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The relationship between Autism Spectrum Quotient (AQ) and uneven intellectual development in school-age children

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Abstract: Previous studies have found correlations between uneven intellectual development and autistic symptom severity but thus far each study has looked only at specific types of discrepancy score and results have been inconsistent. This study used the Autism Spectrum Quotient (AQ) and the British Ability Scales (second edition) to look for a correlation between autistic-like traits and an overall index of unevenness based on three types of discrepancy score, namely: discrepancies between IQ subscales; discrepancies between IQ domain scores; and, discrepancies between overall IQ and word-level literacy skills. The AQ scale was designed to measure autistic-like symptoms both in those with an Autism Spectrum Disorder and at all levels across the general population. The study sample was therefore not restricted to children with an ASD. The 106 school age participants had a mean IQ of 97 (SD 19.6) and a mean AQ (child version) score of 69.6 (SD 24.6). After controlling for IQ, each of the three intellectual discrepancy types accounted for unique variance in AQ with a large overall effect size. Functional Magnetic Resonance Imaging studies are recommended to examine how far uneven intellectual development may be an analogue for aberrant cortical connectivity.

Subjects: Behavioral Sciences; Child & Adolescent Psychiatry; Clinical Psychology; Clinical Neuropsychology

Keywords: Autism Spectrum Disorders; AQ; cognition; intelligence; reading; spelling; sub-clinical autistic traits

ABOUT THE AUTHORS

Richard Melling and Jeremy M. Swinson are currently associate educational psychologists with Local Authorities in the north-west of England. They have long-standing research interests in both child behaviour management and in literacy difficulties. Subclinical autistic-like traits and the prevalence of these vulnerabilities amongst referrals to Educational Psychology Services in UK school systems is currently their main focus. Richard has a particular interest in the relationship between autistic-like traits and both over-achievement in literacy ("hyperlexia") and underachievement with these skills ("dyslexia"). Jeremy has written extensively on teacher approaches to behaviour management in primary and secondary schools.

PUBLIC INTEREST STATEMENT

We are all better at some things than others, but extreme differences between different types of intellectual skill are very unusual. However, several studies have shown that a surprisingly large number of children with an Autism Spectrum Disorder demonstrate marked discrepancies between their abilities on verbal and non-verbal components of IQ tests. Some show much higher verbal intelligence, while others have much higher non-verbal ability. The project reported here looked at uneven intellectual development in school age children with and without Autism and found that very uneven intellectual ability of any sort was a good predictor of unusual social behaviour even in children who did not have an autistic condition. These findings support the emerging view that autistic-like vulnerabilities are not confined to those with a clinical condition, and also suggest that indicators of risk include marked specific talents or weaknesses in reading and spelling.

1. Introduction

In recent years it has seemed increasingly likely that the social communication deficits and inflexibility of behaviour that have defined the Autism Spectrum Disorder (ASD) also occur to varying degrees below the clinical range. That is to say, many adults and children who may be some way from meeting formal diagnostic criteria nevertheless display related behavioural traits and social skill deficits. Strong supporting evidence has emerged from the development of the Autism Quotient or "AQ" scale (Auyeung, Baron-Cohen, Wheelwright, & Allison, 2008; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) which has consistently shown a normal distribution of trait levels across both non-autistic and autistic samples, with no indication of bimodality. This absence of bimodality supports the concept of a single uninterrupted continuum covering both the general population and those with an autistic condition. The purpose of the study reported here was to explore how far the unevenness of intellectual development that has often been associated with autistic conditions might be correlated with AQ levels both inside and also well outside the clinical range. A large effect size would have potentially important implications. For clinicians it would imply that any significant unevenness across a child's intellectual abilities is very likely to be accompanied by at least some vulnerability to reduced social awareness, and from a theoretical perspective it would help to unify a number of previously disparate lines of enquiry relating to lower order cognitive skills in those with an autistic condition.

