Reading and Arithmetic in Adolescents with Autism Spectrum Disorders: Peaks and Dips in Attainment

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Abstract

In describing academic attainment in autism spectrum disorders (ASD), results are typically reported at the group mean level. This may mask subgroups of individuals for whom academic achievement is incommensurate with intellectual ability. The authors tested the IQ, literacy, and mathematical abilities of a large group (*N* = 100) of adolescents (14–16 years old) with ASD. Seventy-three percent of the sample had at least one area of literacy or mathematical achievement that was highly discrepant (approximately 14 standard score points) from full-scale IQ (FSIQ). The authors focused on four subgroups with either word reading ("Reading Peak" and "Reading Dip") or arithmetic ("Arithmetic Peak" and "Arithmetic Dip") higher or lower than FSIQ. These subgroups were largely mutually exclusive and were characterized by distinct intellectual profiles. The largest was the "Arithmetic Peak" subgroup of participants, who presented with average intellectual ability alongside superior arithmetic skills and who were predominantly in a mainstream educational setting. Overall, the most pervasive profile was discrepantly poor reading comprehension, which associated with severity of social and communication difficulties. The high rate of uneven academic attainment in ASD has implications for educational practice.

Keywords: Autism spectrum disorders, arithmetic, reading, literacy, attainment

Reading and Arithmetic in Adolescents with Autism Spectrum Disorders: Peaks and Dips in Attainment

Individuals with autism spectrum disorders (ASD; the common clinical term for autism, atypical autism and Asperger syndrome; World Health Organization [WHO] International Classification of Diseases [ICD-10, 1993] and American Psychiatric Association [APA] Diagnostic and Statistical Manual *DSM–IV–TR*, 2000; classification systems) can struggle in educational settings due to difficulties engaging with the classroom environment. Such challenges are precipitated by the complex interplay of the cardinal symptoms of ASD: social and communication difficulties and rigid and repetitive thinking and behavior. However, an additional reason for barriers to learning or reaching full potential may be an unusual academic profile that masks or is masked by discrepant general intellectual ability.

Investigation of academic achievement in ASD, specifically word reading and arithmetic, suggests that at the group mean level these abilities are commensurate with IQ (e.g., Goldstein, Minshew & Siegel, 1994; Mayes & Calhoun et al., 2003a,b; Mayes & Calhoun et al., 2008; Minshew, Goldstein, Taylor, & Siegel, 1994). However, whereas there is evidence of basic word reading skills aligning with intellectual level (e.g., Griswold, Barnhill, Myles, Hagiwara, & Simpson, 2002; Mayes & Calhoun, 2008), there is also suggestion that they may exceed intellectual expectation in low functioning individuals with ASD (Mayes & Calhoun, 2003a,b).

The cognitive heterogeneity in ASD means that describing the population at the group mean level can mask subgroups of individuals whose academic achievements are not congruent with their general intellectual functioning. Within the ASD literature, one such subgroup that has been described are individuals with hyperlexia (e.g., Grigorenko, Klin, & Volkmar, 2003). This term, introduced by Silberberg and Silberberg (1967), describes a very small percentage of children with word recognition skills that are elevated compared to reading comprehension and general intellectual functioning. Other features include precocious development of reading and an obsessive interest in words (Needleman, 1982), although there is some contention regarding how hyperlexia is defined (e.g., Grigorenko et al., 2003; Nation, 1999). Although we are not aware of any report of the prevalence of hyperlexia in the general population, prevalence among individuals with ASD has been reported at 6.6%, using criteria including early onset reading in the presence of marked intellectual impairment (Burd, Kerbeshian, & Fisher, 1985), but as high as 20.7% within a clinically referred sample of children with ASD, primarily using discrepancy scores between word reading and intellectual ability (Grigorenko et al., 2002). Thus, there is evidence to suggest that individuals with exceptional and isolated basic reading skills form part of the heterogeneous academic profile in ASD.

Displaying almost the opposite profile are dyslexic individuals who have below average word reading skills despite average or high IQ. This disorder is considered to occur in approximately 10%–15% of children in the general population (see Vellutino, Fletcher, Snowling, & Scanlon, 2004 for a review) and is clinically recognized ("reading disorder" [*DSM–IV–TR*, 2000] and "specific reading disorder"; [ICD-10, 1993]). However, the coincidence of specific reading difficulties and ASD is not known.

When arithmetical ability dips significantly below intellectual functioning an individual is defined as having dyscalculia, also known as "mathematics disorder"

(*DSM–IV–TR*, 2000) or ‘specific disorder of arithmetical skills’ (ICD-10, 1993). Dyscalculia has been reported at a prevalence of between 3% and 6% in the general population (see Shalev, Aurbach, Manor, & Gross-Tsur, 2000 for a review). In a review of mathematical ability in ASD, Chiang and Lin (2007) reported that performance on the WISC arithmetic subtest is significantly lower than for the mean of other WISC subtests, albeit not at a clinically meaningful level (Chiang & Lin, 2007). Mayes and Calhoun (2003a) reported that 22% of high functioning individuals with ASD have a specific learning disability in arithmetic.

At the opposite end of the scale, hypercalculia refers to exceptional arithmetic skills in relation to intellectual ability. This concept is little discussed and is not formally defined although has been used in reference to an autistic savant with prodigious mental calculation abilities (González-Garrido, Ruiz-Sandoval, Gómez-Velázquez & Villaseñor-Cabrera, 2002). However, numeracy-related savant skills appear dissociated from general arithmetical ability, with an autistic savant with calendar calculation skills (Thioux, Stark, Klaiman & Schultz, 2006) and another with lightening mental calculation skills (González-Garrido et al., 2002) both having Wechsler Arithmetic subtest scores more than one standard deviation below the mean. Although Chiang and Lin (2007) draw attention to individuals on the autism spectrum who demonstrate exceptional arithmetical ability, it is unknown whether this ability exceeds or reflects general intelligence. Of note, most previous studies have not presented separate data on arithmetic and broader mathematical skills. In keeping with existing definitions of hyperlexia, dyslexia and dyscalculia, we use the term hypercalculia to refer to individuals whose scholastic arithmetical ability exceeds general intellectual functioning.

