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Title: Visual-motor association learning in undergraduate students as a function of the autism-spectrum quotient.

Running title: Visual-motor association learning and the AQ.

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We examined how performance on an associative learning task changes in a sample of undergraduate students as a function of their autism-spectrum quotient (AQ) score. The participants, without any prior knowledge of the Japanese language, learned to associate hiragana characters with button responses. In the *novel* condition, 50 participants learned visual-motor associations without any prior exposure to the stimuli's visual attributes. In the *familiar* condition, a different set of 50 participants completed a session in which they first became familiar with the stimuli's visual appearance prior to completing the visual-motor association learning task. Participants with higher AQ scores had a clear advantage in the *novel* condition; the amount of training required to reach learning criterion correlated negatively with AQ. In contrast, participants with lower AQ scores had a clear advantage in the *familiar* condition; the amount of training required to reach learning criterion correlated positively with AQ. An examination of how each of the AQ subscales correlated with these learning patterns revealed that abilities in visual discrimination – which is known to depend on the visual ventral-stream system – may have afforded an advantage in the *novel* condition for the participants with the higher AQ scores, whereas abilities in attention switching – which are known to require mechanisms in the prefrontal cortex – may have afforded an advantage in the *familiar* condition for the participants with the lower AQ scores.

1. Introduction

Enhanced visual perception, particularly with respect to perceiving details, is well documented in individuals with an autism spectrum disorder (ASD). This is evident from numerous observations indicating that children and adults with ASD demonstrate superior performance on the embedded figures task and other tasks that require fine-grained visual searches (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). These observations, together with other lines of evidence, led Frith to propose the Weak Central Coherence theory of autism (Frith, 2003). Central coherence is defined as: “the tendency to process incoming information in its context — that is, pulling information together for higher-level meaning — often at the expense of memory for detail” (Happé, 1999). This theory stipulates that the perceptual advantage for details comes at the expense of successfully performing the necessary operations required to integrate elements together to form a Gestalt (Frith, 2003; Happé & Frith, 2006).

Another account of autism, known as the Executive Dysfunction theory, proposes that behavioural impairments in individuals with ASD can be explained in terms of failures in executive functioning (Russell, 1995). Executive function (Luria, 1966) is the cognitive construct adopted to describe behaviors mediated by the frontal lobes, such as mental flexibility, inhibition, working memory, planning, learning, and impulse control. The Executive Dysfunction theory explains many clinically impairing behaviours, including perseverative behaviours due to difficulties in attention switching (McEvoy, Rogers, & Pennington, 1993), failures in Theory of Mind (Pellicano, 2007, 2010), and impaired social skills (Gilotty, Kenworthy, Sirian, Black, & Wagner, 2002). However, its central weakness is that it does not explain why many people with ASD show superior perceptual skills. Given that each of the two theories explains different aspects of ASD, we believe they should be seen as complementary rather than mutually exclusive. If this assertion is correct, this would mean that the cognitive, as well as the neural, operations underlying perceptual abilities and those underlying certain aspects of executive functioning are dissociable in ASD.

Behavioural similarities between ASD probands and unaffected family members have long been recognised (Kanner, 1943) and a surge of more recent twin and genetic studies have also documented the presence of subclinical autistic traits in relatives of individuals with ASD (Bailey et al., 1995; Happé, Briskman, & Frith, 2001; Piven, 2001; see Sucksmith, Roeth & Hoekstra, 2011 for review). This research led to the coining of the term *broader autism phenotype* for describing the presence of autistic-like traits and behaviours among family members outside of the clinical domain. More recently, Gaugler et al. (2014) reported that the majority of genetic liability for ASD is attributed to common inherited variances, with this genetic variability extending well beyond family members and being widely distributed throughout the general population. The broader autism phenotype exists therefore as a continuum in the general population.