A particular pattern of intellectual unevenness that has long been associated with an ASD diagnosis is a tendency to demonstrate two opposite poles of performance on the Wechsler intelligence scales (Wechsler, 1991). These widely used IQ assessment instruments are administered in batteries of up to 15 subtests, 10 of which can be combined to provide a full-scale IQ assessment. Clusters of the same subtests are used to derive an overall Verbal ability score, and up to three categories of relatively Non-verbal ability, namely: a Perceptual Reasoning Index; a Working Memory Index; and, a Processing Speed Index. One particular Wechsler sub-test (the Comprehension task) involves responding to direct questions about the everyday world using 'common-sense' answers. For example, one question posed is, "Why do we turn out lights when we leave a room?" Another sub-test (Block Design) is a test of relatively non-verbal Perceptual Reasoning ability, requiring use of a set of small cubes to copy a two-dimensional abstract pattern as quickly as possible. On average, the Comprehension scale tends to be the most difficult for people considered to have an autistic condition, while the Block Design scale often proves to be the most straightforward, sometimes to a surprising degree in the context of the individual's overall IQ score. Siegel, Minshew, and Goldstein (1996) examined this phenomenon in 45 diagnosed children and 36 diagnosed adults, and found that Comprehension was the lowest scale score in 42% of the children and 33% of the adults, while Block Design was the highest in 38% of the children and 22% of the adults. These workers also located 14 previous studies of Wechsler scale performance in autism of which 13 reported Comprehension as being the lowest mean scale score for verbal tasks, while all 14 reported Block Design as being the highest mean scale score for relatively non-verbal tasks. However, as Siegel et al. point out, the magnitude of these score trends varied considerably from study to study, and in their own research only minorities of the participants showed either a personal performance peak on Block Design or a personal performance trough on Comprehension. It was therefore concluded that Wechsler IQ sub-test performance patterns in autism are essentially unpredictable at the individual level. While more recent studies examining relative strengths and weaknesses on Wechsler scales (Charman et al., 2011; de Bruin, Verheij, & Ferdinand, 2006; Mayes & Calhoun, 2003) have continued to find Comprehension troughs with relative strength on the Block Design scale, trough scores have not been confined to Comprehension, and Block Design advantages have not emerged in all samples.

An increased prevalence in ASD of large discrepancies between overall verbal ability (VIQ) and overall non-verbal ability (NVIQ) has also been identified. The work reported by Joseph, Tager-Flusberg and Lord (2002) created a watershed in studies of the relative strength of VIQ and NVIQ in ASD, as this was the first to examine the possibility that the condition is characterised by an increased likelihood of advantage in *either* direction (i.e. VIQ < NVIQ or vice versa) rather than simply by an increased presence of only one of the two discrepancy categories. In this study of 120 children diagnosed with ASD, significant discrepancies between VIQ and NVIQ occurred at approximately twice the rate found in the general population. For the subsample of 73 pre-school participants, the NVIQ > VIQ profile was by far the most common discrepancy, but with the 47 school age children advantages favoured VIQ and NVIQ with equal frequency. A subsequent study by Black, Wallace, Sokoloff and Kenworthy (2009) of school age children diagnosed with either ASD or Pervasive Developmental Disorder (n = 78) demonstrated a correlation of .34 (p < 0.01) between ASD social symptom measures and VIQ-NVIQ difference scores when no distinction was made regarding the direction of advantage.

The studies by Joseph et al. and by Black et al. focused only on the relationship between autism symptom severity and significant discrepancies in either direction between IQ domain scores. The authors of the present paper have been unable to locate any published work that has examined the relationship between autism symptom severity and non-specific unevenness of intellectual ability within the Verbal and Non-verbal domains (i.e. differences between component scales). However, support for the idea of an increased susceptibility in ASD to a generalised unevenness of intellectual development can be found in the work of Goldstein et al. (2008) who set out to examine the possibility that the factor structure of human intelligence may be atypical in Autism. A specific goal of the research was to test whether a unique "social context" factor might be present in children and adults diagnosed with ASD, but not in the general population. It was thought that if this proved to be the case, it may go some way towards explaining the reports of uneven cognitive development in ASD. The study examined Wechsler IQ test profiles in 137 children and 117 adults, all of whom had an autistic condition and an overall IQ score at or above 70. While no evidence was found of a social context factor unique to those with ASD, a generally reduced level of component test inter-correlation was reported. Of 55 test inter-correlations examined, 54 were lower in the overall sample (i.e. adults and children combined) than is found in the general population, with 25 of these differences reaching statistical significance (p < .05). A limitation of this study is that it was unable to show that reduced inter-correlations between tests is a phenomenon linked specifically to ASD. That is to say, until it is demonstrated that the overall level of intellectual unevenness correlates strongly with a measure of the intensity of autistic symptoms, it may be that increased unevenness of intellectual ability is simply a feature of any developmental disorder.

Overall it seems reasonable at present to conclude that the long-standing reports of uneven intellectual ability in autistic conditions are unlikely to be the result of an association with one specific cognitive profile. It would appear to be much more likely that the nature of any increased unevenness of development varies from case to case, arising from an as yet unexplained reduction in the influence of the intellectual '*g*' factor that is widely assumed to underpin the very strong inter-correlations between intellectual abilities present in the general population. Indeed, the authors' own clinical observations of children undergoing routine behavioural and educational assessment have created the impression that even autistic-like trait levels well below the level associated with Autism Spectrum diagnosis may also be associated with an increased unevenness of intellectual development. For these reasons, the research reported here hypothesised that all levels of AQ score in school age children (i.e. AQ below population average; AQ above population average; and, AQ scores within the clinical range) would show a strong correlation with an index of overall unevenness of intellectual ability. It should be noted that the correlational design was necessary to ensure that results in line with the hypothesis would demonstrate a specific link with autistic-like traits rather than with disorders and unusual behaviour traits of any sort.

