Profiles of academic achievement and attention in children with and without Autism Spectrum Disorder

Emily McDougal[a,b,c], Deborah M. Riby[a,b,*], Mary Hanley[a,b]

[a] Department of Psychology, Durham University, South Road, Durham DH1 3LE, UK
[b] Centre for Developmental Disorders, Durham University, South Road, Durham DH1 3LE, UK
[c] Child Life and Health, University of Edinburgh, 20 Sylvan Place, Edinburgh EH9 1UW, UK

ARTICLE INFO

ABSTRACT

Background: Academic outcomes for autistic individuals are heterogeneous, but the reasons for this are unknown. Attention is known to predict learning in typical development, but there is less evidence about this relationship in Autism Spectrum Disorders (ASD), even though attention is reported as atypical in this group.
Aims: To investigate reading and maths achievement profiles for children with and without an ASD, focusing on the role of attention in these profiles and to enable a better understanding of individual differences.
Methods: Reading, maths and attention abilities of 22 autistic children ($6-16$ years) and 59 TD children (6–11 years) were measured using standardised assessments.
Results: A hierarchical cluster analysis that included all children (N = 81) revealed three distinct transdiagnostic subgroups, characterised by children with good, average, and poorer divided attention and academic achievement respectively. Children with poorer attention and achievement displayed relative weaknesses in maths, while children with average or above-average attention and achievement showed no such weakness.
Conclusions: The findings provide a novel insight into the relationship between attention and achievement and understanding individual differences in ASD and typical development.

What this paper adds

This paper took an approach that recognises the heterogeneity within ASD, when considering the role of attention in academic achievement. A transdiagnostic approach was taken, using a cluster analysis that included both TD and autistic children. The findings demonstrated that children with ASD were characterised across three distinct subgroups, alongside TD children. This has important implications for understanding the heterogeneity of attention and achievement in ASD, highlighting avenues of further investigation for future research.

* Correspondence author at: Department of Psychology, Durham University, South Road, Durham DH13LE, UK.
  E-mail address: deborah.riby@durham.ac.uk (D.M. Riby).

1. Introduction

Educational outcomes for autistic[1] individuals are highly variable (Keen, Webster, & Ridley, 2016), and although this heterogeneity in academic outcome has been widely reported, little is known about cognitive and behavioural factors associated with this variability. The ability to focus attention on task-relevant information is crucial for learning (e.g. Erickson, Thiessen, Godwin, Dickerson, & Fisher, 2015), and in the context of academic achievement this implies that children who cannot concentrate during lessons may also attain limited academic outcomes. Attention atypicalities in autism are well-documented (e.g. Ames & Fletcher-Watson, 2010). Given these differences in both attention and academic outcomes in Autism Spectrum Disorders (ASD), it is important to investigate whether attention abilities play an important role in autistic children's learning outcomes, perhaps even more so than for typically developing (TD) pupils.

The notion that attention is comprised of three separable but related processes is well established; namely, sustained, selective and executive attention (Petersen & Posner, 2012; Posner & Petersen, 1990). Sustained attention is the ability to direct and maintain cognitive activity on stimuli over time, selective attention describes the ability to appropriately orient attention, and executive attention relies on higher cognitive functions to actively maintain attention in the presence of interference. Attention is one of the most consistently reported cognitive atypicalities associated with ASD (Allen & Courchesne, 2001; see Ames & Fletcher-Watson, 2010), however performance varies between attentional components. Although some attentional functions are atypical in ASD, studies have shown that the ability to sustain attention is relatively typical, with performance comparable to TD groups (e.g. Garretson, Fein, & Waterhouse, 1990; May, Rinehart, Wilding, & Cornish, 2013). Comparatively, selective attention has been found to be atypical in ASD in relation to both social (e.g. Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998) and non-social information processing (Keehn, Lincoln, Muller, & Townsend, 2010; Renner, Grofer Klinger, & Klinger, 2006). Specifically, these studies have shown that children with ASD have an attentional preference for non-social information, which may be related to differences in the orienting of attention. Studies have also reported atypical executive attention in autism (Casey, Gordon, Mannheim, & Rumsey, 1993; Mutreja, Craig, & O'Boyle, 2016), although findings are mixed (see Keehn et al., 2010; May et al., 2013). The variability in findings may be related to differing characteristics of attention tasks between studies; for example May et al. (2013) used a visual search task to measure executive attention in which the target object was alternated between trials to tap the child's ability to flexibly switch their attention. By comparison, Mutreja, Craig & O'Boyle (2016) measured executive attention using a flanker task in which children had to ignore irrelevant information while determining the direction in which an object was pointing. Arguably, although these studies both describe their measure as executive attention, they may be tapping different aspects of executive attention. Therefore, further work is required to understand these variable executive attention components in atypical development. As it seems that there is variability in the components of attention that may develop typically / atypically in autism, it is important to consider the different sub-functions of attention, rather than assume performance on a single measure of attention is a strong indicator of overall attention ability. This is important not only to fully understand the attentional profile of children with an ASD, but to also recognise the implications of attentional abilities for other aspects of functioning such as academic achievement in typical and atypical development.

