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Visual/verbal-analytic reasoning bias as a function of self-reported autistic-like traits

A study of typically developing individuals solving Raven's Advanced Progressive Matrices

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ABSTRACT People with autism spectrum condition (ASC) perform well on Raven's matrices, a test which loads highly on the general factor in intelligence. However, the mechanisms supporting enhanced performance on the test are poorly understood. Evidence is accumulating that milder variants of the ASC phenotype are present in typically developing individuals, and that those who are further along the autistic-like trait spectrum show similar patterns of abilities and impairments as people with clinically diagnosed ASC. We investigated whether self-reported autistic-like traits in a university student sample, assessed using the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, et al., 2001), predict performance on Raven's Advanced Progressive Matrices. We found that reporting poorer social skills but better attention switching predicted a higher Advanced matrices score overall. DeShon, Chan, and Weissbein (1995) classified Advanced matrices items as requiring a visuospatial, or a verbal-analytic strategy. We hypothesised that higher AQ scores would predict better performance on visuospatial items than on verbal-analytic items. This prediction was confirmed. These results are consistent with the continuum view and can be explained by the enhanced perceptual functioning theory of performance peaks in ASC. The results also confirm a new prediction about Raven's Advanced Progressive Matrices performance in people with ASC.

KEYWORDS *Autism-Spectrum Quotient, autistic-like traits, Raven's Advanced Progressive Matrices, strategies, typically developing individuals*

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Dawson et al. (2007: 660) found a peak in performance for Raven's Standard Progressive Matrices, a test known to load highly on the general factor in intelligence, in a group of adults with autism spectrum condition (ASC). Scores for the Standard matrices were around the 83rd percentile (i.e., on average 83% of people would have a lower score); for performance IQ (including Block Design) of the Wechsler Adult Intelligence Scale scores were around the 55th percentile, whereas on the verbal IQ part (including comprehension) scores were around the 45th percentile. The authors argue that their 'data challenge the assumption that autistic intelligence is only simple, low-level, perceptual expertise.' Hayashi et al. (2008: 309) found that children with Asperger's syndrome (an ASC) showed better performance on the Standard matrices than did controls. They attributed the increased performance to 'superior abstract reasoning ability and high general fluid intelligence' in Asperger's syndrome.

Individuals with autism spectrum condition (ASC) also tend to perform well on tests such as the Block Design subtest of the Wechsler intelligence scales (Shah and Frith, 1993) and the Embedded Figures test (Shah and Frith, 1983). Weak Central Coherence theory (WCC) attempts to provide a cognitive basis for enhanced performance on tasks such as these. The theory suggests that those with ASC show enhanced or preserved processing of detailed information but a weakening of the ability to process information into a meaningful whole or a 'Gestalt' (Happé and Frith, 2006). Other evidence of WCC in ASC includes superior pitch identification skills (Heaton et al., 1998), absence of interference from pitch patterns (Foxton et al., 2003), and absence of inference from the lexicon on a non-word versus word phonological test (Stewart and Ota, 2008).

A series of studies have found correlations between the Standard matrices and the Embedded Figures Test (see McKenna, 1984). Meo et al. (2007) report evidence that reduced visual element salience, due, for example, to overlapping or difficult to name features, increases Raven's item difficulty. The processes required to identify items, they argue, are similar to the perceptual processes required to solve Embedded Figures, and seem related to Raven's original motivation that the Progressive Matrices measure how good people are at 'making meaning out of confusion'. Together this correlational and theoretical evidence suggests a possible causal mechanism linking Embedded Figures and Raven's performance. Raven's matrices seem to require ignoring a global Gestalt and focusing on local details, an explanation which is consistent with WCC.

An alternative explanation of the peaks of performance is provided by the enhanced perceptual functioning theory (Mottron et al., 2006), which predicts locally oriented and enhanced visual and auditory processing in people with ASC. Recently supporting evidence has been found of increased cortical thickness in visual cortex and primary auditory cortex in people with ASC (Hyde et al., 2009). Also consistent with the theory is evidence that when solving the Standard matrices, people with ASC show more activation in regions of the brain known to support visuospatial processing than do typically developing individuals (Soulières et al., 2009).