To the best of the authors' knowledge no previous research has looked for a correlation between autistic symptom severity and an index of this type, and no previous study has looked at the possibility of a link between uneven intellectual development and AQ scores well outside the clinical range for ASD.

2. Methods

2.1. Participants

The 80 boys and 26 girls recruited to the study were children undergoing routine educational psychology assessment in connection with a range of school-related issues. Twenty-seven of the children were referred by their teachers in connection with concerns over behaviour at school, and a further 48 were described as underachieving in their academic work. The remaining 31 had a medical diagnosis of ASD and were undergoing educational assessment to support intervention planning. In total, 10 experienced educational psychologists (EPs) carried out the recruitment procedure in the course of their day to day professional practice. The mean age of the sample was 11.0 years (SD 2.6) with a mean IQ of 96.7 (SD 19.8). Autism Spectrum Quotient (AQ Child Version) ranged from 27 to 125 (maximum score possible = 141; group mean = 69.6; SD 24.6). AQ (Child Version) scores above 75 are very closely associated with clinical diagnosis of an Autism Spectrum condition (Auyeung et al., 2008). An AQ score of 76 is 3 points short of 2 standard deviations above the reference sample mean of 41.7 (SD 18.6). Further details of the AQ scale are provided below, in Section 2.2. In the present study 26 of the 31 children diagnosed with an autistic condition had AQ scores above 75. The remaining 5 had AQ scores in the range 64–74. The characteristics of the sample by referral category are presented in Table 1.

2.2. Instruments

2.2.1. British Ability Scales, second edition (BAS-II)

Intellectual abilities were measured using all six core scales of the BAS-II (Elliott, 1996) along with the Word Reading, Spelling and Numeracy scales that were co-normed with the core scales. A brief description of core scale content is provided in Table 2. The design of this instrument reflects current conceptions of the structure of intelligence and the scales have a well-established history in UK Educational Psychology practice (Hill, 2005). A total of four composite scores can be derived from the child's performance on the six core scales. These composite scores are: an overall General Conceptual Ability score (GCA) and separate scores for Verbal, Non-verbal Reasoning and Spatial Abilities. To assist with clarity and to be consistent with the large majority of studies describing standardised intellectual abilities this report refers to the composite abilities as IQ, Verbal IQ (VIQ) Non-verbal Reasoning IQ (NIQ) and Spatial IQ (SIQ), respectively. While the four BAS-II composite scores and both literacy scales were standardised to a mean of 100 (SD 15) the core scale outcomes are given as *T*-scores with a mean of 50 (SD 10).

Table 1. Characteristics of sample by referral category means

Referral category (*n*)	Number of girls in category	Age in years (SD)	AQ (autistic-like traits) (SD)	IQ (BAS) (SD)	Verbal score (VIQ) (SD)	Non-verbal reasoning score (NIQ) (SD)	Spatial ability score (SIQ) (SD)
ASD referrals (31)	4	12.5 (2.0)	93.5 (17.5)	92.0 (15.4)	92.4 (19.5)	94.4 (18.2)	93.2 (22.2)
Behaviour referrals (27)	6	10.4 (1.9)	66.9 (20.4)	97.9 (19.5)	97.3 (21.8)	103.1 (13.7)	94.4 (20.2)
Academic progress referrals (48)	16	10.4 (2.8)	55.7 (18.7)	99.1 (22.3)	101.3 (21.1)	99.1 (18.9)	97.3 (22.4)
Full sample (*N* = 106)	26	11.0 (2.6)	69.6 (24.6)	96.7 (19.8)	97.7 (21.0)	98.8 (17.6)	95.4 (21.7)

Table 2. Brief description of the six core scales of the BAS-II items by cognitive domain

Cognitive domain	Core scale	Task
Verbal	Word Definitions	Define given words to show accurate understanding
	Verbal Similarities	Identify how three given words are related in meaning
Non-verbal Reasoning	Matrices	Choose a design that completes a matrix of related designs
	Quantitative Reasoning	Identify sequential relations between shapes/numbers
Spatial	Pattern Construction	Arrange two-tone plastic cubes to copy 2-dimensional patterns. (Directly equivalent to the Block Design sub-test of Wechsler IQ batteries)
	Recall of Designs	Draw copies of geometric designs using short-term visual memory