Measures of observed attention behaviours, as rated either by parents or teachers, are predictive of academic achievement for TD children both concurrently (Pham, 2016) and longitudinally (McClelland, Acock, Piccinin, Rhea, & Stallings, 2013). Children observed to be more attentive generally perform better in academic domains such as reading and maths than children who are inattentive. Despite these findings, research regarding cognitive measures of attention and their concurrent and longitudinal relationships with academic outcomes is limited. For TD children, executive attention has been found to concurrently predict academic achievement in pre-schoolers (Lan, Legare, Ponitz, Li, & Morrison, 2011; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012), but not in older children (Colom, Escorial, Shih, & Privado, 2007). Steele et al. (2012) measured executive attention in $3-6$ year olds using a spatial conflict task, and found that performance on this task predicted early reading and maths skills. Colom et al. (2007) considered the same relationship in 13-year-olds, finding that performance on a flanker task did not predict academic achievement. These patterns indicate that by the time children reach secondary school attention has less of a direct influence, but at younger ages the impact is more direct. By comparison, sustained attention has been noted as longitudinally predictive of reading and maths achievement (Razza, Martin, & Brooks-Gunn, 2012; Steele et al., 2012). While Steele et al. (2012) reported executive attention as a concurrent predictor of literacy and numeracy in $3-6$ year olds, they found that performance on a version of the Continuous Performance Test predicted these skills 12 months later. This finding was supported by Razza et al. (2012), in that sustained attention ability at age 5 predicted reading and maths performance at age 9. Taken together, the literature suggests that the ability to sustain attention is important for academic achievement over time, as opposed to executive attention, an ability that is more likely to be relevant for allocating appropriate cognitive resources during learning.

The relationship between attention and academic achievement in ASD is more ambiguous. Mayes and Calhoun (2007) considered the concurrent relationship between attention and academic achievement (reading and maths) in $6-16$ year-olds using the Vigilance and Distractibility subtests from the Gordon Diagnostic System (GDS; Gordon, 1983) which provided a composite measure of attention. Academic achievement was assessed using the Word Reading, Reading Comprehension, and Numerical Operations subtests of the Wechsler Individual Achievement Test (WIAT; Psychological Corporation, 1992). Although IQ was the strongest predictor of

---

[1] Many individuals on the spectrum prefer identity-first language such as 'autistic person', but this preference is not universal and others prefer person-first language such as 'person with autism' (Bury, Jellett, Spoor, & Hedley, 2020; Kenny et al., 2016). We therefore use both of these terms interchangeably throughout the current paper to acknowledge the different preferences across the wider autism community.

reading and maths achievement, attention made a significant independent contribution to both aspects of achievement. May et al. (2013) also considered sustained attention and attention switching as concurrent predictors of reading and maths in 7–12 year-old autistic children. To measure attention switching, children were presented with a scene on the computer screen containing trees and a river, amongst other objects, and were instructed to search for a target object, and to click on the target to reveal a monster. The target object was alternated between trials to tap the child's ability to flexibly switch their attention. To measure sustained attention, children were presented with the same display as in the previous task, but were asked to watch for a yellow border that would appear around a target shape. The children had seven seconds to click on the target. Reading and maths achievement was measured using the WIAT-II (Psychological Corporation, 2002). Whereas attentional switching significantly predicted maths achievement, neither of the attention measures predicted reading. It is possible that this is due to the assessment tool used; the authors administered only the Word Reading subtest from the WIAT-II, rather than the full Reading Achievement composite, which also includes subtests of Reading Comprehension and Pseudoword Decoding. Considering that children with ASD show discrepancies between reading and maths abilities (Kim, Bal, & Lord, 2018; Miller et al., 2016), it is important to obtain a wider assessment of reading and maths in these children, rather than measure their academic achievement using single subtests that might touch on pockets of strength or weakness. It is also important to recognise that across published studies different measures of attention have been used. Normed scores are available for the Gordon Diagnostic System, but not for the visual search tasks used by May et al. (2013). When comparing a child's performance to age expectations, and between developmental groups (TD vs. ASD), standardised measures are particularly informative.

Keen et al. (2016) reviewed studies of maths and reading achievement with 5–16 year olds with ASD and reported strengths and weaknesses across specific domains of ability alongside vast heterogeneity. This demonstrates the importance of considering within-syndrome differences in ASD, rather than focusing only at the group level. At the group level, reading achievement was in the average range for children with higher general intelligence (IQ of 80 or above), but was highly variable; some individuals showed weaknesses in reading, while others performed within the "gifted" range. Children with lower IQ (< 80) had a relative strength in basic reading ability in relation to their IQ, but struggled with reading comprehension. The discrepancy between word reading and reading comprehension has also been observed elsewhere (Huemer & Mann, 2010; Jones et al., 2009; Kim et al., 2018; Nation, Clarke, Wright, & Williams, 2006) and suggests that the ability to infer meaning from text passages is particularly difficult for this group (e.g. even when word recognition is 'typical'). Given that cognitive factors such as attention are strong predictors of reading and maths achievement in TD (Lan et al., 2011; Steele et al., 2012) it is possible that attention difficulties have implications for this skill in ASD.