By focusing on group mean scores, previous research has largely overlooked individual differences across the academic profile in ASD. No study has systematically explored the number of individuals with exceptionally strong or poor reading or arithmetic skills compared to general intellectual ability, across the full measurable range of intellectual function. To this end, we assess the IQ, reading and arithmetic abilities within a large cohort of 100 adolescents with ASD. Using standardized norms to define discrepancies between full scale IQ and reading and arithmetic attainment that fall in the top and bottom 10% of performers, we calculate the number of individuals with ASD with both exceptional (*Reading Peak* and *Arithmetic Peak* subgroups) and poor (*Reading Dip* and *Arithmetic Dip* subgroups) attainment compared to general intellectual level. We also investigate other aspects of literacy and mathematics, namely spelling, reading comprehension, single word reading efficiency and phonemic decoding efficiency, and mathematical reasoning. Given the debate surrounding the validity of IQ-discrepancy models for capturing learning disabilities (e.g., Kavale, 2005), we purposefully do not assign diagnostic labels to the subgroups we identify. Thus, our focus is on identifying comparable cognitive profiles and not on the detection of learning disabilities. Further, by using a psychometric rather than diagnostic approach to investigating learning impairments and strengths, we are able to more directly compare the relative sizes and intellectual profiles of these extreme subgroups. We aim to (i) establish an estimate of the frequency of specific attainment dips and peaks within the ASD population, and (ii) report the profile of intellectual ability of individuals with specific peaks or dips in their attainment profile.

Method

Participants

One hundred adolescents with an ASD were recruited from the Special Needs and Autism Project cohort (SNAP; Baird et al., 2006). For this cohort, consensus clinical ICD-10 diagnoses were made using information from the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) and Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al., 2000) as well as IQ, language, and adaptive behavior measures. For a subsample of cases agreement on diagnosis was checked against a panel of international experts and was found to be high (see Baird et al., 2006 for details). Ninety-one male and 9 female participants were tested, with 54 reaching criteria for childhood autism and 46 reaching criteria for broader ASD. The sample had a mean age of 15 years 6 months (*SD* _ 6 months; range 14 years 8 months–16 years 9 months) at their first assessment and a mean WASI Full Scale IQ (FSIQ) of 84.3 (*SD* = 18.0; range 50–119). Fifty-seven of the cohort attended mainstream schools, while the remaining 43 attended schools for pupils with special educational needs (8 of the 43 were at a residential school). The study was approved by the South East Research Ethics Committee (05/MRE01/ 67), and informed consent was obtained from all participants.

Measures

The following tests were administered to participants:

IQ. The Wechsler Abbreviated Scale of Intelligence (WASI^U.K.^: Wechsler, 1999) was used to measure IQ. The WASI is a shortened intelligence test comprising components from both the Wechsler Intelligence Scale for Children (WISC–III: Wechsler, Golombok,

& Rust, 1992) and Wechsler Adult Intelligence Scale (WAIS-III: Wechsler, 1997). It consists of four subtests, two that tap verbal IQ (Vocabulary and Similarities) and two that tap performance IQ (Block Design and Matrix Reasoning). Vocabulary required the participant to verbally define orally and visually presented words, while Similarities necessitated an explanation of the similarity between two orally presented word pairs. Block Design required the participant to recreate two-dimensional geometric patterns using a set of two-color cubes within a time limit, while Matrix Reasoning involved completion of a gridded pattern by choosing between five different options.

Reading. The Wechsler Objective Reading Dimensions (WORD[U.K].K.: Rust, Golombok, & Trickey, 1993) consists of three subtests. For Basic Reading, participants read a list of progressively more difficult words, testing for single word reading ability. For Spelling, the requirement was to write down the spellings of dictated words. For Reading Comprehension, the participants were asked to read written passages then answer verbally presented questions that tap their understanding of the text. The Test of Word Reading Efficiency (TOWRE: Torgesen, Wagner, & Rashotte, 1997) comprises two subtests. For Sight Word Efficiency, participants were asked to read correctly as many words as possible from a list within a 45-s time limit. This tests speeded reading of real single words. For Phonemic Decoding Efficiency, participants were required to read aloud as many nonwords as possible from a list within a 45-s time limit. This tests phonemic abilities at speed.

Arithmetic. The Wechsler Objective Numerical Dimensions (WOND[U.K] U.K.: Rust, 1996) comprises two subtests. For Mathematics Reasoning, participants were presented with pictures or written passages, which are also read aloud by the examiner, that define a mathematical problem. The problem is solved using mathematical reasoning, with the questions designed to tap areas of mathematics that include problem solving, numeration and number concepts, graphs and statistics, geometry and measurement. Many of the problems were embedded in everyday context or included extraneous detail. For Numerical Operations, a pen and paper test of computational problems (e.g., addition, subtraction, multiplication, division and algebra) was presented.

Procedure

For each individual, assessment occurred over 2 days and the tasks were interspersed with other tests. The average lag between the two testing sessions was 34 days (*SD* = 38 days, range 1–259 days). The WASI and TOWRE typically occurred on the first day and the WORD and WOND typically occurred on the second day. The order of testing on both days was pseudorandomized. All tests are directly comparable to each other, having been normed in the general population to have a mean of 100 and a *SD* of 15.

Discrepancy Groupings

To ensure our discrepancy subgroups were confined to sufficiently atypical individuals, we considered as noteworthy a discrepancy between WOND/WORD standard scores and WASI FSIQ that was in the 10th percentile of the normed population in either direction i.e. WOND/WORD > FSIQ and WOND/WORD < FSIQ. Full scale IQ is the most widely recommended metric for identifying learning disabilities (WOND manual, p. 68) and by using a measure that includes both verbal and performance expertise, attainment is being compared to the broadest ‘composite’ measure of intellectual ability. Further, full scale IQ has been shown be a strong predictor of literacy and arithmetical achievement (Mayes & Calhoun, 2008). This approach also avoids potential issues and confounds such as the stronger correlation between verbal intelligence and literacy than between nonverbal intelligence and literacy (see Bishop & Snowling, 2004).