The Autism-Spectrum Quotient (AQ) questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001) was developed to quantify the continuum of subclinical autistic behaviours in the general population. The AQ has been validated on a number of occasions in large samples of individuals without any formal diagnosis of ASD ($n > 600$; Baron-Cohen et al., 2001; Hurst, Nelson-Gray, Mitchell & Kwapil, 2007). Behavioural investigations of unaffected family members and undergraduate samples with high degrees of autistic-like characteristics often show similar patterns in perceptual and cognitive abilities, such as enhanced detail-focused processing (Baron-Cohen & Hammer, 1997; Bayliss & Tipper, 2005; Bölte & Poustka, 2006), diminished Gestalt processing (Chouinard, Noulty, Sperandio & Landry, 2013; Reed, Lowe & Everett, 2011; Stewart, Watson, Allcock & Yaqoob, 2009), reduced language abilities (Russer et al., 2007; Whitehouse, Barry & Bishop, 2007), difficulties in social cognition (Hudson, Nijboer & Jellema, 2012; Palermo, Pasqualetti, Barbati, Intelligente & Rossini, 2006), repetitive behaviours (Poljac, Poljac & Yeung, 2012) and reduced skills in an assortment of other executive function tasks (Christ, Kanne & Reiersen, 2010; Hughes, Leboyer & Bouvard, 1997; Hughes, Plumet & Leboyer, 1999; Richmond, Thorpe, Berryhill, Klugman & Olson, 2013). Thus, relating the AQ to performance on perceptual and cognitive tasks not only provides insight into individual differences in the general population, but can also arguably provide preliminary insight into how perception and cognition might be affected in autism from an undergraduate student sample free of confounds associated with task compliance and/or the presence of co-morbid disorders (for further discussion, see Chouinard et al, 2013).

Thus, considerable evidence exists across studies to show that visual discrimination and executive functioning abilities are both affected as a function of subclinical autistic traits. Yet, previous research has tended to focus on one or the other without testing both in the same experiments. Given the number of cognitive theories that are invoked to explain behavioural abilities in autism, it is imperative that more experiments be designed to compare them against each other and examine the relative degree to which their underlying mechanisms affect a specific behaviour. In this study, we examined the contributions of two different cognitive mechanisms (visual discrimination versus executive functioning) in typical adults' abilities to learn a task as a function of their subclinical autistic traits.

Visual-motor association learning, in which participants learn a series of paired associations between a visual stimulus and a motor response, relies, conceivably, on both a visual perception system and an executive system. Visual perception is required to identify a stimulus based on its physical attributes. One cannot act upon a symbolic visual stimulus without first recognising it, which is known to necessitate the ventral stream of visual processing (Chouinard & Goodale, 2009). In terms of executive functioning, we know from work in brain-lesion monkeys, brain-damaged patients, and functional neuroimaging that prefrontal and striatal mechanisms are required to learn new paired-associations (Petrides, 1982; 1985; Petrides, Alivisatos, Evans & Meyer, 1993; Boettiger & D'Esposito, 2005; Grol, de Lange, Verstraten, Passingham & Toni, 2006; Toni & Passingham, 1999; Toni, Rowe, Stephan & Passingham, 2002). fMRI investigations on visual-motor associations show increases in activation in the prefrontal cortex in individuals with ASD as compared to typical controls, suggesting that this part of the brain is less efficient and has to work harder at selecting the correct responses specified by visual cues (Müller, Kleinhan, Kemmotsu, Pierce & Courchesne, 2003; Müller, Cauch, Rubio, Mizuno & Courchesne, 2004).

Limited research has been carried out on visual-motor association learning in autism and there are no studies to our knowledge that have examined these abilities as a function of subclinical traits in the general population. In one study, Zalla, Sav, and Leboyer (2009) presented two visual stimuli on a computer touch screen and had participants with ASD learn by trial-and-error when to touch or not to touch them in the context of a game. The authors showed

that the individuals with ASD took longer to learn the associations relative to control participants. The precise cognitive explanations for these diminished abilities are not yet understood.