There is mixed evidence regarding maths ability in children with ASD. While a number of studies have found that children with an ASD have less proficient maths ability than TD children (Estes, Rivera, Bryan, Cali, & Dawson, 2011; Jones et al., 2009; Troyb et al., 2014), others have found maths ability is comparable to, or better than, TD children (Brosnan et al., 2016; Iuculano et al., 2014). Keen et al. (2016) reviewed the literature and concluded that mean maths performance was generally within the average or below-average range, although there is vast heterogeneity. As with reading achievement, it is important to investigate factors that may underlie discrepancies of maths skill. If the factors that influence achievement in children with ASD can be identified, they can inform intervention development to support children with particular difficulties in reading or maths.

The first aim of the current study was to use standardised measures of attention and academic achievement to investigate the relationship between reading and maths achievement and attention skills for children with ASD. Based on the multi-computational model of attention, sustained, selective, and executive attention were the three theoretically derived attentional processes of interest. It was important to use a standardised attention measure that provided scores for these subtypes of attention, and that was appropriate for use with autistic children. The Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999) has previously been used with autistic children and provides subtests for individual attentional processes (Harper-Hill, Copland, & Arnott, 2014; Kenworthy, Black, Harrison, Rosa, & Wallace, 2009). Although various sub-tests tapping executive attention exist within the TEA-Ch, the divided attention task was chosen alongside sustained and selective attention tasks as it reflects the division of attention between auditory and visual domains that children experience while learning in the classroom (e.g. listening to the teacher while looking at their work). Divided attention has been found to be atypical in both adults and children with autism (Boxhoorn et al., 2018; Casey et al., 1993), reflecting similar findings in the literature regarding atypicalities in executive attention.

To measure reading and maths achievement, the WIAT-II was chosen for two reasons. First, this measure has been used with children with ASD (May, Rinehart, Wilding, & Cornish, 2015; May et al., 2013; Mayes & Calhoun, 2007), therefore it was appropriate for use with the current sample. Secondly, it provides composite scores of academic outcomes that are calculated based on two (maths) or three (reading) subtests, allowing for an in-depth examination of abilities both within and between academic domains. Importantly, previous research on this topic has only used individual subtests of the WIAT-II as measures of reading and maths achievement, which do not provide a full assessment of ability within the domains of interest.

Due to the ambiguity of the findings from existing studies that have investigated relationships between sustained attention, selective attention and academic achievement in children with ASD, the investigations related to these measures were exploratory. Research suggests that higher order executive attention skills (e.g. attention switching) are predictive of maths achievement in ASD (May et al., 2013), therefore it was predicted that divided attention would be related to maths achievement.

The existing literature acknowledges the heterogeneity of academic achievement in ASD (Keen et al., 2016; Kim et al., 2018), but does not consider the context of outcomes for individuals with ASD when looking transdiagnostically (i.e. alongside TD individuals). It is important to consider whether or not these profiles are unique to ASD, therefore the second aim of this study was to investigate profiles of attention and achievement broadly across TD children and children with ASD using cluster analysis. The purpose was to discover meaningful subgroups based on achievement and attention abilities that may exist within the ASD population, but also look transdiagnostically (i.e. both TD and ASD) to examine the variance within the sample as a whole, and to understand where children

Table 1
Descriptive statistics for cognitive measures.

	TD children (N = 59)				Children with ASD (N = 22)				Group differences	Effect size
	M	SD	Min	Max	M	SD	Min	Max	t	d
Age (years)	9	1.22	6.92	11.25	11.1	2.81	6.08	16	−4.7***	.96
FSIQ-4	98.28	12.07	75	129	91.09	14.82	64	127	2.24*	.53
Reading achievement	102.74	12.66	71	132	88.45	20.67	43	148	3.76***	.83
Maths achievement	104.36	15.76	74	145	82.77	25.11	42	142	4.62***	1.03
Selective attention	6.95	2.51	1	12	5.64	3.08	1	11	1.97	.47
Sustained attention	9.07	3.27	2	15	8.18	3.43	1	15	1.07	.27
Divided attention	7.36	3.68	1	15	3.95	4.28	1	17	3.53***	.85

* $p < .05$, *** $p < .001$.

with ASD fall. This analysis was exploratory, however distinct subgroups were expected to emerge that were not solely driven by ASD diagnosis.

2. Method

2.1. Participants

Presence or absence of ASD diagnosis was confirmed by parent report for both groups of children. All children, with or without ASD, who had a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), confirmed by parent report, were not eligible to participate due to the focus on attention in the current study. Cognitive ability inclusion criteria for TD children dictated that those with potential learning difficulties (i.e. score of 70 FSIQ or below) were not eligible to take part. Due to the known heterogeneity of cognitive ability in the ASD population, no children from the ASD sample were excluded on the basis of cognitive ability. Means and range of cognitive ability can be found in Table 1.

A total of 59 TD children and 27 children with ASD were recruited to the study. TD children were recruited from mainstream schools or through a database of families signed up to be contacted about research, run by the developmental psychology group at Durham University. Children with ASD were recruited from i) mainstream schools with Special Educational Needs (SEN) provision, ii) SEN or ASD specialised schools, iii) the Autism Spectrum Disorder-UK database (ASD-UK), and iv) the families database. For all recruitment through schools, schools who agreed to take part distributed recruitment packs (i.e. information sheets, consent forms) to parents of children at the school who were eligible to take part. Parents who consented returned their consent forms. For all other methods of recruitment, parents were contacted directly, either by the researchers or by ASD-UK. Parents provided informed consent and children provided assent prior to participation.

