measures, which suggest that, on average, they may be academically underachieving even at this young age, given their (crystallized) intellectual ability.

One of the main aims of this study was to examine whether individual differences in EF are one source of the variance in autistic children's school readiness scores – just like they are for typical children (e.g., Blair & Razza, 2007; Brock et al., 2009; McClelland & Cameron, 2011). All three EF tasks were significantly correlated with almost all of the school readiness variables in both samples of children. Furthermore, children's scores on the Less is More task and the Corsi Blocks Backwards task explained unique variance in their overall school readiness scores, beyond that already accounted for by age and verbal ability. Importantly, and despite the fact that the autistic children performed significantly worse on both EF and school readiness tasks than typical children, the pattern of EF-school readiness relationship was similar for both groups. This result supports the few existing studies that have investigated this relationship in clinical samples of preschoolers (e.g., with externalizing behaviour problems: Graziano & Garcia, 2016).

Nevertheless, it is difficult to draw strong conclusions on the direction of the EF-school readiness relationship given the cross-sectional nature of our data. One possibility is that EF skills directly promote learning in the classroom, particularly for those skills that require less rote learning or automatic processing and more controlled problem solving (Blair & Diamond, 2008; Blair & Razza, 2007). Clues from longitudinal studies on the relationship between autistic children's EF and play (Faja et al., 2016) and theory of mind (Pellicano, 2010a) suggest that the nature of the EF-school readiness link may well be in one specific direction for autistic children on the autism spectrum – that is, that EF has a direct influence on school readiness. It is also possible, however, that there may be bidirectional associations between EF and early academic learning. For example, children who are able to learn academic content more quickly and effectively may be better placed to take part in academically-demanding activities that in turn foster their executive control (see Fuhs, Nesbitt, Farran, & Dong, 2014).

Another possibility still is that children's language skills may (partially) mediate the EF-school readiness relationship. Variation in children's language skills made a strong contribution to school readiness in the current study. Having good language abilities is certainly important for understanding teacher directions and academic content in the classroom. It is also critical for children's emerging EF skills, including in autistic children (Pellicano, 2007; Williams et al., 2012). According to Zelazo and colleagues' cognitive complexity and control account (Zelazo & Müller, 2002), developmental gains in EF reflect advances in the ability to represent complex (if-if-then) rule structures. Language is held to be the medium through which these higher-order rules are formulated. It remains possible, therefore, that autistic children's language skills might mediate, at least in part, the link between early EF and their readiness to learn in school. It is also possible that an unmeasured third variable accounts for the significant relationship between children's EF and their school readiness (Blair & Willoughby, 2013; Müller & Kerns, 2015). Both future longitudinal studies considering a broader range of potentially confounding variables (Blair & Willoughby,

2013) and experimental interventions targeting EF (see below) will be important for teasing out the precise nature of the EF-school readiness relationship.

Research in this area should not, however, be limited to child-level factors. There is growing evidence that early environmental influences, including socioeconomic status (SES: see Müller, Baker, & Yeung, 2012, for a review) and parenting practices (e.g., Bernier, Carlson, & Whipple, 2010; Blair & Raver, 2012; Hughes & Ensor, 2009; NICHD Early Child Care Research Network, 2003), can have a substantial impact on emerging EF. Furthermore, the quality of children's relationships with their teachers is an important predictor of children's early adjustment to school (e.g., Baker, 2006; Curby, Rimm-Kaufman, & Ponitz, 2009). These factors are no less important for autistic children, who are also sensitive to parenting factors (e.g., Green et al., 2010), school-related supports (Eisenhower, Bush, & Blacher, 2015) and most likely SES, although this is rarely examined (see Pickard & Ingersoll, 2015). It is therefore plausible that the effects of poor EF on autistic children's school readiness could well be buffered by different parenting strategies and strong teacher-child relationships. Future research investigating the factors involved in successful school transition should focus on the child and their broader learning environments (Pianta & Rimm-Kaufman, 2006).

Our finding of a similar relationship between EF and school readiness in autistic and typical preschoolers strengthens the empirical evidence for the potential role of executive function in early academic success and suggests that the mechanism(s) underlying this link (in whatever guise; Blair & Willoughby, 2013) might well be highly constrained across different types of children. Our findings also have important implications for intervention. Early EF makes specific contributions to autistic children's later social competence (Pellicano, 2013), play skills (Faja et al., 2016), theory of mind (Pellicano, 2010a), adaptive behaviour (Pugliese et al., 2016) and, as we have shown herein, at least cross-sectionally, their school readiness. Taken together, these findings underscore the importance of EF as a candidate target for early intervention. Remarkably, despite the plethora of studies showing autistic children and young people's difficulties in EF, attempts to try to bolster EF – either directly or indirectly – through training are virtually nonexistent. Two notable exceptions (Fisher & Happé, 2005; Kenworthy et al., 2014) have focused on direct training programmes with school-age autistic children. Kenworthy et al.'s findings are particularly promising but the current results suggest that it may be beneficial to target EF interventions especially during the preschool period, at a time when there is particular growth and the greatest chance of influencing a range of important skills – school readiness, play and theory of mind.

This study is not without its limitations. The relatively small sample sizes and the challenges associated with testing young autistic children precluded the possibilities of using several indicators of each aspect of EF and employing confirmatory factor analysis to delineate the underlying factor structure in autistic preschoolers. This work also concentrated on a group of cognitively able autistic children and so it is unclear whether similar EF-school readiness relationships would extend to autistic children with additional intellectual disabilities and/or limited communication. Indeed, Faja et al.'s work (2016), which showed that early EF predicted children's later play skills only in those autistic children whose basic language skills were in place, suggests that it may not. These will all be important next steps for future research.

Notwithstanding, our EF tasks were sufficiently sensitive to detect differences in autistic relative to typical preschoolers. This is noteworthy because most (though not all: Dawson, Meltzoff, Osterling, & Rinaldi, 1998; McEvoy, Rogers, & Pennington, 1993; Pellicano, 2007) studies with autistic preschoolers have failed to find evidence of poor EF (Dawson et al., 2002; Griffith et al., 1999; Stahl & Pry, 2002; Yerys et al., 2007), raising the possibility that autistic children may "grow into" EF difficulties with development. The most straightforward explanation for the discrepancy between the findings of these latter studies and our own relates to sampling characteristics. Many of these studies assessed EF in autistic and non-autistic children with additional developmental delays, thus questioning the specificity of any such EF difficulties. Here, we show that intellectually able autistic pre-schoolers show EF difficulties compared to typical children of similar age *and* ability, findings that map onto studies using parent ratings of EF problems in autistic preschoolers (Smithson et al., 2013). Whether a similar but younger group of autistic children might not show EF difficulties relative to typical children is an important avenue for future research.

In conclusion, we found that cognitively able autistic preschoolers performed significantly worse on measures of school readiness than typical children of similar age and intellectual ability. It is well-established that early EF is the best predictor of academic achievement in later school years (see Blair, 2006, for review) – at least in typical children – which, alongside other factors (e.g., social isolation; Humphrey & Lewis, 2008) potentially explains why children on the autism spectrum have been shown to be at risk of academic *underachievement* (Estes et al., 2011). Randomised controlled trials targeting EF during the preschool period are needed to determine definitively the causal role of EF in autistic children's early academic skills.

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