The WORD (p. 135, table C.9) and the WOND (p. 114, table C.5) manuals give the ability-achievement discrepancies between standard scores and WISC-III FSIQ for performance in the 10^{th} percentile where WORD/WOND ability is *lower* than FSIQ i.e. where achievement 'dips' below ability. Specifically, the cut off points were discrepancy scores of 14 for Basic Reading (i.e. a Basic Reading standard score 14 points or more lower than FSIQ), 16 for Spelling and 13 for Reading Comprehension on the WORD. For the WOND the cut off points for discrepancy scores were 12 points for Mathematics Reasoning and 15 for Numerical Operations. These discrepancy scores reach statistical significance criteria ($p < .05$), although the discrepancy score is only on the cusp of significance for Reading Comprehension (see WORD p. 135, table C.8 and WOND p. 113, table C.4). In the absence of any published data for normed discrepancies where WORD/WOND ability is *higher* than FSIQ, we used the same discrepancy cutoffs to define our 'peak' subgroup (i.e. a Basic Reading standard score 14 points or more greater than FSIQ and so on). We made the assumption that, given a normal distribution, these 10^{th} percentile ability-achievement discrepancies would be equivalent. Minshew, Turner and Goldstein (2005) found that the WASI had a strong association with the longer forms of the Wechsler tests when used with individuals with ASD. Further, Wechsler (1999) reports that the mean IQ scores of the WASI and WISC-III are "nearly equivalent" (p. 135), thus the substitution of the WASI for the WISC-III was deemed acceptable.

We used the discrepancy between Basic Reading and FSIQ to identify individuals with a Reading Peak and a Reading Dip and.the discrepancy between Numerical Operations and FSIQ to identify individuals with an Arithmetic Peak and Arithmetic Dip. Distinction is made between arithmetic ability, which is the most elementary form of mathematics and specifically refers to mastery of the four basic operations (addition, subtraction, division and multiplication) and associated number facts, and mathematic ability, which engages conceptual and higher-order understanding of mathematical relations including geometry, algebra and calculus. Numerical Operations primarily taps arithmetic ability, whilst the Mathematics Reasoning subtest assesses broader mathematical understanding, hence we selected the Numerical Operations subtest to define our arithmetic subgroups.

Notably, we avoid labelling these subgroups as hyperlexic, dyslexic, hypercalculaic and dyscalculaic. As mentioned in the Introduction, this is partly because the use of IQ-achievement discrepancy criteria for defining learning disabilities is problematic but also because the adolescents were not formally clinically assessed for the degree of clinical impairment that is required to satisfy diagnostic criteria for dyslexia and dyscalculia (DSM-IV, 2000; ICD-10, 1993). Additionally, there are issues of the contentious (hyperlexia) or underspecified (hypercalculia) nature of some of the definitions. Further, we were keen to take a more psychometric and comparative approach than that afforded by the varied diagnostic criteria of the clinical terms. This comparative approach is also sympathetic to the suggestion that genes for mathematics and reading disability are at the extreme of the same genetic and environmental factors that explain typical variation in learning abilities (Plomin & Kovas, 2005). For these reasons, we assigned the more neutral descriptive labels of 'Reading Peak', 'Reading Dip', 'Arithmetic Peak' and 'Arithmetic Dip.

Results

Group Profile

A small number of participants were not administered all tasks, due to either their age surpassing the boundary for standard score allocation, the examiner not having time to administer the task, or the adolescent being unable to perform the task. The descriptive statistics for the subtests of the standardised tasks are shown in Table 1, alongside the exact number of participants who completed each task.

The mean scores across the group indicate similar performance across most of the subtests. The majority of means fall in the low average range (using Wechsler criteria for qualitative interpretation of scores, see Wechsler, 1999, p. 156). The average performance IQ (M = 90.4; SD = 18.6) was the highest score across the tests and was significantly higher than the average verbal IQ (M = 80.8; SD = 18.0), $t(99) = -6.32$, $p < .001$. The lowest score was Reading Comprehension (M = 76.3; SD = 19.1), which was significantly lower than FSIQ, $t(97) = -6.73$, $p < .001$ and both the Basic Reading, $t(97) = 7.42$, $p < 0.001$ and Spelling, $t(97) = 5.09$, $p < .001$ subtests of the WORD. For the TOWRE, four adolescents had Sight Word Efficiency scores that were too low to obtain standard scores, and fell in the '<55' bracket. In addition, ten adolescents had Phonemic Decoding Efficiency scores that were '< 55' (N.B. two individuals were < 55 in both subtests, thus twelve participants were affected). One participant had a raw score for Sight Word Efficiency that was too high to obtain a standard score (>118). These cases falling outside of the standard score allocation were not included in the TOWRE summary statistics. In addition, the Sight Word Efficiency subtest could not be successfully attempted by two individuals and the Phonemic Decoding Efficiency subtest could not be successfully attempted by four individuals. As the bias is towards removing those at low end of the spectrum, the TOWRE scores in Table 1 slightly overestimate the ability level of the group.

Table 1 about here

Table 2 shows the number of participants allocated to each discrepancy subgroup for each subtest. For almost every subtest there were small groups of adolescents who either performed much better or much worse than would be predicted by FSIQ. In total, 72 adolescents (72.7%) fell into at least one of the discrepant subgroups. Of note, 37.8% (37 adolescents) of the sample showed a dip in Reading Comprehension ability compared to FSIQ. Table 2 also indicates the division of autism and broader ASD diagnoses across the discrepancy groupings. Using Chi-square analysis, we established that the distribution of individuals across the three categories (academic achievement above, below or commensurate with FSIQ) did not significantly differ by diagnosis for any of the five tests of achievement ($p > .1$). Consequently, we do not distinguish the cohort by diagnosis in any further analysis or discussion.