2.2.2. The Autism Spectrum Quotient (AQ) scale (child version)

The AQ scale was designed specifically to identify the distribution of autistic-like traits across the population as a whole and has known psychometric properties following large-scale research (Auyeung et al., 2008; Baron-Cohen et al., 2001). Items were designed to reflect all three domains of the autistic triad as defined by DSM IV (American Psychiatric Association [APA], 1994). While the DSM 5 (APA, 2013) has subsequently provided amended guidelines for the formal diagnosis of autistic disability in those with severe trait levels, the fundamental nature of autistic conditions has not been redefined. The authors are not aware of any published concerns with regard to continued use of the AQ scale, which was constructed specifically for research and screening purposes, not for disability diagnosis. Adult respondents are required to self-report which of 50 characteristic behaviours apply to them by choosing one response category from the four options: Definitely Agree; Slightly Agree; Slightly Disagree; or, Definitely Disagree. The wording of the statements is counterbalanced so that agreement suggests the presence of an autistic-like trait in approximately half of the items. Statements in the social and communication domains where possible describe preferences rather than actual behaviour to reduce the likelihood of false negatives being reported. For example, “I prefer to do things with others rather than on my own” (AQ item 1); and, “I enjoy social chit-chat” (AQ item 17).

The AQ scale has been adapted to create both adolescent and child versions (Auyeung et al., 2008; Baron-Cohen, Hoekstra, Knickmeyer, & Wheelwright, 2006). For the first adaptation, 131 adolescents with an autistic diagnosis were compared with 50 controls on a rating scale very similar to that used in the adult version. Outcomes were in line with the findings from the earlier study of over 1,000 adults (Baron-Cohen et al., 2001) in that trait levels were approximately normally distributed across the non-autistic and autistic samples, with no indication of bimodality. To develop the version for children, Auyeung et al. asked parents to rate how far each statement applied to their 4–11 year-old child by choosing one of the four possible responses. The scoring scheme awarded between 0 and 3 points for each item response, with three points reflecting maximum indication of an autistic-like trait. An item analysis comparing outcomes from 1,225 non-ASD children with the results from another 540 who had been medically diagnosed with an ASD identified three items in which the non-ASD children were given higher ratings than the ASD group. The authors concluded that these particular items may be difficult to assess in younger children and therefore omitted them from further analysis. Based on the remaining 47 items, the highest possible AQ score for an individual child is 141, with 0 being the lowest possible overall rating. For the sample of 1,225 children with no history of ASD the mean AQ score was 41.7 (boys: 45.7; girls: 37.7) with only 4% scoring at or above a total rating of 76. In contrast, 95% of the sample of 540 children with a medical diagnosis of ASD scored at or above AQ 76. Again, overall scoring patterns appeared to be consistent with a normal distribution curve across both autistic and non-autistic participants with no evidence of bimodality. Scores in the reference samples of children showed no correlation with age, and in a smaller sample of 89 children AQ did not correlate with IQ as measured by the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). An AQ test-retest exercise involving 272 participants indicated a strong correlation of .85.

2.3. Procedure

Ten experienced Educational Psychologists (EPs) carried out both the recruitment and the research procedure as part of their day to day work. Whenever a referred child or young person completed the literacy, numeracy and core British Ability Scales as part of a routine assessment the psychologist asked the parents if they were willing to complete an AQ questionnaire, and to provide their written consent to all data being included in the research project. No parent refused the request, although 23 parents either failed to return the questionnaire or omitted more than 5 items. Where only five or fewer items were omitted the child's average score was substituted, in keeping with the procedure followed by Auyeung et al. (2008). Data collection was maintained until the sample size met the 102 minimum required to achieve a power level of 80% with a seven variable standard multiple regression analysis.

2.4. Data analysis

Data for BAS II Numeracy were available only for a handful of cases as clinic time was often a constraint and in practice psychologists can often draw on existing school data for this part of an assessment when necessary. The analysis of evenness of intellectual development for the study was therefore based only on outcomes from all six core ability scales and the co-normed reading and spelling scales. For all participants, unevenness was examined at each of three levels, namely, the largest discrepancy (i.e. difference) between any two of the IQ domain standardised scores (VIQ, NIQ and SIQ); the total for discrepancies between the two standardised core scale scores within each of the three IQ domains; and, discrepancies between IQ and standardised word-level literacy scores. Observed differences between standardised scores were first subjected to regression control to improve the accuracy of the discrepancy score used for the analysis. This was achieved by calculating a predicted level of difference score for the child's ability level based on the mean, standard deviation and age-specific correlation data provided in the BAS-II manual. This predicted level of difference was then subtracted from the observed difference score, thereby taking into account the degree of difference attributable simply to regression to the mean. The BAS-II manual provides details of measurement error confidence limits for each of the three types of difference score. These confidence levels are specific to the child's age. Only regression-controlled difference scores of a magnitude likely to be greater than test measurement error alone ($p < .05$) were recorded as discrepancies. Preliminary analysis compared discrepancy scores across three groups as defined by a low, medium or high AQ score. The comparison was made both graphically and by application of Jonckheere's trend test. Following the preliminary analysis significant IQ/Literacy discrepancy scores were further classified as either Dyslexic-type (i.e. literacy skill lower than predicted by IQ) or Hyperlexic-type (i.e. literacy skill greater than predicted by IQ). AQ was then regressed simultaneously on VIQ, NIQ, SIQ and all four types of discrepancy score using standard multiple regression. Absolute levels of VIQ, NIQ and SIQ were included as independent variables in the model with a view to confirm the previous findings of no relationship between AQ and IQ. Complete sets of assessment results were available for 106 participants, which was above the minimum sample size of 102 required to achieve statistical power of 80% for a medium effect at the 5% significance level (Cohen, 1992).