Five children with ASD (18 %) could not complete the divided attention subtest, and four of these children could also not complete the sustained attention subtest (15 %). Non-completion was due to difficulties understanding instructions or task requirements. The final sample was therefore comprised of 59 TD children (32 males), ranging from 6 years 11 months to 11 years 3 months ($M = 9$ years, $SD = 1.22$), and 22 children with ASD (18 males), ranging in age from 6 years 1 month to 16 years 0 months ($M = 11.1$ years, $SD = 2.81$). The age range of children with an ASD was larger due to the heterogeneity of cognitive ability in this sample.

2.2. Materials

2.2.1. Measures of attention

Three attention measures were obtained using subtests of the Test of Everyday Attention for Children (TEA-Ch; Manly et al., 1999), which is suitable for children aged $6-16$ years. Scores on each subtest were standardised based on age and gender. Scaled scores within one standard deviation ($SD = 3$) of 10 indicated performance in the average range (12th to 87th percentiles). The authors report that test-retest reliability for each subtest is good (all r's $> .7$).

Selective attention was measured using the Sky Search subtest; a pen and paper visual search task in which children must circle matching pairs of spaceships among distractors. The overall time taken and number of targets correctly identified were used to determine a "time-per-target" score, from which the motor control time-per-target score was removed.

To measure sustained attention, the "Score!" subtest was administered. This involved a 10-trial counting task in which the participant listened to a series of identical tones (9–15 tones per trial) and was asked to silently count the number of tones. The number of correct trials provided a measure of ability to sustain attention over time.

The Sky Search Dual Task subtest was used to measure divided attention. This assessment combines the Sky Search and Score! subtests, making this a dual task, as participants must complete both tasks at the same time. To obtain an overall score for divided attention, scores from both dual task components and from the single task Sky Search were used. The dual task Sky Search time-per-target score was divided by the proportion of counting items correct (total items correct/total items attempted), and the raw time-per-target from the single task Sky Search was then subtracted from this value. This provided a divided attention score based on the

discrepancy between single-task and dual-task visual search performance.

2.2.2. Measures of academic achievement

Measures of reading and maths achievement were obtained using the Wechsler Individual Achievement Test, Second Edition (WIAT-II; Wechsler, 2005), which can be administered with children aged 4 years to 16 years 11 months. Normed scores were calculated for each child based on their age at time of testing, for both individual sub-tests and composite scores of reading and maths. According to the author, the WIAT-II has strong inter-item consistency within subtests (Cronbach's alpha > .8), and has good test-retest reliability (all *r's* > .85). The reading achievement composite score was calculated using scores on three sub-tests: Word Reading (WR), Reading Comprehension (RC), and Pseudoword Decoding (PD). The maths achievement composite score was calculated based on two subtest scores: Numerical Operations (NO) and Mathematical Reasoning (MR).

2.2.3. Cognitive ability

The Wechsler Abbreviated Scale of Intelligence, Second Edition (WASI-II; Wechsler, 2011), suitable for individuals aged 6–90 years, was used to obtain an estimate of full-scale intelligence (FSIQ-4). This measure includes four subtests focusing on vocabulary and non-verbal reasoning. This measure has good test-retest reliability for child samples ($r = .96$) and the FSIQ-4 scores from this measure correlate with the Wechsler Intelligence Scale for Children – Fifth Addition (WISC-V; Wechsler, 2014), $r = .87$ (Raiford, Zhou, & Drozdick, 2016) indicating good concurrent validity.

2.3. Procedure

Testing was conducted individually either in a quiet room at the child's school, their home, or at Durham University. Testing occurred across four sessions, each lasting approximately 30 min. In the first session, participants completed the WASI-II. The WIAT-II was completed across the second and third sessions, and the TEA-Ch was completed in the final session. Testing sessions took place on different days to ensure children remained focused during each assessment. All children completed the assessment battery within a three-week period.

3. Results

Within-group analyses were conducted using age-standardised scores for each measure, therefore age differences were accounted for in the analyses.

3.1. Descriptive statistics and correlations

3.1.1. Group profiles

As a group, TD children performed as expected across the majority of measures (Table 1). Reading achievement, maths achievement, and FSIQ standardised scores fell within the average range (i.e. 70–130). Sustained attention group performance was average, and selective and divided attention scores were within one standard deviation of the norm.

Autistic children were significantly older than the TD children (Table 1), with a wider age range. In terms of cognitive and academic performance, children with ASD scored lower on almost all measures; they had significantly lower IQ and poorer reading and maths achievement, although performance was still within one standard deviation of age norms for reading. TD children had significantly higher divided attention scores than children with ASD; however the groups did not differ on sustained or selective attention.

3.1.2. Correlational analyses

Two-tailed correlations were conducted between the standardised measures. For TD children (Table 2), IQ was significantly positively related to reading achievement and maths achievement, but not to any of the attention measures. None of the attention scores were significantly correlated with the achievement measures, although the relationship between divided attention and reading approached significance, $r (59) = .212$, $p = .053$.