For the Reading and Arithmetic subgroups, which were our particular focus, 14.1% (14 adolescents) of the sample showed a Reading Peak and 10.1% (10 adolescents) showed a Reading Dip. 16.2% (16 adolescents) of the sample showed an Arithmetic Peak whilst 6.1% (6 adolescents) of the sample showed an Arithmetic Dip.

Overall, 42.4% (42 adolescents) fell into one of these four discrepancy subgroups. The subgroups were largely mutually exclusive, with only four individuals falling into more than one subgroup (2 in the Reading Peak and Arithmetic Peak subgroups; 1 in the Reading Dip and Arithmetic Dip subgroups; 1 in the Reading Dip and Arithmetic Peak subgroups).

Table 2 about here

Reading Peak and Dip

In Table 3, the descriptive statistics for the reading subtests and FSIQ are ordered by discrepancy grouping (i.e. Reading Peak, where Basic Reading was discrepantly higher than FISQ, a flat profile subgroup that showed no significant discrepancy and Reading Dip, where Basic Reading was discrepantly lower than FSIQ). The mean Basic Reading ability of the adolescents with a Reading Peak was in the average range (M = 94.7, SD = 11.2), whilst FSIQ (M = 74.0, SD = 12.5) was below average and considered borderline according to Wechsler classification (only two individuals had a FSIQ above 85, i.e. within 1 SD of the mean). The difference between the two mean scores was approximately 21 points. None of the cases who were excluded from the TOWRE for having standard scores that were too low to be categorised were in this subgroup. Unlike the pattern of results for the whole group, there was no significant difference between Performance IQ and Verbal IQ (*t* test, $p > .3$). The Reading Dip subgroup had below average ('extremely low', according to Wechsler classification) Basic Reading (M = 66.7, SD = 15.8) and also below average Spelling and Reading Comprehension, yet a mean FSIQ (M = 88.4, SD = 15.0) at the low average level (one individual had a FSIQ below 85). The difference between the mean Basic Reading and FSIQ scores was approximately 22 points. Performance IQ was significantly higher than verbal IQ, $t(9) = -2.52$, $p = .03$. The subgroup with a flat profile had a mean Basic Reading (M = 86.0, SD = 20.4) and FSIQ (M = 85.7, SD = 18.9) in the low average range, but below average Reading Comprehension (M = 76.4, SD = 19.8), reflecting the overall pattern for the whole sample. T tests were used to confirm that the Reading Peak subgroup had a lower full scale IQ than those without a significant Peak or Dip (i.e. the flat profile subgroup), $t(25.6) = -2.9$, $p = .007$. The intellectual ability of the Reading Dip subgroup did not differ from the flat profile subgroup ($p > .6$).

Individuals with exceptional word reading compared to IQ are also hypothesised to have elevated reading skills compared to reading comprehension. We confirmed this by finding significantly higher Basic Reading than Reading Comprehension in the Reading Peak subgroup, $t(13) = 6.03$, $p < .001$. This pattern was also true for the flat profile subgroup, $t(73) = 7.64$, $p < .001$, although not for the Reading Dip subgroup ($p > .2$).

Table 3 about here

Arithmetic Peak and Dip

In Table 4, the descriptive statistics for the arithmetic subtests and FSIQ are ordered by discrepancy grouping (i.e. Arithmetic Peak, where Numerical Operations was discrepantly higher than FISQ, a flat profile subgroup that showed no significant discrepancy and Arithmetic Dip, where Numerical Operations was discrepantly lower than FSIQ). The Arithmetic Peak subgroup had superior range Numerical Operation skills (M = 120.4, SD = 10.0), with average range FSIQ (M = 96.9, SD = 11.5) that was elevated compared to the overall sample. The difference between the two mean scores was approximately 24 points. 14 out of the 16 adolescents in this subgroup had a FSIQ equal to or above 85. Performance IQ was significantly higher than verbal IQ, $t(15) = -3.84$, $p = .002$. Of note, 13 of the 16 adolescents were attending a mainstream school, which equates to 23.2% of the 56 individuals who attended mainstream schools and who completed the WOND. The Arithmetic Dip had below average (borderline) Numerical Operations skills (M = 77.8, SD = 9.2), with average IQ (M = 96.3, SD = 9.9) that was again elevated compared to the overall sample. The difference between the two mean scores was approximately 19 points. 5 of the 6 adolescents in this subgroup had a FSIQ above 85. Performance IQ was higher than Verbal IQ by almost 22 points, but just failed to reach statistical significance, $t(5) = -2.36$, $p = .06$. We attribute this to the small n and because one member of the subgroup showed the opposite pattern of VIQ>PIQ. The flat profile subgroup had below average Numerical Operations (M = 79.4, SD = 20.7) and low average FSIQ (M = 80.7, SD = 18.3) scores. T tests were used to confirm that both the Arithmetic Peak ($t(33.0) = 4.55$, $p < .001$) and Arithmetic Dip ($t(7.80) = 3.43$, $p = .009$) subgroups had significantly higher full scale IQs than the remaining individuals without a significant Peak or Dip (i.e. the flat profile subgroup).

Given the limited previous comparative investigation of arithmetic and broader mathematics, we statistically contrasted the scores on these subtests. For the Arithmetic Peak subgroup, the mean score for Mathematics Reasoning was significantly lower than that of Numerical Operations, $t(15) = -3.21$, $p = .006$, but did not differ in the Arithmetic Dip ($p > .2$) or flat profile subgroup ($p > .4$).

A summary of the intellectual profiles of the four subgroups can be found in Table 5.