Evidence is accumulating that milder variants of the ASC phenotype are present in typically developing individuals. Baron-Cohen, Wheelwright, Skinner, et al. (2001) developed a self-report questionnaire, the Autism-Spectrum Quotient (AQ), which assesses self-reported levels of autistic-like traits and may also be used as a screening tool (Woodbury-Smith et al., 2005). The traits measured by AQ are continuously distributed and heritable in typically developing populations (Baron-Cohen, Wheelwright, Skinner, et al.., 2001; Hoekstra et al., 2007). The parents of children with ASC have higher scores on two subscales of AQ (social skills and communication) than parents of typically developing children (Bishop et al., 2004).

Typically developing individuals with high but sub-clinical AQ scores show similarities in the patterns of abilities and impairments to those found in people with ASC. For instance, people with ASC are impaired on a facial emotion expression decision task, the Reading the Mind in the Eyes test (Baron-Cohen, Wheelwright, Hill, et al., 2001). In typically developing individuals, AQ is negatively correlated with accuracy on the task (Baron-Cohen, Wheelwright, Hill, et al., 2001; Voracek and Dressler, 2006). People with ASC are impaired in eye gaze following (e.g., Baron-Cohen et al., 1995); higher AQ was associated with less eye gaze following in typically developing individuals (Bayliss et al., 2005). Using a series of experimental variants of block design, Shah and Frith (1993) found that people with ASC were better than typically developing individuals for global designs, whereas they had no advantage on segmented designs which highlighted how the blocks map to the pattern. These results indicate that people with ASC require less effort than typically developing people to segment the global designs, so the adapted version of the task with explicit segmentation only had a benefit for the typically developing group. Stewart et al. (2009) found a similar pattern in typically developing individuals: participants with high AQ were better than those with lower AQ for global designs, but there was no difference in performance for segmented designs.

No previous work has examined whether performance on Raven's matrices is predicted by self-reported autistic-like traits in typically developing individuals. The present study aims to address this. Superficially, it would seem that all items on Raven's matrices can be solved using the same strategy; however, detailed theoretical and experimental studies have suggested this is not the case (e.g., Hunt, 1974; Carpenter et al., 1990; DeShon et al., 1995). By considering strategies of solution as a function of self-reported autistic-like traits we may gain a greater understanding of the nature of processes underlying peaks and troughs in performance. This is the main focus of the present study.

Strategies of Raven's Matrices performance

Carpenter et al. (1990) analysed performance on Raven's Standard Progressive Matrices and Advanced Progressive Matrices using verbal protocols and eye tracking. They constructed a rule-based cognitive model of how people solve the task and classified items according to the rules required for their solution. Drawing on this work, DeShon et al. (1995) sorted the rules into two classes: *visuospatial* and *verbal-analytic*. (See the Appendix for a description of the classes.) They argue that some items are solvable using rules from only one of the two classes, some may be solved by rules from *either* class, and some items require the use of rules from *both* classes. To test their hypothesised classifications, they used the verbal-overshadowing effect (Schooler and Engstler-Schooler, 1990), the effect that task relevant verbalisation forces a verbal encoding, which impairs performances on tasks better served by a visual encoding (e.g., face recognition). Specifically, participants were asked to 'express their thoughts out loud' as they solved the items, saying 'anything that came into their minds, even if it was not relevant to the problems', and were reminded to verbalize if they became silent. Participants in the verbalisation group were half as likely to answer correctly the items classified as visual compared to those who were not verbalising, confirming their hypothesis that the items tap into visuospatial processing.

Raven's matrices scores load highly on the general factor in intelligence, *g* (Carpenter et al., 1990). Since *g* emerges as the shared variance in a range of tests of cognitive abilities, we wondered whether these qualitative differences in strategy requirements were deliberately designed into the tests to tap into *g*. We could find no evidence of this, though in the first discussion of the development of the matrices by Raven (1936), excerpts from participant self-reports indicated that some individuals became aware of differences in the strategies required for solution. Of one item, a participant (a certain Karl Duncker – later to become a famous Gestalt psychologist) noted (p. 112) that 'verbalisation helps'. Of another item he remarked that 'parts of the figure are so similar that you cannot distinguish between them by words. Verbalisation sometimes helps, but not so here'.

The present study

This study aimed to characterise performance on Raven's Advanced Progressive Matrices as a function of autistic traits. We hypothesised that a high score on the autistic trait continuum would predict better performance on visual items than on the verbal-analytic items. We also sought to investigate whether overall performance on the Advanced matrices would be predicted by position on the autistic trait continuum.