Table 2
Correlation matrix for TD sample (N = 59).

	1	2	3	4	5
FSIQ					
Reading achievement	.510***				
Maths achievement	.609***	.647***			
Selective attention	.089	−.099	.063		
Sustained attention	.106	.216	.199	−.187	
Divided attention	.213	.212	.003	−.088	.092

*** p < .001.

Table 3

Correlation matrix for ASD sample (N = 22).

	1	2	3	4	5
FSIQ					
Reading achievement	.796***				
Maths achievement	.795***	.799***			
Selective attention	.186	.187	.271		
Sustained attention	.368	.286	.319	.290	
Divided attention	.537**	.591**	.729***	.461*	.221

*p < .05, ** p < .01, *** p < .001.

For autistic children (Table 3), IQ was significantly positively related to reading and maths achievement. IQ was not significantly related to either selective or sustained attention; however, it was strongly positively related to divided attention. Divided attention was also related to reading and maths achievement, in that autistic children with better divided attention ability had higher reading and maths scores. As maths, reading, and divided attention were all significantly correlated with IQ, there was a possibility that IQ was driving these relationships, therefore the correlations were re-run controlling for IQ. The relationship between divided attention and maths achievement remained significant, r (19) = .589, p = .005, however the relationship between divided attention and reading achievement was no longer significant, r (19) = .320, p = .158. Selective and sustained attention were not significantly related to achievement measures.

3.2. Transdiagnostic clustering

3.2.1. Hierarchical cluster analysis

As previous analyses showed that divided attention was significantly related to reading and maths achievement for autistic children, and approached significance for TD children, this measure of attention was entered into the cluster analysis alongside reading and maths achievement composites. All children who completed the divided attention measure were included in the analysis (N = 81). Hierarchical cluster analysis identified profiles of children according to their reading, maths and divided attention scores. This analysis method combines cases into homogenous clusters in sequential steps; at each step the squared Euclidean distance between two cases or clusters is compared, and cases or clusters with the smallest distance are merged into a single cluster. Average-linkage criterion was used, therefore, at each step, the distance between every case in the first cluster and every case in the second cluster was calculated and averaged, before being compared to one another.

A three-cluster solution was determined, and the characteristics of each cluster are shown in Table 4. Profiles A, B and C characterised 6.2 %, 70.4 % and 23.5 % of the sample, respectively. The "good-attention-higher-achieving" profile (A) characterised children whose IQ, reading achievement and divided attention scores were 1 SD above average (i.e. 100), and whose maths achievement was 2 SDs above average. The "average-attention-average-achieving" profile (B) characterised children whose IQ, reading and maths achievement scores were at average. Their divided attention was slightly below average, but still within 1 SD. The "poor-attention-lower-achieving" profile (C) characterised children whose reading achievement was 1 SD below average, and maths achievement was almost 2 SDs below average.

In terms of ratio between TD and ASD children in each profile, ASD children comprised 20 % of profile A (N = 1), 10.5 % of profile B (N = 6), and 78.9 % of profile C (N = 15). Children with ASD were therefore present in all profile groups, but were more dominant in the "poor-attention-low-achievers" group. This emphasises the heterogeneity in attention and achievement between children with ASD.

3.2.2. Within-cluster achievement profiles

Also of interest were the achievement profiles within the three sub-groups of children. Within profiles A and B, reading and maths achievement scores did not differ (A: t (4) = 2.2, p = .09, d = .79; B: t (56) = .83, p = .41, d = .12). For profile C, maths achievement was significantly lower than reading achievement (t (18) = 2.71, p = .01, d = .54). To investigate this further, the deviance of maths achievement from IQ was examined. The purpose was to determine whether maths achievement scores were different from what should be expected based on IQ, and whether this varied between profile groups. Fig. 1 displays the mean

Table 4

Descriptive statistics for IQ, achievement, and divided attention by cluster.

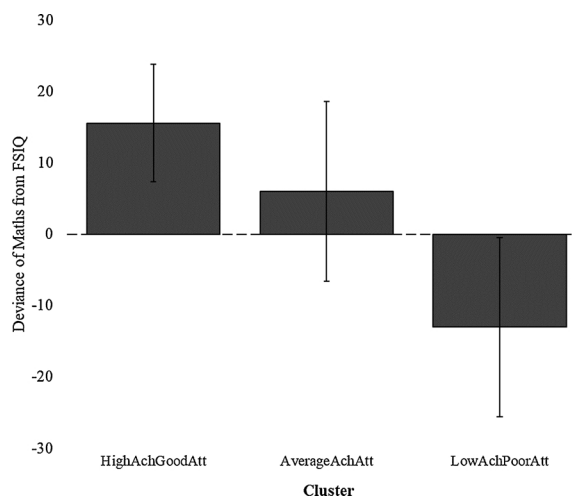|	A: Good attention higher achieving (N = 5) M (SD)	B: Average attention, average achieving (N = 57) M (SD)	C: Poor attention, lower achieving (N = 19) M (SD)
FSIQ-4	120.8 (6.65)	97.49 (10.48)	86.42 (12.09)
Reading	128.4 (12.3)	102.09 (11.17)	81.42 (13.36)
Maths	136.4 (7.47)	103.53 (13.14)	73.42 (16.04)
Divided attention	13.4 (2.7)	7.42 (3.16)	1.63 (1.38)