Table 4 and Table 5 about here

Reading comprehension

Due to the large number of individuals with a dip in Reading Comprehension compared to FSIQ, we investigated this subgroup further (see Table 6). The 37 individuals had a mean full scale IQ of 87.7 (*SD* = 19.8), performance IQ of 97.5 (*SD* = 20.1), and verbal IQ of 79.8 (*SD* = 20.0). The difference in performance and verbal IQ met statistical significance, $t(36) = -6.95$, $p = .001$. The mean Reading Comprehension score was below average (extremely low) at 67.8 (*SD* = 19.7) and considerably lower than the other literacy measures of Basic Reading (*M* = 83.5; *SD* = 24.0) and Spelling (*M* = 84.8; *SD* = 24.8). The difference between the mean Reading Comprehension score and mean FSIQ was approximately 20 points. Four of the subgroup showed concomitant "dip" performance for both Basic Reading and Spelling, a further two individuals showed a dip for Spelling and one individual showed a dip for Basic Reading. For the remaining 26 individuals, this was an isolated deficit within the reading domain. Compared to those with a dip in Reading Comprehension, the 60 individuals with a flat profile had a mean full scale IQ of 82.3 (*SD* = 17.1), performance IQ of 86.2 (*SD* = 16.8), and verbal

IQ of 81.3 (*SD*=17.3). The mean Reading Comprehension score was in the low average range at 81.3 (*SD* = 17.0), as were the Basic Reading (*M*=86.2; *SD*=17.8) and Spelling (*M*=83.6; *SD*=20.6) subtest scores. There was no significant difference in the mean FSIQ of the two subgroups ($p > .2$). Thus, those with a dip in Reading Comprehension have a more discrepant performance versus verbal IQ profile than those without, and do not show the same degree of deficit in other areas of reading. The one individual with a peak in Reading Comprehension had a full scale IQ of 78, performance IQ of 77 and verbal IQ of 85. All WORD reading measures were in the average range (Reading comprehension = 92; Basic Reading = 93; Spelling = 101), with TOWRE sight word efficiency score of 81 and a TOWRE phonemic decoding score of 97.

Table 6 about here

Associations with social and communication impairments

To explore the possible association between ability-achievement discrepancy and the core behavioural features of ASD we used Pearson's r to correlate the discrepancy score (FSIQ – achievement subtest) with the ADOS social and communication algorithm score and the ADOS repetitive behaviour score for each achievement subtest. All participants were included in the analysis. No significant correlations (r -.081 to -.154; all $p > .1$) were found for the Basic Reading, Spelling, Numerical Operations or Mathematics Reasoning subtests. However, there was a significant association between the discrepancy between Reading Comprehension and FSIQ and the ADOS social and communication score ($r = .296$; $p = .003$), suggesting that reading comprehension falls increasingly below general intellectual ability in line with increasing social and communication impairments. There was no association between Reading Comprehension and repetitive behaviours ($r = .076$, $p > .4$).

Discussion

The heterogeneity of attainment in autism spectrum disorders (ASD) was explored, specifically testing for individuals across the range of intellectual ability with discrepant attainment-IQ profiles. From studying 100 adolescents with ASD, our data suggest that 72.7% have at least one area of literacy or mathematical achievement that is highly discrepant from their general intellectual ability. The specific intellectual and attainment profiles of these subgroups are discussed, alongside the educational implications of having an uneven profile.

General Profiles

Reflecting previous research (e.g. Griswold et al., 2002; Mayes & Calhoun, 2008), the results show that adolescents with ASD exhibit a wide range of aptitude on each test of attainment, from extremely low to superior range. Group mean scores do not show many specific patterns of high achievement or impairment, with most scores falling in the low average range. Again, this reflects previous work that has failed to show significant differences at the group mean level, across the spectrum of IQ, between intellectual skill and either arithmetical ability, basic word reading or spelling (e.g. Goldstein et al., 1994; Griswold et al., 2002; Mayes & Calhoun et al., 2003a,b; Mayes & Calhoun et al., 2008; Minshew et al., 1994).

This study attempted to go beyond description of group means to investigate individual differences and thus better capture the heterogeneity of academic achievement in ASD. Further, we chose a psychometric rather than diagnostic approach as it affords a more direct comparison of individuals at the extreme ends of different ability-attainment continuums. The ability-achievement literature does not have a 'gold standard' discrepancy criteria and the thresholds selected vary substantially (see Shalev et al., 2000 for examples). Our own criteria selects discrepancy only seen in 10% of individuals (at least where achievement is below ability) in the general population and, for the majority, meets statistical difference cutoffs[1]. Given that our sample of individuals with ASD is less intellectually able than the normal distribution as well as being of a narrower age-range (14-16 years compared to 6-16 years) than the standardisation sample used in the Wechsler manuals, we are unable to confidently extrapolate whether our distribution of discrepancies is significantly different to the norm. However, by using systematic and statistically substantiated criteria, we can be confident that we have identified individuals for whom intellectual ability and academic achievement are meaningfully statistically incommensurate and can directly compare occurrence across domains of achievement. Moreover, although the ability-achievement discrepancy cutoffs were around 14 standard score points, the actual mean ability-achievement differences across the subgroups that we focused on were in excess of this and varied between 19 and 24 standard score points. We suggest that the ability-achievement discrepancies we describe are likely to be clinically and functionally meaningful for the majority of individuals.

Our data suggest that around 7 in 10 adolescents with ASD have at least one area of significant strength or weakness in attainment, covering the core academic domains of reading, spelling, reading comprehension, arithmetic and broader mathematical skill. We placed particular emphasis on individuals with a significant discrepancy between full scale IQ and word reading (Reading Peak and Dip subgroups) or arithmetic (Arithmetic Peak and Dip subgroups), and found these individuals accounted for 42.4% of the sample. Driving our interest, these are two areas of attainment that speak to clinical phenomena (hyperlexia, dyslexia, hypercalculia and dyscalculia).