Finally, mean cognitive task scores within and across the three IQ domains were compared for the subgroup of participants with AQ scores above 75. At this level there is a very high probability the child would qualify for the diagnostic category of "ASD" (Auyeung et al., 2008). This analysis was carried out to examine how far very high AQ levels in the sample might be dominated by specific areas of strength or weakness across the BAS cognitive test battery.

3. Results

Figure 1 provides a graphical representation of the relationship between ability discrepancy scores and autistic-like traits (AQ) across three levels. Jonckheere's test confirmed that each of the three types of unevenness score showed a significant rising trend in relation to AQ ($p < .05$) with the following effect sizes: Scale discrepancies, $r = 0.27$; Cluster discrepancy, $r = 0.41$; IQ/Literacy discrepancy, $r = 0.39$.

The overall intellectual unevenness score was calculated by simply adding together all three of these discrepancy types (i.e. Scale; Cluster; and IQ/Literacy). The relationship between AQ level and this composite discrepancy score (Figure 2) showed a large effect size of $r = 0.55$ ($p < 0.05$).

Given the significant results found in the preliminary analyses, a standard multiple regression analysis was employed to explore the relative effect sizes of four types of discrepancy score (Scale, Cluster, Hyperlexic and Dyslexic) after controlling for VIQ, NIQ and SIQ. The SPSS software programme identified only one case with a standardised residual value outside the range +/−2.58, and none beyond +/−3.29. The frequency of extreme error was therefore accepted as consistent with the sample size of 106. Checks for normality of residual distribution; linearity; homoscedasticity and multicollinearity were also satisfactory. Outcomes from the regression analysis are shown in Table 3.

Each of the four types of discrepancy score included in the model accounted for a unique proportion of the variance in autistic-like behaviour traits at a moderate level (see Table 3, column 4). Additional unique variance was accounted for by NIQ which showed a modest negative correlation with AQ. However, there was no independent correlation between AQ and VIQ, or between AQ and SIQ. The model overall gave a correlation with AQ of .60 ($p < .0005$) accounting for 36% of the variance in this sample. The same standard multiple regression analysis was also repeated for each of seven specific categories of participant to illuminate the consistency of the correlation across the sample. Overall model correlations with AQ for each of these seven subsamples are reported in Table 4.

Group mean ability scores for the 38 participants with a very high level of autistic-like traits (AQ > 75) are displayed in Table 5.

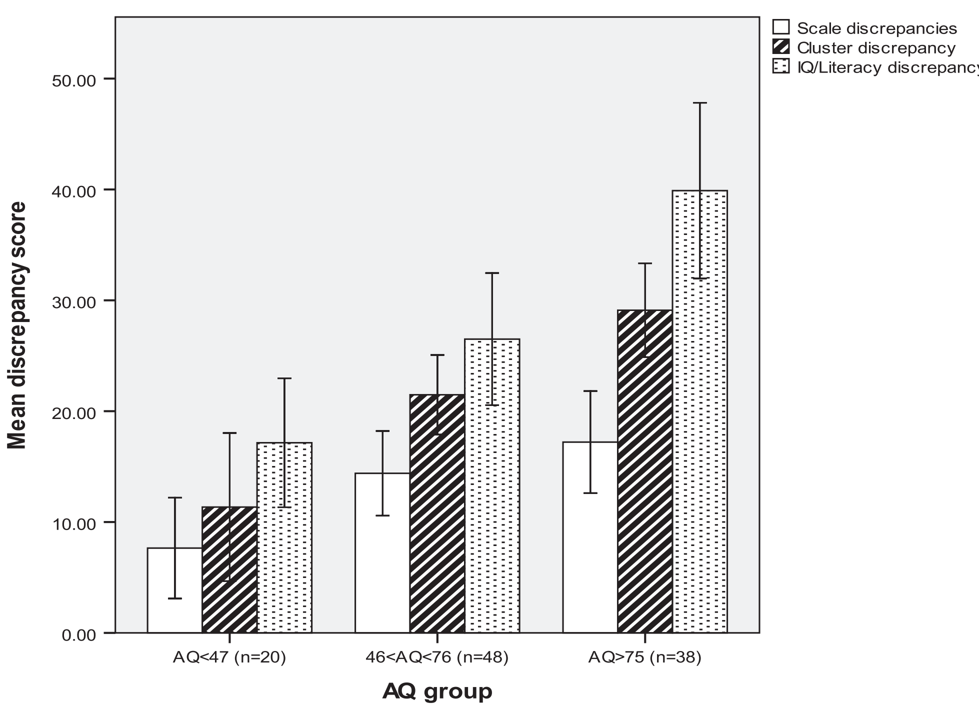

Figure 1. Mean intellectual unevenness scores of children at three different AQ levels: firstly, children with AQ below the average for the general population (boys: 46; girls: 38); secondly, children with AQ above the average for the general population; and thirdly, children with AQ scores in the clinical range (AQ > 75). Error bars represent 95% confidence intervals.