The purpose of this study was to examine the learning of visual-motor associations in undergraduate students who varied in their degree of subclinical autistic traits. Our task consisted of having the participant chose a particular button response to a particular hiragana symbol (Fig. 1). In the first condition, referred to as the *novel* condition, the participant learned visual-motor associations without any prior exposure to the stimuli's visual attributes. Under this set of circumstances, we reasoned that abilities in visual discrimination might afford an advantage given that none of the participants were familiar with the visual attributes of the stimuli at the beginning of training and those participants who could discriminate them better would learn the paired-associations faster. In the second condition, referred to as the *familiar* condition, a different group of 50 participants completed a session in which they first became familiar with the stimuli's appearance prior to completing the visual-motor association learning task. Under this set of circumstances, we reasoned that abilities in visual discrimination would no longer afford an advantage given that all participants were already familiar with the visual attributes of the stimuli and that abilities in executive function related to learning paired-associations would provide an advantage instead. The subsequent assessment of which specific subscales within the AQ correlated with learning was used to provide insight into which particular cognitive styles associated with autism (i.e. Attention to Detail, Attention Switching, Communication, Imagination, and Social Skill) could explain differences between the two conditions.

We had the following two hypotheses. First, we hypothesised that the amount of training required to reach learning criterion would decrease as a function of AQ in the *novel* condition (i.e. there would be a negative correlation). This hypothesis is based on the numerous reports that individuals with ASD are better at discerning visual details and discriminating between visual patterns (Bölte et al., 2007; Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Furthermore, a study by Reed et al. (2011) demonstrated that typical individuals with higher overall AQ scores learned to associate lexical labels to novel visually similar stimuli more easily than those with lower AQ scores. Second, we hypothesised that the amount of training required to reach learning criterion would increase as a function of AQ in the *familiar* condition (i.e. there would be a positive correlation). This hypothesis is based on the Executive Dysfunction theory, which, if

supported, would imply that individuals with higher AQ scores might have weaker higher-order mechanisms associated with the actual learning of paired associations. Previous support for this notion also comes from the aforementioned Reed et al. (2011) study, which also showed how individuals with low AQ scores are better at a paired perceptual association task with familiar compared to novel visual stimuli.

2. Methods

One hundred undergraduate students, recruited through the Psychology department experimental participation pool, participated in the study for course credit. Participants were randomly assigned to one of the two conditions. Fifty participants completed the *novel* condition (43 females, $M = 20.12$ years, $SD = 2.21$) and 50 participants completed the *familiar* condition (39 females, $M = 20.34$ years, $SD = 2.54$). All participants spoke English fluently, had normal or corrected-to-normal vision, reported no prior knowledge (formal or informal) of the Japanese language, and were high-functioning adults who had never been formally diagnosed with an ASD. Additionally, all participants were right-handed, as indexed by a score of at least eight out of ten on a modified version of the Edinburgh Handedness Inventory Questionnaire (Oldfield, 1971). IQ was not measured in the current study because the distribution was expected to be within a restricted range in our undergraduate sample, and matched across conditions due to random allocation. All experimental procedures, including the administration of the AQ questionnaire, were computerised and presented using E-Prime 2.0.8.90 software (Psychology Software Tools, 2002) on an 18.5" computer screen with a resolution of 1024 x 768 pixels. Visual stimuli subtended a visual angle of 8.5 degrees.

2.1. Assessing the degree of subclinical autistic traits

All participants completed the AQ questionnaire (Baron-Cohen et al., 2001). In brief, the questionnaire is a self-report instrument designed to quantify the degree of cognitive styles associated with ASD in adults from the general population. The questionnaire contains 50 questions comprising the following five subscales: Attention to Detail, Attention Switching, Imagination, Communication, and Social Skill. Responses were scored on a binary scale with 1 corresponding to a response characteristic of ASD and 0 corresponding to a response not characteristic of ASD. Scores could range between 0 and 50. The overall AQ and each of the different AQ subscales were then correlated with each of our different measures of learning. No comparisons were made across the different AQ components and hence applying a form of correction such as the Bonferroni method was not deemed necessary.