Methods

Participants

Participants were students studying at Heriot Watt University, Edinburgh, Scotland. Ethical approval was obtained from the Ethics Committee of Heriot Watt University and all participants gave informed consent. Questionnaires were collected and completed by participants at their leisure. Participants who returned questionnaires were asked to take part in a larger study on reasoning styles, part of which included the Raven's Advanced Progressive Matrices. (See Fugard, 2009, for details of the study.)

The questionnaires were completed by 105 participants (mean age = 23, *SD* = 5.1, range 17–49), of whom 67 were female (mean age = 22, *SD* = 4, range 18–38) and 38 male (mean age = 24, *SD* = 6.7, range 17–49). Of these, 85 agreed to take part in this study and completed the Advanced matrices (mean age = 23, *SD* = 5.1, range 17–49), of whom 55 were female (mean age = 22, *SD* = 3.4, range 18–31) and 30 were male (mean age = 24, *SD* = 7.2, range 17–49).

Material

Autism-Spectrum Quotient The Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, et al., 2001) consists of 50 questions, divided into 5 theoretically defined subscales: Social Skill, Attention Switching, Attention to Detail, Communication, and Imagination. Each item has four possible answers: 'strongly agree', 'agree', 'disagree', and 'strongly disagree'. Baron-Cohen, Wheelwright, Skinner, et al. (2001) originally prescribed a binary scoring scheme, ignoring the degree of agreement or disagreement; we follow later studies (e.g., Austin, 2005; Hoekstra et al., 2007) and include all four levels when computing scores. Item scores range from 1 to 4 so total AQ scores range from 50 to 200, and the sub scores range from 10 to 40, with a higher score indicating more autistic traits. Cronbach's αs were similar to those found in the literature: 0.85 for the composite score, 0.81 for Social Skill, 0.68 for Communication, 0.67 for Attention Switching, 0.60 for Attention to Detail, and 0.54 for Imagination.

Raven's Advanced Progressive Matrices We used the test set (set II) of Raven's Advanced Progressive Matrices (Raven et al., 1998), which consists of 36 items. Each item is multiple choice, with eight options. Answering an item correctly gives a score of 1, and incorrectly a score of 0, so the range of possible scores is 0–36. The task items were presented by computer using the E-prime package (Psychological Software Tools, Pittsburgh, PA). Since the Advanced matrices were used as part of a battery of tasks, we chose to use a shorter form to reduce participant fatigue. Rather than select a subset of items, to preserve the progressive nature of the task we chose to present the full task with a 20-minute time limit. Importantly for our item-level analyses, participants were not made aware they were being timed, so item-level performance is equivalent to that which would have been shown for the full task. Hamel and Schmittmann (2006) show that the Advanced matrices score after 20 minutes in such conditions is also an adequate predictor of the full test score ($r = 0.74$ between the full score and the score after 20 minutes).

Results

See Table 1 for descriptive statistics. The distribution of scores on the Autism-Spectrum Quotient (AQ) were similar to those found by Austin (2005) in students at the University of Edinburgh and Raven's Advanced Progressive Matrices scores were around the same as those found by Hamel and Schmittmann (2006) for their sample of psychology students at the University of Amsterdam. All 85 participants completed item 17 on the Advanced matrices within 20 minutes. See Figure 1 for graphs of the number of participants reaching each item, and the number of people answering each item correctly and incorrectly.

Table 1 **Descriptive statistics for the Autism-Spectrum Quotient (AQ, and its subscores) and Raven's Advanced Progressive Matrices (APM)**

	Mean	*SD*	*Min*	*Max*
AQ	109.2	14.7	79	150
Attention to Detail	25.6	4.1	19	40
Attention Switching	23.8	4.3	14	35
Communication	20.2	4.5	10	32
Imagination	19.7	4.0	10	29
Social Skills	20.3	5.2	11	38
APM (20 minutes)	20.9	4.4	7	30