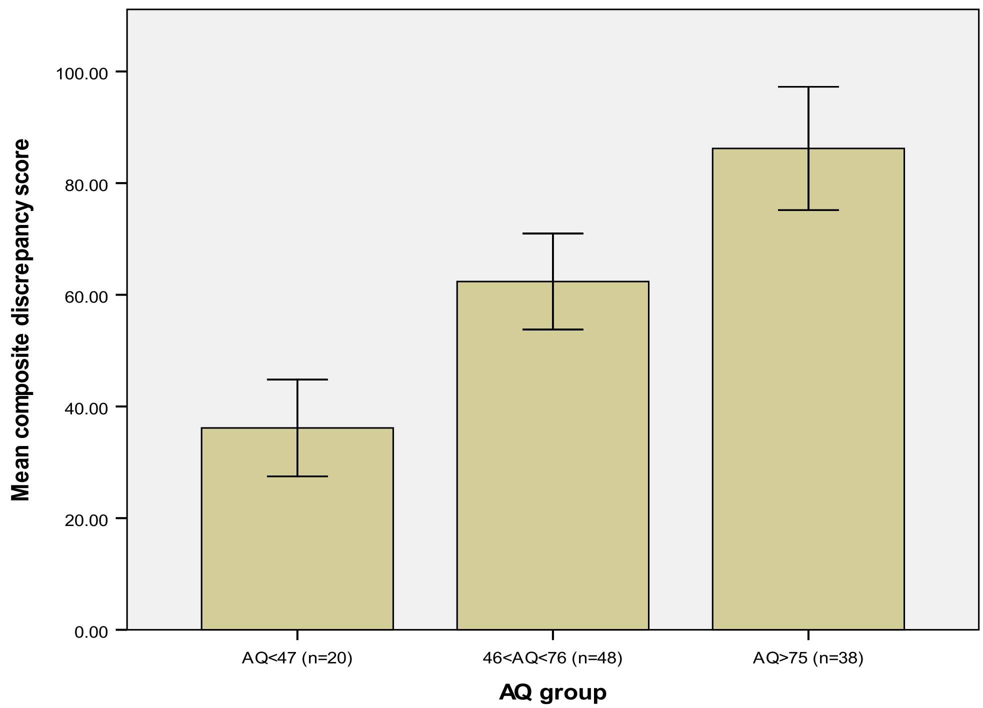

Figure 2. Mean composite intellectual unevenness score of children at three different AQ levels: firstly, children with AQ below the average for the general population (boys: 46; girls: 38); secondly, children with AQ above the average for the general population; and thirdly, children with AQ scores in the clinical range (AQ > 75). Error bars represent 95% confidence intervals.

Table 3. Standard multiple regression analysis of seven variables on Autism Spectrum Quotient (*n* = 106)

Variable	Unstandardised coefficients (standard error)	Standardised coefficients (Beta)	Variance proportion (unique)	Significance (ns: *p* > .05)
Total scale discrepancy	0.49 (0.16)	0.27	0.061	*p* = 0.003
Largest cluster discrepancy	0.45 (.16)	0.26	0.052	*p* = 0.006
Dyslexic-type discrepancy	0.29 (0.11)	0.26	0.047	*p* = 0.009
Hyperlexic-type discrepancy	0.43 (0.12)	0.35	0.085	*p* < 0.0005
NIQ	−0.40 (0.15)	−0.29	0.045	*p* = 0.010
VIQ	0.08 (0.13)	0.07	0.003	*p* = 0.531 (ns)
SIQ	0.10 (0.13)	0.09	0.004	*p* = 0.453 (ns)

Note: Model overall: $R = 0.60$ ($p < .0005$); $R^{(2)} = 0.36$.