2.2. Familiarisation phase and recognition test

Only participants in the *familiar* condition underwent the familiarisation phase of the study, followed by a recognition test. Participants were instructed to carefully study four different hiragana symbols (“ma”, “he”, “no”, and “wi”; Fig. 1a). Each character was presented for 1,000 ms following the presentation of a 500 ms fixation cross (Fig. 1b). No response was required on behalf of the participant. Participants were exposed to a total of 64 trials (16 trials per stimulus), and the order of presentation of the hiragana symbols was randomised with the restriction that each symbol had to be shown once in a chunk of four trials before repeating again. Following the familiarisation phase, participants completed a short recognition task (Fig. 1c). This consisted of eight randomly presented trials with four trials of the familiar stimuli (“ma”, “he”, “no”, and “wi”) and four trials of hiragana symbols that the participant had never seen before (“chi”, “yu”, “su”, and “yo”). Each recognition trial consisted of a 500 ms fixation cross followed by the presentation of one of the symbols. The symbol remained on the computer screen until the participant made a response. Participants pressed one response key for “yes” if they recognised the symbol and a different response key for “no” if they did not.

2.3. Visual-motor association learning phase

Participants in both the *novel* and *familiar* conditions underwent this phase of the experiment. Participants learned associations between four hiragana symbols (corresponding to the “ma”, “he”, “no”, and “wi” characters) and four response buttons (“1”, “2”, “3”, and “Enter” on a numerical keyboard; Fig. 1d) by trial-and-error. The corresponding keys for each of the characters were counterbalanced across participants. On each trial, a fixation cross was presented for one of two inter-stimulus intervals (700 ms or 1,000 ms) followed by the visual stimulus for a maximum viewing time of 1,000 ms. Participants were encouraged to respond while the symbol was presented on the screen. After the visual stimulus disappeared, visual feedback was presented for 500 ms. Namely, the word “Correct” in a blue font was presented when the participant pressed the correct key and the word “Incorrect” in a red font was presented when the participant either pressed the wrong key or did not respond during the 1,000 ms time window. Participants completed 360 trials. The order of the hiragana symbols was randomised with the restriction that each symbol had to be shown once in a chunk of four trials before repeating again. The participants were not given specific instructions as to whether they should respond as accurately and / or as fast as possible. This was purposely done so that they could be left to their own learning strategies.

2.4. Calculating and analysing the learning-time index

For each participant, we plotted a learning curve by fitting a psychometric function to the accuracy data and then determined at what point the participant reached a learning criterion (Ebbinghaus, 1913; for review, see Yelle, 1979). The 360 trials from the learning phase were divided into 45 bins (each bin consisting of eight trials). For each participant, the percentage of correct trials was calculated for each bin and accuracy A at time point t was then described with the following equation using a least squares fit model:

$$A(t) = b \ln(t) + a \quad (1)$$

where a and b (the slope) are constants and \ln is the natural logarithmic function. Similarly, the average reaction time RT in a given bin was calculated before describing it at time point t with the following equation using a least squares fit model:

$$RT(t) = b \ln(t) + a \quad (2)$$

After both measurements were calculated, we then calculated an index of *learning time*, which served as the main dependent variable for this study. *Learning time* was defined as the time point t when accuracy A reached 90%. This was calculated using the following equation:

$$\text{learning time} = e^{\frac{0.9-a}{b}} \quad (3)$$

The smaller this *learning time* index, the faster the participant learned the visual-motor associations. Hence, a larger *learning time* indicates poorer performance. We correlated this measure of learning as a function of overall AQ to examine how learning relates to the degree of subclinical autistic traits. We also correlated *learning time* with each subscale of the AQ (Attention to Detail, Attention Switching, Imagination, Communication, and Social Skill) to provide further insight into which particular aspects of the AQ may relate to differences in learning.

We used the following procedure to determine whether or not these correlations were different between the *novel* and *familiar* conditions. First, each correlation coefficient was converted into a z-score using the Fisher's r-to-z transformation (Fisher, 1915):

$$Z = \frac{1}{2} \ln \left(\frac{1+r}{1-r} \right) \quad (4)$$

where "ln" is the natural logarithm function. Then, making use of the sample size employed to obtain each correlation coefficient, these z-scores were compared with each other using the following formula 11.11 from Cohen (1996, p. 354):

$$Z_{12} = \frac{Z_1 - Z_2}{\sqrt{\frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}}} \quad (5)$$

The end result is an overall z-score denoting the significant differences between the two independent correlation coefficients. The level of statistical significance was set at $p \leq .050$ (two-tailed) for all analyses.