Reading Peak in adolescents with ASD

The mean intellectual level of the 14 individuals (14.1% of sample) in the Reading Peak subgroup was below average, which aligns with Mayes and Colhoun's (2003a,b) finding of elevated reading in school age children with ASD and of lower intellectual ability (FSIQ < 80) but not higher ability (FSIQ >= 80). Notably, the Reading Peak subgroup also show relatively elevated word reading (Sight Word Efficiency) and non-word reading (Phonemic Decoding Efficiency) on the TOWRE. This suggests that these individuals are appropriately proficient at phoneme-grapheme mapping and is congruent with the hypothesis that they read in the same way as individuals without facilitated reading. Similarly, commensurate non-word reading skills are often reported in hyperlexia (e.g. Newman et al., 2007).

The Reading Peak subgroup fit a hyperlexic profile by meeting criteria for discrepancy with respect to both IQ and reading comprehension (e.g. Grigorenko et al., 2003) and in being of below average intelligence (see Nation, 1999). However, our discrepancy cut-off approach is tailored to identifying individuals who would fall at the 10th percentile within the general population on one specific dimension. Some have argued that hyperlexia is a generic phenomenon, which occurs in the general population across the range of intellectual abilities and within the parameters of typical development. However, for many, true hyperlexia is a hallmark of atypical development and specific to those with a developmental disorder, or even a distinct syndrome in itself (see Grigorenko et al., 2003 and Nation, 1999 for discussion). Reflecting this, studies of 'hyperlexic' individuals usually include other defining criteria, namely early and spontaneous onset of reading and a compulsive interest in words and reading (e.g. Healy, 1982; Healy, Aram, Horwitz & Kessler, 1982; Goldberg & Rothermel, 1984; Sparks, 2001), which may or may not be part of the profile of our particular group seen in adolescence. Indeed, there may be a distinct developmental course to hyperlexia, with previous research indicating that, despite still reaching criteria for hyperlexia, the relatively exceptional word reading in hyperlexic individuals diminishes past the age of 10 as the result of a plateau or even decline in single word reading ability (Newman et al., 2007).

Reading Dip in adolescents with ASD

The 10.1% of individuals in the Reading Dip subgroup performed below the average on Basic Reading. This subgroup could be seen as fitting a 'dyslexic' profile, particularly as full scale IQ was within broadly average limits and phonemic decoding (TOWRE) was also poor (see Catts, Adlof, Hogan & Weismer, 2005), although there is debate concerning the validity of IQ-achievement discrepancy definitions of dyslexia (e.g. Vellutino et al. 2004). Previous studies have focussed on the double dissociation between dyslexic and autistic attainment profiles, with individuals with dyslexia showing reduced word reading and phonological processing and individuals with ASD exhibiting difficulties with reading comprehension and verbal problem solving (Frith & Snowling, 1983; Rumsey & Hamburger, 1990). As far as we are aware, this is the first study to comprehensively explore whether specific reading difficulties are apparent in ASD. Of note, five of the ten individuals in the Reading Dip subgroup have both significantly poorer basic reading *and* significantly poorer reading comprehension compared to general intellectual ability.

Arithmetic Peak in adolescents with ASD

The Arithmetic Peak subgroup included 16.2% of the sample and was the largest of the four subgroups. 13 of the 16 attend mainstream schools, which accounts for 23% of the 56 individuals who took part in the study and who are in a mainstream education setting. We therefore suggest a particular need for awareness of isolated exceptional arithmetical skills amongst young people with ASD who are accessing a mainstream education. These individuals are characterised by average intelligence and superior arithmetic ability, alongside significantly stronger performance than verbal skills. Of relevance, autistic traits are self-reported more amongst scientists than non scientists and mathematicians report significantly more of these traits than other scientists (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001). As an explanation for this, Baron-Cohen's (2002) extreme male brain theory of autism has suggested superior 'systemising' in ASD (Baron-Cohen, 2006). Systemising involves detecting laws to predict events, which lends itself much better to rule-based areas, such as maths and science. When considering these hypotheses, it could be expected that a larger proportion of individuals with ASD than within the population-at-large would demonstrate a 'peak' skill of arithmetical ability.

The Arithmetic Peak subgroup performed within the high average range on Mathematics Reasoning. However, this is significantly lower than their superior arithmetical ability. This suggests that the arithmetic skill in the Arithmetic Peak subgroup is not as equally matched in the broader mathematical domain, where the approach is more linguistic, varied and conceptually demanding. Further, it is a discrepancy that is not apparent in the other subgroups.

Arithmetic Dip in adolescents with ASD

The Arithmetic Dip subgroup is the smallest of the four groups and accounts for 6.1% of the sample. These individuals perform within the average range intellectually, at a similar level to their peers in the Arithmetic Peak subgroup, but are below average at arithmetic. There was no significant difference between their poor arithmetical skill and their performance on the broader test of mathematical reasoning, although the mean Mathematics Reasoning score fell into the higher clinical category of 'low average'.

That this type of profile is the smallest subgroup is potentially important in understanding susceptibility vs. protection to unusual academic profiles in ASD. Combined with the relatively large size of the Arithmetic Peak subgroup this further confirms that arithmetical ability is an area of strength for individuals with an ASD. The finding is notably different to Mayes and Calhoun's (2003a) report of 22% of individuals with ASD having a specific learning difficulty in arithmetic. However, a longer form of the Wechsler intelligence test (WISC) was used as well as different criteria for discrepant performance (predicted difference method). Further, the group with ASD all had FSIQ equal to or greater than 80 and the age range was broader (6-15 years), all of which make a direct comparison difficult.