Table 4. Correlations (*R*) between the standard multiple regression model and AQ for each of seven specific categories of participant

Category of participant	ASD referral	Behaviour referral	Academic progress referral	Girls	Boys	Lowest ages Mean: 9.0 years (SD 1.2)	Highest ages Mean: 13.1 years (SD 1.8)
n	31	27	48	26	80	53	53
Model correlation with AQ (*R*)	*0.51*	*0.54*	*0.52*	*0.82*	*0.62*	*0.60*	*0.54*

Table 5. Mean BAS cognitive ability standardised scores (AQ > 75; *n* = 38)

Scale/Cluster	Mean standard score (*n* = 38)	*t* (*df* 37)	Significance (2 tailed; *p* < 0.05)
Verbal Similarities; Word Definitions	48.47; 45.47		
Difference	3.00	2.006	*p* = 0.052*
Matrices; Quantitative Reasoning	50.53; 45.79		
Difference	4.74	2.940	*p* = 0.006
Pattern Construction; Recall of Designs	50.55; 45.05		
Difference	5.50	2.615	*p* = 0.013
NIQ cluster; SIQ cluster	96.63; 95.66		
Difference	0.97	0.275	Not significant
NIQ cluster; VIQ cluster	96.63; 95.16		
Difference	1.47	0.385	Not significant
SIQ cluster; VIQ cluster	95.66; 95.16		
Difference	0.50	0.117	Not significant

*Borderline significance (0.05 level).

4. Discussion

In this study a composite score measuring overall unevenness of intellectual ability in school age children accounted for 30% of the variance in autistic-like traits as measured by AQ. Given the high level of imprecision involved when measuring underlying constructs with behaviour rating scales and cognitive tests, this represents a large effect size (Cohen, 1988). The strength of the identified correlation of 0.55 is emphasised when considered in the context of the 60 non-test related benchmark correlations listed by Meyer et al. (2001). Only two of the examples provided were greater than .55. These were: "Nearness to the equator and daily temperature in the USA". (*r* = .60) and "Gender and height for U.S. adults" (*r* = .67). The identified relationship between AQ and unevenness of intellectual ability also compares well with the reading/IQ correlation of .61 reported in the BAS II Technical Manual (p. 215).

Two further points relating to the proportion of variance explained warrant comment. The first concerns the limits imposed by the test–retest reliability of the measurements made. As noted by Vul, Harris, Winkielman and Pashler (2009, p. 276) the maximum proportion of shared variance that can be identified is equal to the product of the test–retest reliabilities of the two scales concerned. On this basis, the maximum levels of variance that the eight difference scores in this study would have been able to account for ranged from 23 to 77%, with a median value of 57%. These limits arising from reliability factors were *additional* to those imposed by the inevitable inaccuracy of the instruments. The second point is that each of the three discrepancy measures that comprised the composite unevenness score accounted for unique AQ variance. It therefore seems reasonable to suppose that additional AQ variance might be explained if ability discrepancies for a broader range of cognitive skills involving both executive functioning and number skills were also considered. Examples of potential additional measures include differences between IQ and tests of executive functioning, and discrepancies between IQ and tests of arithmetic abilities.

A potential criticism of the use of the AQ scale for this study is that the reported link with uneven intellectual ability may have relatively little to do with reduced social awareness, and be very largely a reflection of the non-social aspects of autistic-like behaviour that involve repetitive behaviour and attention to detail. To examine this possibility, scores from each of the four AQ subscales (Social skills; Imagination; Mind-reading; and, Attention to Detail) identified by Auyeung et al. (2008) were substituted in turn for overall AQ in four follow-up standard multiple regression analyses. While three of the four AQ subscales clearly reflect the social dimension of autistic symptoms, the Attention to Detail scale is comprised only of non-social symptoms. The four follow-up analyses revealed that all categories of unevenness score (i.e. total scale discrepancy; cluster discrepancy; dyslexic type-discrepancy; and hyperlexic-type discrepancy) accounted for unique variance in social symptoms. However, of these four discrepancy categories only the within domain scale difference scores accounted for unique variance in non-social symptoms. This very clearly contradicts the idea that the relationship between uneven intellectual development and AQ may be largely an artefact of a particularly strong link with non-social autistic symptoms. Full details of the follow-up standard multiple regressions that substituted the AQ subscales for overall AQ are available from the corresponding author, on request.

The correlation between AQ and the degree to which word level literacy skills were above IQ may account for the strong association between ASD and the condition known as "Hyperlexia" (Grigorenko, Klin, & Volkmar, 2003) in which extraordinary word reading talent can be demonstrated by young children who have severe levels of overall learning difficulty. The additional finding of a moderate positive correlation between AQ and an unexpected *difficulty* with word-level literacy skill (i.e. dyslexic-type discrepancies) underlines the idea that if a single primary cognitive factor underlies high AQ this factor must be able to simultaneously account for an idiosyncratic range of relative advantages and disadvantages that are unpredictable at the level of the individual case.