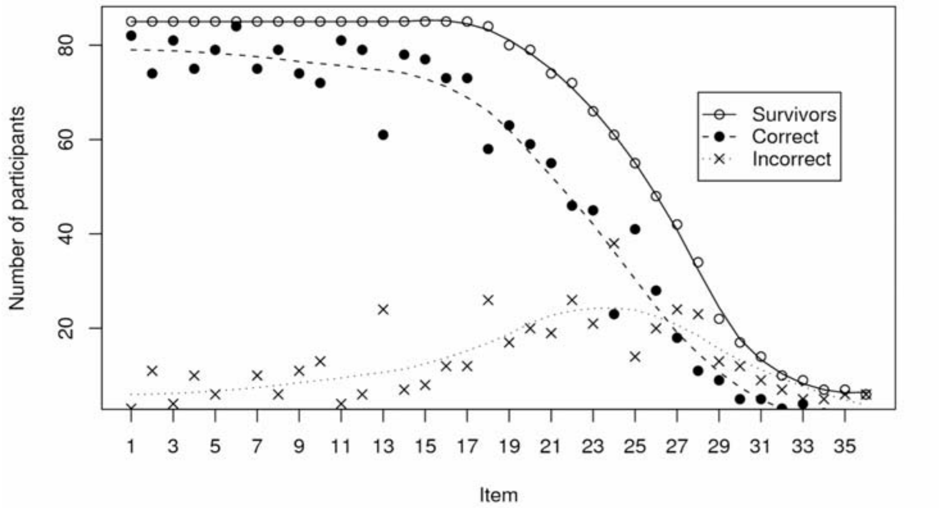

Figure 1 **Graph of number of people reaching each item, number correct, and number incorrect. (The curves were fitted using local polynomial regression.)**

Autism-Spectrum Quotient and composite Advanced matrices score

No correlation was found between the total AQ score and total Advanced matrices score ($r = 0.05$, $p = .6$), nor the number of questions answered in the time ($r = 0.11$, $p = .32$). At the subscale level, however, there was an association. For AQ, a linear regression showed that a higher score on the Social Skill scale (which reflects less sociability; $\beta = 0.27$, $t = 2.76$, $p = .007$) and a lower score on Attention Switching (which reflects better ability at attention switching; $\beta = -0.26$, $t = -2.23$, $p = .029$) predicted a higher Advanced matrices score (adjusted $R^2 = 0.08$, $F(2,81) = 4.51$, $p = .01$).

Autism-Spectrum Quotient and Advanced matrices item-level analysis

The item-level analyses were performed using mixed-effects logistic regression models, fitted using the *lme4* package (Bates, 2007; Baayen et al., 2008) in *R* (R Development Core Team, 2008), with probability of a correct response as the outcome variable. We began the analyses by investigating whether there were differences in difficulty between the different items when variance due to participant ability was partitioned out using a random intercept (i.e., the intercept was allowed to vary between participants). There was a main effect of item type ($\chi^2(3) = 53.8$, $p < .001$). Participants were more accurate for items solvable by either strategy (visual or verbal-analytic) than they were for visual items ($\beta = -1.5$, $z = -2.1$,

p = .04), verbal-analytic items (β = −2.2, z = −3.0, p = .003), and items requiring both visual and verbal-analytic strategies (β = −2.5, z = −3.0, p = .002). There were no other effects found.

Next we modelled the effect of AQ on performance, now adding a random intercept for items to control for overall item difficulty. As predicted, there was an interaction between item type and AQ ($\chi^2(3)$ = 12.0, p = .007). The higher an individual's AQ, the more accurate they were on visual items compared to verbal-analytic items (β = −0.03, z = −2.7, p = .006), items requiring both verbal-analytic and visual strategies (β = −0.03, z = −2.6, p = .01), and items solvable by either strategy (β = −0.04, z = −2.2, p = .02). Figure 2 shows the probability of responding with the correct answer for visual and verbal-analytic items.

To explore the effect further and facilitate future work, we also fitted individual logistic regressions models for all of the visual and verbal-analytic items, using AQ as a predictor. Table 2 shows z-scores for the estimate of the AQ slope for each model. Of the visual part of the Advanced