Differences between reading and arithmetic profiles

One of the most striking findings is that the four attainment profile types are largely mutually exclusive. Further, the subgroups generally exhibit a high degree of consistency of intellectual and academic profiles across individuals, which gives confidence to interpretation. The Reading Peak subgroup is the most different of the four, being defined by a below average intellectual ability, which is significantly lower than those without a reading discrepancy, and by equivalent performance and verbal skills. The other three subgroups all reflect the overall sample by showing significantly greater performance than verbal ability. However, whilst the intellectual ability of the Reading Dip subgroup is not significantly different to the overall sample, both of the Arithmetic subgroups show a mean intellectual level that is within the average range and significantly higher than those who do not fall into the arithmetic discrepancy subgroups. The qualitative difference in intellectual ability across the subgroups may simply reflect the nature of the skills being measured and the subsidiary skills that they rely upon. For example, fluent reading is the norm for adolescents, meaning that strong word reading skills are more closely associated with a strong vocabulary in brighter adolescents. Further, perhaps a minimum level of proficiency in the essential 'building blocks' for successful arithmetic, including attention and working memory (e.g. Berg, 2008), is necessary to exhibit arithmetical skill above a certain level. The specific patterns of the degree of intellectual skill across subgroups might also reflect the distribution of both ability and achievement in the general population. We argue that the augmented intellectual ability of the Arithmetic Dip subgroup may reflect that the probability of an ability-achievement discrepancy, where the academic achievement is below intellectual level, increases as a function of increased IQ (see Dyck et al., 2004). The Reading Dip subgroup also shows increased FSIQ compared to those with a flat profile, although not at a statistically significant level. In having a significantly lower FSIQ than their contemporaries with a flat profile, the Reading Peak subgroup aligns with the reverse of this theory (i.e. as IQ decreases the chance of displaying a significantly enhanced academic ability increases). Notably, in demonstrating a significantly higher FSIQ, the Arithmetic Peak subgroup goes against the predictions of probability. Despite a lack of association between arithmetical skill and social and communication symptoms, this lends confidence to our assertion that the Arithmetic Peak subgroup captures a real phenomenon within ASD, perhaps driven by a particular cognitive style (e.g. Baron-Cohen, 2006).

Poor reading comprehension associates with ASD symptoms

Reading Comprehension is distinct from the other areas of attainment in being significantly lower than FSIQ at the group mean level. This reflects previous studies (e.g. Frith & Snowling, 1983; Minshew et al., 1994; Nation, Clarke, Wright & Williams, 2006) although is not a universal finding (e.g. Griswold et al., 2002; Mayes & Calhoun, 2008). Notably, the Reading Comprehension Dip subgroup was by far the largest, accounting for over a third of the sample. Although this subgroup is at a similar level intellectually to the remainder of the sample, their relative strength in performance IQ is considerably larger than the performance IQ advantage observed in the remainder of the group. Further, we demonstrated that the more that reading comprehension skill fell below intellectual level, the greater the observed social and communication difficulties (ADOS). This significant correlation was not observed in any of the other discrepancies and, to our knowledge, has not previously been reported. Therefore, unlike the other ability-achievement discrepancies, which are more likely to have a co-incidental aetiology, this suggests that reading comprehension difficulties are associated with the cardinal impairments in social and communication understanding that characterise children with ASD. Reading comprehension difficulties have previously been associated with oral language difficulties, including language comprehension (e.g. Catts, Adlof & Weismer, 2006; Nation, Clarke, Marshall & Durand, 2004; Nation et al., 2006); our finding suggests that they may also reflect broader difficulties in social and linguistic understanding. In summary, a relative difficulty in reading comprehension is not only the most prevalent ability-achievement discrepancy in ASD but also the most relevant to diagnosis.

Implications and Conclusions

The results of this study highlight the importance of comparing *relative* performance within individuals rather than just focussing on group means. We have identified that around 72.7% of 14-16 year olds on the autism spectrum have at least one ability-achievement discrepancy across five areas of academic achievement. Further research is needed to establish the corresponding prevalence for the general population. This heterogeneity of academic strengths and weaknesses in ASD is of relevance to educational and clinical psychologists and teachers. It suggests the need for vigilance for individuals whose islets of ability or difficulty may mask their true intellectual level (leading to over- or under-expectation) or remain undiscovered. This is particularly pertinent in ASD, where primary social and communication difficulties are an obvious explanation for difficult classroom behaviours that may, in fact, have a more specific and academic route (see Charman, Hood & Howlin, 2008; for relevant case examples).

Further, consideration needs to be given to the educational implications for those who have a ‘double hit’ of an autism spectrum disorder and a specific learning disability, with recognition of the separable ways in which these can be targeted. Building on recognised strengths could benefit individuals, particularly those adolescents who show enhanced arithmetic skills and arguably have the potential (see Kovas, Petrill & Plomin, 2007) for augmenting their broader mathematical skills.

The present study examined adolescents with ASD at a particular developmental time point, further research would benefit from exploring peaks and dips in ability earlier in childhood. Related to this, evidence that the Reading and Arithmetic subgroups are largely mutually exclusive suggests scope for exploring the contributing cognitive and behavioural factors that influence the development and expression of specific skills and deficits in academic ability.

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Footnotes

1. If we have tapped true psychometric phenomena then the profiles of the subgroups found at the 10th percentile should be broadly similar (albeit relatively smaller or larger in size) at lower and higher cutoffs. To this end, we also investigated the 5th and 15th percentile subgroups (contact T Charman for data). The pattern of results reported for the 10th percentile cutoffs is broadly consistent with results for the 5th and 15th percentiles, in terms of both the intellectual profiles and relative sizes across the subgroups.

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Table 1

Descriptive statistics for the WASI, TOWRE, WORD and WOND subtest standard scores

	Mean	SD	Range	N
WASI				
Verbal IQ	80.8	18.0	55 – 120	100
Performance IQ	90.4	18.6	53 – 126	100
Full Scale IQ	84.3	18.0	50 – 119	100
WORD				
Basic Reading	85.2	20.1	40 – 118	99
Spelling	84.1	22.1	45 – 126	99
Reading Comprehension	76.3	19.1	40 – 114	98
TOWRE				
Sight Word Efficiency	82.8	13.6	56 – 115	92
Phonemic Decoding Efficiency	85.6	16.5	56 – 126	83
WOND				
Numerical Operations	85.9	24.2	43 – 134	99
Mathematics Reasoning	84.0	22.7	44 – 130	99

Table 2

The number of cases with literacy (WORD) and mathematical (WOND) scores higher than, lower than or not different to full scale IQ, based on discrepancy criteria. Data for all cases presented, followed by division of cases into autism and broader ASD diagnoses.