Fig. 1. Deviation of maths achievement score from FSIQ by cluster.

deviance of maths achievement score from FSIQ score for each profile group. For every group, maths achievement significantly deviated from what we would expect based on FSIQ. For the "good-attention-high-achievers", maths achievement was significantly higher than FSIQ (t (4) = 4.25, p = .013, d = 2.21), and this pattern was the same for the "average-attention-average-achievers" (t (56) = 3.61, p = .001, d = .51). However, for the "poor-attention-low-achievers" group, maths achievement was much lower than FSIQ (t (18) = 4.51, p < .001, d = .92).

4. Discussion

Overall, the current study has investigated the role of attention in academic achievement for children with and without ASD. Examination of relationships between academic achievement and components of attention suggest that divided attention is related to both maths and reading in ASD. The cluster analysis reinforced the finding that divided attention is important for maths achievement, in that it characterised three distinct subgroups of children, who showed either strengths or weaknesses in maths achievement (compared to their IQ), based on whether their divided attention was above, at, or below average. The exploratory cluster analysis demonstrated the importance of considering children with an ASD not only within-syndrome, but also transdiagnostically.

4.1. Attentional characteristics of children with ASD

Sustained attention was similar in TD and ASD, supporting previous findings that sustained attention ability is more typical in autistic children than other components of attention (Garretson et al., 1990; May et al., 2013). Selective attention was also similar across groups, which was somewhat unexpected as previous studies have suggested difficulties with orienting attention in ASD (Dawson et al., 1998; Mutreja et al., 2015). This discrepancy could be due to the nature of the visual search task used. Renner et al. (2006) investigated the atypicalities of orienting in autism in detail and found that while endogenous (i.e. controlled) orienting in ASD was comparable to TD children, exogenous (i.e. automatic) orienting was poorer, suggesting atypicalities in the automatic orienting of attention. It may be the case that when an autistic individual knows what information they are looking for, they can find this amongst distractors, while they have difficulty orienting their attention when the appropriate target is not explicit. The task used in the current study tapped controlled orienting, in that children were explicitly told what to search for (i.e. pairs of spaceships in a visual array), which may explain why the performance of autistic children was comparable to the TD children.

When comparing divided attention between groups, autistic children scored lower on average than TD children. This supports previous studies that have found divided attention to be atypical in children with an ASD (Boxhoorn et al., 2018). As this divided attention task recruits a higher-order attentional component to manage attention across two modalities, arguably this reflects executive attention ability, which has also been previously reported as atypical in autistic children (Mayes & Calhoun, 2007).

4.2. Attention and academic achievement in ASD

As predicted, children who were better able to divide their attention between auditory and visual tasks had higher maths achievement scores. The current study also found that divided attention was related to reading achievement, although when IQ was

controlled for, the relationship between these measures was no longer significant. This supports May et al. (2013) who found that executive attention was not related to reading achievement. Neither sustained nor selective attention were related to achievement measures; therefore, divided attention appears more relevant for achievement in this sample.

4.3. Cluster analysis

Three distinct subgroups of children emerged from the transdiagnostic cluster analysis and these groups were characterised by children with good, average, and poor divided attention and academic achievement respectively. Children who had average or above average attention and achievement scores displayed a relative strength in maths, compared to their IQ. Conversely, children who had poorer divided attention and achievement scores had a discrepancy in their maths achievement, relative to their IQ and their reading achievement. The difference between subgroups suggests that divided attention plays a role in maths ability; not only is it clear that divided attention plays a role in characterising children who have a relative weakness in maths, but also those for whom maths is a relative strength. Being able to divide attention between two modalities supports skills relevant for maths achievement, and maths ability may be impacted for children whose divided attention skill is weaker.

One important and interesting finding was that although most of the children with an ASD fell into the "poor-attention-low-achievers" subgroup, there was evidence of heterogeneity (evidenced by the distribution of children across all three clusters). This finding also demonstrates that the subgroups were not defined by ASD diagnosis. This has important implications for the way in which data are analysed; looking within- and between-groups that are defined by ASD diagnosis does not capture a complete picture and de-emphasises the heterogeneity of ASD (Charman, 2015). Accounting for autism heterogeneity in research does present significant challenges, however, future research should consider using data analysis techniques that investigate abilities and behaviours of children transdiagnostically in order to understand the wider autism phenotype and the role of attention.

Mean IQ differed significantly between the three cluster subgroups, and it is likely that it plays a role in the patterns reported. Indeed, IQ is known to be a strong predictor of academic achievement (Eaves & Ho, 1997), however this is not always the case for autistic children (Kim et al., 2018). Lower achieving children with poor attention demonstrated a discrepancy in their maths achievement relative to their IQ that was not observed in the other two subgroups; in fact, children in each of the other subgroups had a relative strength in maths relative to their IQ. Furthermore, the correlation between maths achievement and divided attention in the ASD group was significant, even when controlling for IQ. In addition, IQ and divided attention were not significantly related in typical development. As a consequence, IQ cannot solely explain the differences in these groups, and the findings suggest that divided attention played a role in defining these subgroups.