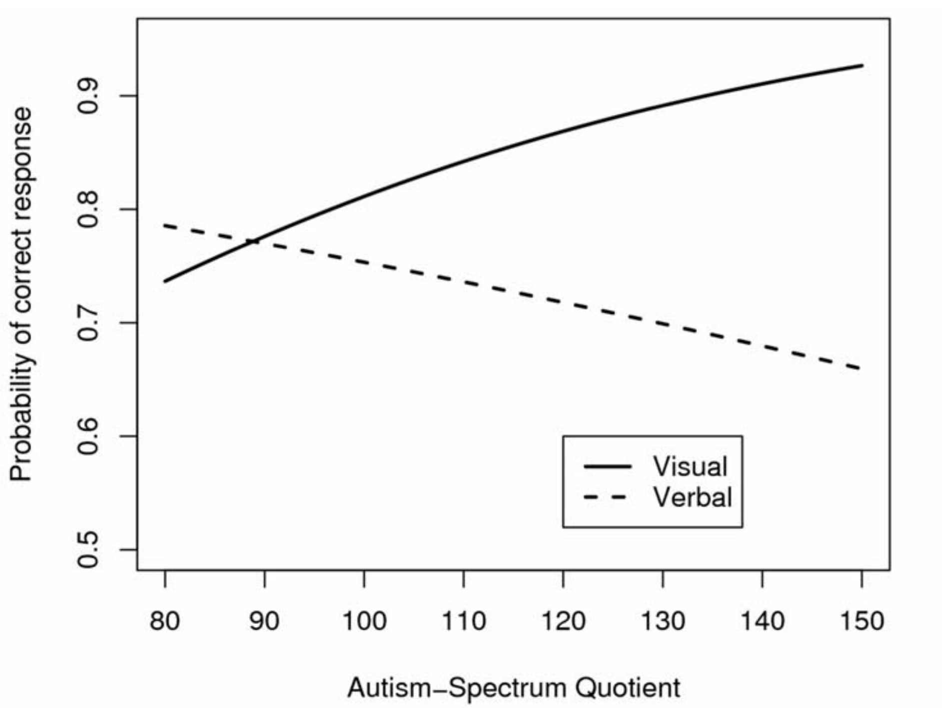

Figure 2 **The probability of giving the correct answer on verbal-analytic and visual items (according to the classification by DeShon et al., 1995) as a function of AQ. Between-participant variance in ability and between-item variance in difficulty are modelled using random effects.**

Table 2 The z-scores of the slope for the AQ predictor for individual logistic regression models predicting accuracy on each item

Visual		*Verbal-analytic*	
Item	*z*	*Item*	*z*
3	–0.78	1	–0.30
7	–0.78	4	–0.90
9	1.19	8	–2.27
10	0.53	13	–1.68
11	0.87	17	0.43
12	0.15	21	–0.43
16	0.36	27	–0.28
18	–0.10	28	1.71
22	2.11	29	–0.29
23	1.48	30	–0.80
24	2.38	34	0.03
32	–1.40	36	0.00
33	–1.42		

Note. A positive z-score indicates better performance the higher AQ and a negative z-score indicates worse performance. AQ = Autism-Spectrum Quotient.

matrices, items 9, 22, 23, and 24 showed the largest association with AQ and of the verbal-analytic part, items 8, 13, and 28 showed the largest association, though the direction of the effect for item 28 is the opposite to that expected.

Discussion

We set out to investigate whether there were associations between self-reported autistic-like traits measured using the Autism-Spectrum Quotient (AQ) and performance on Raven's Advanced Progressive Matrices in a typically developing student sample. The first finding was that composite AQ score did not predict performance on the Advanced matrices. However there was an association with two sub scores of AQ: a higher score on the Social Skill scale, which reflects less sociability, and a lower score on the Attention Switching scale, which indicates better ability to attention switch, predicted better overall performance on the Advanced matrices.

The factor structure of the AQ does not appear to fall into the five factors suggested by Baron-Cohen et al. (2001); however, all factor analytic studies to date agree on a 'social' factor (Austin, 2005; Hurst et al., 2007; Hoekstra et al., 2008; Stewart and Austin, 2009). The present result is further evidence of the predictive validity of the social aspect of AQ. The exact cognitive processes underlying the self-report Attention Switching scale have not been elaborated, but it seems likely that some element of executive functioning is involved. In terms of Advanced matrices performance, some autistic-like traits – those driving poorer social skills – are advantageous, whereas reporting problems with attention switching are not so. One explanation for the negative effect of attention switching problems is that different strategies are required to solve the items; problems with attention switching might indicate a reduced ability to switch to alternative strategies.