	Higher than FSIQ (Peak)	Not different from FSIQ	Lower than FSIQ (Dip)	N
	All cases	All cases	All cases	
WORD				
Basic Reading	14	75	10	99
Spelling	13	70	16	99
Reading Comprehension	1	60	37	98
WOND				
Numerical Operations	16	77	6	99
Mathematics Reasoning	14	70	15	99
	Autism/ASD	Autism/ASD	Autism/ASD	
WORD				
Basic Reading	5/9	42/33	6/4	53/46
Spelling	6/7	36/34	11/5	53/46
Reading Comprehension	1/0	28/32	24/13	53/45
WOND				
Numerical Operations	11/5	38/39	4/2	53/46
Mathematics Reasoning	8/6	36/34	9/6	53/46

Table 3

Descriptive Statistics for IQ, WORD and TOWRE subtest standard scores for subgroups based on Basic Reading – FSIQ discrepancies

	Mean	SD	Range	N
	Reading Peak: Basic Reading higher than FSIQ			
WASI Full Scale IQ	74.0	12.5	54-95	14
WASI Verbal IQ	77.6	12.3	59-99	14
WASI Performance IQ	74.8	13.0	55-99	14
WORD Basic Reading	94.7	11.2	79-112	14
WORD Reading Comprehension	78.6	9.1	65-92	14
WORD Spelling	91.1	17.3	64-126	14
TOWRE Sight Word Efficiency	86.9	7.5	72-98	14
TOWRE Phonemic Decoding Efficiency	88.8	12.3	64-109	13
	Basic Reading not different from FSIQ			
WASI Full Scale IQ	85.7	18.9	50-119	75
WASI Verbal IQ	81.1	19.5	55-120	75
WASI Performance IQ	92.5	18.4	53-126	75
WORD Basic Reading	86.0	20.4	40-118	75
WORD Reading Comprehension	76.4	19.8	40-114	74
WORD Spelling	85.2	22.2	45-126	75
TOWRE Sight Word Efficiency	83.1	14.5	56-115	69
TOWRE Phonemic Decoding Efficiency	86.2	17.0	56-126	63
	Reading Dip: Basic Reading lower than FSIQ			
WASI Full Scale IQ	88.4	15.0	57-107	10
WASI Verbal IQ	82.8	15.0	60-116	10
WASI Performance IQ	96.3	17.9	58-116	10
WORD Basic Reading	66.7	15.8	42-93	10
WORD Reading Comprehension	72.0	24.1	40-104	10
WORD Spelling	65.8	18.7	51-114	10
TOWRE Sight Word Efficiency	74.3	11.2	57-90	8
TOWRE Phonemic Decoding Efficiency	70.8	13.7	57-97	6

Table 4

Descriptive Statistics for IQ and WOND subtest standard scores for subgroups based on Numerical Operations – FSIQ discrepancies

	Mean	SD	Range	N
	Arithmetic Peak: Numerical Operations higher than FSIQ			
WASI Full Scale IQ	96.9	11.5	77-113	16
WASI Verbal IQ	90.6	13.2	61-112	16
WASI Performance IQ	104.6	12.2	77-126	16
WOND Numerical Operations	120.4	10.0	100-134	16
WOND Mathematics Reasoning	111.3	10.1	95-129	16
	Numerical Operations not different from FSIQ			
WASI Full Scale IQ	80.7	18.3	50-119	77
WASI Verbal IQ	78.3	18.7	55-120	77
WASI Performance IQ	86.1	18.3	53-120	77
WOND Numerical Operations	79.4	20.7	43-126	77
WOND Mathematics Reasoning	78.6	21.2	44-130	77
	Arithmetic Dip: Numerical Operations lower than FSIQ			
WASI Full Scale IQ	96.3	9.9	77-104	6
WASI Verbal IQ	85.7	18.8	55-109	6
WASI Performance IQ	107.5	8.4	96-119	6
WOND Numerical Operations	77.8	9.2	61-88	6
WOND Mathematics Reasoning	81.5	10.6	62-91	6

Table 5

Summary of intellectual characteristics of the ability-achievement subgroups, using Wechsler classification labels for FSIQ and achievement

	Full scale IQ	Peak/Dip in attainment	VIQ/PIQ discrepancy
Reading Peak	Borderline	Average	Small
Reading Dip	Low average	Extremely low	Large (PIQ > VIQ)
Arithmetic Peak	Average	Superior	Large (PIQ > VIQ)
Arithmetic Dip	Average	Borderline	Large (PIQ > VIQ)

Table 6

Descriptive Statistics for IQ, WORD and TOWRE subtest standard scores for subgroups based on Reading Comprehension – FSIQ discrepancies

	Mean	SD	Range	N
	Reading Comprehension not different from FSIQ			
WASI Full Scale IQ	82.3	17.1	50-115	60
WASI Verbal IQ	81.3	17.3	55-120	60
WASI Performance IQ	86.2	16.8	53-117	60
WORD Reading Comprehension	81.3	17.0	40-114	60
WORD Basic Reading	86.2	17.8	41-115	60
WORD Spelling	83.6	20.6	45-126	60
TOWRE Sight Word Efficiency	82.4	12.8	56-115	59
TOWRE Phonemic Decoding Efficiency	83.4	16.9	56-124	54
	Reading Comprehension lower than FSIQ			
WASI Full Scale IQ	87.7	19.8	53-119	37
WASI Verbal IQ	79.8	20.0	55-118	37
WASI Performance IQ	97.5	20.1	57-126	37
WORD Reading Comprehension	67.8	19.7	40-104	37
WORD Basic Reading	83.5	23.9	40-118	37
WORD Spelling	84.8	24.3	40-126	37
TOWRE Sight Word Efficiency	84.4	15.5	57-113	30
TOWRE Phonemic Decoding Efficiency	89.5	15.7	57-126	26