4.4. Limitations

One limitation of the current study is the small sample size of both groups, particularly the ASD group. Undoubtedly the small sample size of the ASD group is problematic for capturing within-syndrome variability in ASD. One approach taken within this study that attempted to recognise heterogeneity was the use of a transdiagnostic cluster analysis. Conducting cluster analysis with small samples is not ideal. However, this transdiagnostic approach to analysing the data was exploratory and not intended to be used to make broad claims; rather, the purpose was to investigate whether children within each diagnostic group clustered together or were distributed across different clusters. In this sense, the aim was achieved and has highlighted the importance of considering cognition in autism transdiagnostically.

4.5. Conclusions

Examination of academic achievement profiles between subgroups of children with and without ASD suggested that divided attention plays an important role in maths achievement. The study makes a novel addition to the literature with findings suggesting that these profiles may be characterised in part by divided attention ability. The exploratory cluster analysis demonstrated the importance of considering the variability between children with ASD. The results raise important issues for educational interventions, suggesting that targeting divided attention abilities in cognitive training sessions may positively affect reading and maths achievement. Indeed, cognitive training can be successful in improving attention (Tullo, Guy, Faubert, & Bertone, 2018) and therefore future research could consider whether an improvement in attention is also related to an improvement in maths and reading achievement.

Ethical approval

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

Informed consent

Informed consent was obtained for all participants included in the study.

Funding

Declaration of Competing Interest

The authors report no declarations of interest.

References

Allen, G., & Courchesne, E. (2001). Attention function and dysfunction in autism. *Frontiers in Bioscience, 6*, 105–119.

Ames, C., & Fletcher-Watson, S. (2010). A review of methods in the study of attention in autism. *Developmental Review, 30*, 52–73.

Boxhoorn, S., Lopez, E., Schmidt, C., Schulze, D., Hanig, S., & Freitag, C. M. (2018). Attention profiles in autism spectrum disorder and subtypes of attention-deficit/hyperactivity disorder. *European Child & Adolescent Psychiatry, 27*, 1433–1447.

Brosnan, M., Johnson, H., Grawemeyer, B., Chapman, E., Antoniadou, K., & Hollinworth, M. (2016). Deficits in metacognitive monitoring in mathematics assessments in learners with autism spectrum disorder. *Autism, 20*(4), 463–472.

Bury, S. M., Jellett, R., Spoor, J. R., & Hedley, D. (2020). "It defines who I am" or "it's something I have": What language do [autistic] Australian adults [on the autism spectrum] prefer? *Journal of Autism and Developmental Disorders.* https://doi.org/10.1007/s10803-020-04425-3.

Casey, B. J., Gordon, C. T., Mannheim, G. B., & Rumsey, J. M. (1993). Dysfunctional attention in autistic savants. *Journal of Clinical and Experimental Neuropsychology, 15*(6), 933–946.

Charman, T. (2015). Variability in neuro-developmental disorders: Evidence from autism spectrum disorders. In J. Van Herwgen, & D. Riby (Eds.). *Neurodevelopmental disorders: Research challenges and solutions* (pp. 117–140). London: Psychology Press.

Colom, R., Escorial, S., Shih, P. C., & Privado, J. (2007). Fluid intelligence, memory span, and temperament difficulties predict academic performance of young adolescents. *Personality and Individual Differences, 42*, 1503–1514.

Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders, 28*(6), 479–485.

Eaves, L. C., & Ho, H. H. (1997). School placement and academic achievement in children with autistic spectrum disorders. *Journal of Developmental and Physical Disabilities, 9*, 277–291.

Erickson, L. C., Thiessen, E. D., Godwin, K. E., Dickerson, J. P., & Fisher, A. V. (2015). Endogenously and exogenously driven selective sustained attention: Contributions to learning in kindergarten children. *Journal of Experimental Child Psychology, 138*, 126–134.

Estes, A., Rivera, V., Bryan, M., Cali, P., & Dawson, G. (2011). Discrepancies between academic achievement and intellectual ability in higher-functioning school-aged children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 41*, 1044–1052.

Garretson, H. B., Fein, D., & Waterhouse, L. (1990). Sustained attention in children with autism. *Journal of Autism and Developmental Disorders, 20*(1), 101–114.

Gordon, M. (1983). *The gordon diagnostic system.* DeWitt, NY: Gordon Systems.

Harper-Hill, K., Copland, D., & Arnott, W. (2014). Efficiency of lexical access in children with autism spectrum disorders: does modality matter? *Journal of Autism and Developmental Disorders, 44*, 1819–1832.

Huemer, S. V., & Mann, V. (2010). A comprehensive profile of decoding and comprehension in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 40*, 485–493.

Iuculano, T., Rosenberg-Lee, M., Supekar, K., Lynch, C. J., Khouzam, A., Phillips, J., et al. (2014). Brain organization underlying superior mathematical abilities in children with autism. *Biological Psychiatry, 75*, 223–230.

Jones, C. R. G., Happé, F., Golden, H., Marsden, A. J. S., Tregay, J., Simonoff, E., et al. (2009). Reading and arithmetic in adolescents with autism spectrum disorders: Peaks and dips in attainment. *Neuropsychology, 23*(6), 718–728.