The most noteworthy result is that the higher an individual's AQ, the more accurate they are on visual items and the less accurate on verbal-analytic items. This is consistent with the finding by Soulières et al. (2009) that people with ASC show more recruitment of neural regions responsible for visuospatial processing than do typically developing people when solving Raven's Standard Progressive Matrices. We noted in the introduction that there is evidence of overlap between the processes required to solve the Standard matrices and the Embedded Figures Test. Correlations have been found between test scores (McKenna, 1984) and there is also evidence that decreasing element salience increases item difficulty in the Standard matrices (Meo et al., 2007). A consequence of our results is the hypothesis that the processes required for solving the visual items of Advanced matrices are similar to those needed for Embedded Figures. Weak Central Coherence theory (Happé and Frith, 2006) explains enhanced performance on Embedded Figures; however, it is difficult to see how it can explain better performance only for visuospatial and not verbal-analytic Advanced matrices items in those with higher AQ. Enhanced perceptual processing (Mottron et al., 2006) seems the more plausible candidate for explaining the better performance.

It might be argued that the visual items are just easier than the other items and this is why we found the association between item type and AQ. To address this concern, we tested whether visual items were easier than verbal-analytic items and found no difference in accuracy. We also statistically controlled for item difficulty using a random effect. This suggests that the effect is not due to overall difficulty but rather to a requirement for the recruitment of qualitatively different processes for the different item types, as argued by DeShon et al. (1995). Our results also partially support the argument by Dawson et al. (2007) that autistic intelligence is not only 'simple, low-level, perceptual expertise'. The visuospatial processing required for Raven's matrices is as difficult as the verbal-analytic processing and cannot be characterized as 'simple'. However it does seem that enhanced perceptual processes, rather than more widespread fluid intelligence as suggested by Hayashi et al. (2008), explain better performance in ASC on Raven's Matrices.

One aspect of the results which is somewhat confusing, though a weaker effect than the others, is that people with higher AQ were less accurate on problems which can be solved using either a verbal-analytic or a visual strategy than those requiring only a visual strategy. Speculatively, this could be indicative of a problem with appropriate strategy selection (e.g., the higher an individual's AQ, the more likely they are to be disrupted by competing cues in the items).

Of interest is whether this is truly a style of processing that will predict performance on other tasks. For instance, whether there are indeed associations between embedded figures performance and the visual items of the Advanced matrices in particular. Also, tests of verbal-analytic reasoning may predict performance on the verbal-analytic items.

This study focused on whether autistic traits would predict performance on the Raven's Matrices and whether performance might be predicted by a particular strategy. It would be interesting to see if the effect is also present in people who have a diagnosis of ASC.

On a methodological note, we recommend digging deeper into the details of the various standard tasks which have been administered to large numbers of participants. Analyses which utilize the logic of test performance are likely to reveal details of performance which are not exposed by examining only summed scores. These can then be used to generate hypotheses for experimental manipulations as well as contributing to knowledge of the cognitive processes measured by a test. Importantly, there is growing evidence that just because a test superficially appears to be visual and nonverbal does not imply that the cognitive processes required are nonverbal.

In conclusion, drawing on theories of the cognitive processes required to solve Raven's Advanced Progressive Matrices test, which loads highly on the general factor of intelligence, we hypothesised that people with more autistic-like traits would show greater accuracy on Advanced matrices items requiring a visuospatial strategy than items requiring a verbal-analytic strategy. This hypothesis was confirmed in a student population using the Autism Spectrum Quotient (AQ) to measure autistic-like traits. These results are consistent with the enhanced perceptual functioning theory of ASC. We have also provided evidence that composite Raven's score is predicted by better attention switching and poorer social skills, as measured by AQ. This study contributes to the growing evidence that a higher position on autistic-like trait continua predicts cognitive processing similar to but milder than that found in ASC. The results also confirm in a typically developing population a new prediction about Advanced matrices performance in a clinically diagnosed ASC population.

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Appendix

Classification of the strategies

DeShon et al. (1995) classify the following rules as visuospatial: superimposition, superimposition with cancellation, object addition/subtraction, movement, rotation, and mental transformation. Superimposition refers to features being placed on top of each other, whereas object addition/subtraction refers to whole objects being added or removed in a jigsaw puzzle fashion, with no overlap. Movement and rotation are as you would expect. Mental transformation involves recognising a feature in one object and using it to transform a feature in another object.

The verbal-analytic rules they give are *constant in row* (same feature across columns; i.e. within a row, different quantity as you move down the rows); *quantitative pairwise progression* (same shape, incremented number); *distribution of three values* (a shape is distributed in number, the same number, across three columns); *distribution of two values* (two shapes are distributed through a row; one shape is not there or 'categorically inconsistent' with the other features).