The study of intellectual ability in ASD reported by Goldstein et al. (op. cit.) found that compared to the general population, inter-correlations between IQ sub-test scores were generally reduced. The results of the study reported here build on the previous research in three ways. Firstly, the demonstration of a strong positive correlation with AQ indicates that very uneven intellectual development is linked specifically to autistic-like traits rather than behavioural anomalies in general. Secondly, the inclusion of IQ/Literacy discrepancy data shows that the phenomenon is not confined to intellectual abilities found within IQ test batteries; and thirdly, the findings demonstrate that the relationship between AQ and unevenness of intellectual development extends to trait manifestations at any level, and is not limited to groups with AQ scores in the range associated with ASD diagnosis. Goldstein et al. note the apparent concordance between their findings and evidence of disrupted cortical connectivity in ASD (Just, Cherkassky, Keller, Kana, & Minshew, 2006; Noonan, Haist, & Müller, 2009). The present findings may mean that effective communication between brain regions is in fact a normally distributed component of intellectual ability, with behavioural correlates closely linked to the AQ scale. However, as Goldstein et al. acknowledge, a link between disrupted connectivity and reduced inter-correlations between cognitive ability tests cannot be assumed without direct evidence from functional magnetic resonance imaging (*f*MRI) studies.

As a group, participants with scores above AQ 75 showed a small but significant performance bias towards specific core scales. Interestingly, the three scales that appeared to either benefit most or suffer least (Verbal Similarities, Matrices and Pattern Construction) all involve tasks that have a major analytic component. In this way the findings are in with studies showing relatively strong "systemizing" skills (Baron-Cohen, 2009) and detail-focus (Happé & Frith, 2006) in groups diagnosed with high-functioning autism. However, the magnitude of these within-cluster performance biases was low, and would be within the limits of test measurement error ($p < .05$) for an individual assessment. The absence of an advantage or disadvantage for any particular IQ cluster in the high AQ group is consistent with the study by Black et al. (op. cit.) in which VIQ/NIQ split was associated with autistic symptoms regardless of the direction of relative strength.

In addition to intellectual unevenness a further modest but unique proportion of AQ variance was accounted for by NIQ level, which correlated negatively with AQ. This had not been anticipated given the previous research (Auyeung et al., op. cit.) showing no correlation between WISC IQ and AQ. However, the BAS Technical Manual (Elliott, Smith, & McCulloch, 1997, p. 20) argues that BAS NIQ is in fact untapped by WISC IQ batteries of the type used in the earlier research (i.e. versions pre-dating WISC IV) and that BAS NIQ largely reflects the ability to integrate visual and auditory information processing. On this basis the unique proportion of variance accounted for by the negative correlation between NIQ and AQ is consistent with the idea of an association between autistic-like traits and reduced interdependence of intellectual abilities. A difficulty for this explanation is that the mean NIQ for participants in the high AQ range was very similar to the group means for both VIQ and SIQ. An alternative possibility is that while high AQ is associated with idiosyncratic advantages and disadvantages in the verbal and spatial domains, effects on BAS NIQ may be relatively consistent. This line of reasoning provides a stronger explanation of the negative correlation between AQ and BAS NIQ as it can account for both the previously reported failure to find a relationship between AQ and WISC IQ and also for the absence of a relatively low mean NIQ (compared to VIQ and SIQ) in the high AQ group of the present study. An important implication of this interpretation is that BAS NIQ may be more reliable than overall IQ as an indicator of the relationship between "general intelligence" and AQ.

The study was limited by its cross-sectional nature, and it is not possible to say whether uneven intellectual development and increased AQ level arose simultaneously or that one showed temporal precedence. A further limitation is that the sample was drawn primarily from school referrals to Educational Psychology Services, and it remains to be seen how far the findings can be replicated with a sample drawn at random from the general population. On the other hand, the children and young people in this sample were referred for a very wide range of school-related issues. Their mean IQ score was only 3 points below the general population mean of 100, and AQ scores ranged from below average (for the general population) through above average (for the general population) to the well above average scores associated with ASD diagnosis (AQ > 75). In other words, the results did not reflect only restricted ranges of intellectual ability or of autistic-like traits. It is also notable that a strong correlation (i.e. $R > .5$) between AQ level and the overall regression model was found in all seven subsamples that were examined to provide a check on the consistency of the findings across the whole sample (see Table 4).

5. Conclusion

This study has identified a strong correlation between uneven intellectual development in school age children and AQ score at all levels. The degree to which an individual's overall ability reflects a dispersed profile of intellectual abilities may therefore represent a potentially important second dimension of cognitive ability measures. Further research is now required to explore the possibility of links between specific types of intellectual ability discrepancy and particular categories of autistic-like behaviours. *f*MRI studies are also called for to establish how far unevenness of intellectual development may be an analogue for the aberrant cortical connectivity that has been associated with ASD.

6. Ethical approval and consent

Ethical approval was granted by the local departmental committee (School of Environment, Education and Development, University of Manchester, UK) and informed, written consent was obtained from the parents of all participants. None of the analysed data can be traced back to individuals.

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Correction
This article was originally published with errors. This version has been corrected/amended as follows: In order to standardise terminology throughout the text, any instances of Autistic Spectrum Disorder have been changed to Autism Spectrum Disorder, and Autism Quotient has been changed to Autism Spectrum Quotient.

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