Keehn, B., Lincoln, A. J., Muller, R., & Townsend, J. (2010). Attentional networks in children and adolescents with autism spectrum disorder. *Journal of Child Psychology and Psychiatry, 51*, 1251–1259.

Keen, D., Webster, A., & Ridley, G. (2016). How well are children with autism spectrum disorder doing academically at school? An overview of the literature. *Autism, 20*(3), 276–294.

Kenny, L., Hattersley, C., Molins, B., Buckley, C., Povey, C., & Pellicano, E. (2016). Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism, 20*(4), 442–462.

Kenworthy, L., Black, D. O., Harrison, B., Rosa, A., & Wallace, G. L. (2009). Are executive control functions related to autism symptoms in high-functioning children? *Child Neuropsychology, 15*, 425–440.

Kim, S. H., Bal, H., & Lord, C. (2018). Longitudinal follow-up of academic achievement in children with autism from age 2 to 18. *Journal of Child Psychology and Psychiatry, 59*(3), 258–267.

Lan, X., Legare, C. H., Ponitz, C. C., Li, S., & Morrison, F. J. (2011). Investigating the links between the subcomponents of executive function and academic achievement: A cross-cultural analysis of Chinese and American pre-schoolers. *Journal of Experimental Child Psychology, 108*, 677–692.

Manly, T., Robertson, I., Anderson, V., & Nimmo-Smith, I. (1999). *The test of everyday attention for children.* London: Thames Valley Test Company.

May, T., Rinehart, N., Wilding, J., & Cornish, K. (2013). The role of attention in the academic attainment of children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 43*, 2147–2158.

May, T., Rinehart, N., Wilding, J., & Cornish, K. (2015). Attention and basic literacy and numeracy in children with autism spectrum disorder: A one-year follow-up study. *Research in Autism Spectrum Disorders, 9*, 193–201.

Mayes, S. D., & Calhoun, S. L. (2007). Learning, attention, writing, and processing speed in typical children and children with ADHD, autism, anxiety, depression, and oppositional-defiant disorder. *Child Neuropsychology, 13*(6), 469–493.

McClelland, M. M., Acock, A. C., Piccinin, A., Rhea, S. A., & Stallings, M. C. (2013). Relations between preschool attention span-persistence and age 25 educational outcomes. *Early Childhood Research Quarterly, 28*, 314–324.

Miller, M., Iosif, A., Young, G. S., Hill, M., Hanzel, E. P., Hutman, T., et al. (2016). School-age outcomes of infants at risk for autism spectrum disorder. *Autism Research, 9*(6), 632–642.

Mutreja, R., Craig, C., & O'Boyle, M. W. (2016). Attentional network deficits in children with autism spectrum disorder. *Developmental Neurorehabilitation, 19*, 389–397.

Nation, K., Clarke, P., Wright, B., & Williams, C. (2006). Patterns of reading ability in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 36*, 911–919.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73–89.

Pham, A. V. (2016). Differentiating behavioural ratings of inattention, impulsivity, and hyperactivity in children: Effects on reading achievement. *Journal of Attention Disorders, 20*(8), 674–683.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25–42.

Psychological Corporation (1992). *Wechsler individual achievement test manual.* San Antonio, TX: Psychological Corporation.

Psychological Corporation (2002). *Wechsler individual achievement test second edition examiner's manual.* San Antonio, TX: Psychological Corporation.

Raiford, S. E., Zhou, X., & Drozdick, L. W. (2016). *Using the WASI-II with the WISC-V*(Report #3). Pearson.

Razza, R. A., Martin, A., & Brooks-Gunn, J. (2012). The implications of early attentional regulation for school success among low-income children. *Journal of Applied Developmental Psychology, 33*, 311–319.

Renner, P., Grofer Klinger, L., & Klinger, M. R. (2006). Exogenous and endogenous attention orienting in autism spectrum disorders. *Child Neuropsychology, 12*, 361–382.

Steele, A., Karmiloff-Smith, A., Cornish, K., & Scerif, G. (2012). The multiple subfunctions of attention: Differential developmental gateways to literacy and numeracy. *Child Development, 83*(6), 2028–2041.

Troyb, E., Orinstein, A., Tyson, K., Helt, M., Eigsti, I. M., Stevens, M., et al. (2014). Academic abilities in children and adolescents with a history of autism spectrum disorders who have achieved optimal outcomes. *Autism, 18*(3), 233–243.

Tullo, D., Guy, J., Faubert, J., & Bertone, A. (2018). Training with a three-dimensional multiple object-tracking (3D-MOT) paradigm improves attention in students with an neurodevelopmental condition: A randomized controlled trial. *Developmental Science, 30*, Article e12670. https://doi.org/10.1111/desc.12670.

Wechsler, D. (2005). *Wechsler individual achievement test 2nd edition (WIAT II)*. London: The Psychological Corp.

Wechsler, D. (2011). *Wechsler abbreviated scale of intelligence* (2nd ed.). San Antonio, TX: Psychological Corporation.

Wechsler, D. (2014). *Wechsler intelligence scale for children* (5th ed.). Bloomington, MN: Pearson.