2.5. Re-analysis of the data

In Baron-Cohen and colleague's (2001) initial development of the AQ, they determined that on average only 2% of typical adults score higher than 32, indicating a higher probability of clinical ASD symptomology above this cut-off. In the current study, this distribution was replicated, with two female participants (out of a total of 100 participants) receiving a score above 32. However, it should be noted that both participants who received a score above this cut-off were randomly assigned to the *familiar* condition, resulting in subsequent group differences in overall AQ. While these group differences do not affect the correlation analyses, the above analyses were also performed with these two individuals removed such that the two groups would be more equally matched on AQ. In addition to the removal of these two participants, we also removed a third female participant in the *familiar* condition who happened to get all answers correct in the first bin. The probability that a person could get the first three trials correct and then deduce the correct response for the fourth (assuming that s/he is paying careful attention and realises that s/he got the first three trials correct) is 4%, which is plausible for a study with a sample of 100. Given that chance could have weighted heavily in this person's learning, we also excluded this participant in the re-analysis.

3. Results

3.1. AQ distributions between studies

In the *novel* condition, the AQ scores were normally distributed with a range of 6 to 27 ($M = 14.64$, $SD = 5.10$, Skewness: $z = 0.05$, $p = .960$, Kurtosis: $z = -0.81$, $p = .418$; see Fig. 2a). In the *familiar* condition, the AQ scores were also normally distributed with a range of 7 to 35 ($M = 17.14$, $SD = 6.03$, Skewness: $z = 1.10$, $p = .271$, Kurtosis: $z = 1.63$, $p = .103$; see Fig. 2b). Due to two participants with high AQ scores of 35 in the *familiar* condition, there was a significant difference between groups in terms of overall AQ, as well as the Communication and Social Skill subscales (all AQ and subscale distributions are presented in Table 1). The groups were better matched in the re-analysis of the data (Table 1).

3.2. Visual-motor association learning in the *novel* condition

Fig. 3ab shows the accuracy and reaction time curves for the *novel* condition. Visual inspection of the curves clearly shows that accuracy but not reaction time changed over time. Our correlation analyses revealed that participants with greater degrees of subclinical autistic traits had a clear advantage in the *novel* condition. *Learning time* correlated negatively with overall AQ ($r(48) = -0.28$, $p = .049$; Fig. 4a). Namely, the higher a participant's AQ score, the faster they could learn the visual-motor associations. To examine further the relationship between subclinical autistic traits and the learning of visual-motor associations, we also correlated the different subscales of the AQ with *learning time* (Fig. 4b-f). Attention to Detail ($r(48) = -0.31$, $p = .027$; Fig. 4b) was the only subscale that correlated with *learning time* (all other subscales had p -values $> .145$; see Table 2a for all correlation coefficients). Taken together, these findings demonstrate that participants with more subclinical autistic traits learned the visual-motor

associations in a fewer number of trials than those who had fewer autistic-like traits. This effect was largely driven by the Attention to Detail subscale of the AQ.

3.3. Visual-motor association learning in the *familiar* condition

When tested for stimulus recognition after the familiarisation procedure, participants achieved a mean accuracy score of 97.2% (range: 75% - 100%; SD = 6.8%). These levels of accuracy did not correlate with AQ ($r(48) = -0.15$, $p = .305$). Participants were therefore quite familiar with the visual properties of the hiragana symbols following the familiarisation phase of the study and this degree of familiarity was not related to subclinical autistic traits. Reaction times also did not correlate with AQ ($r(48) = -0.20$, $p = .166$). Thus, the familiarisation procedure also facilitated the participant's ability to discriminate between the visual stimuli, irrespective of their AQ.

Fig. 3cd shows the accuracy and reaction time curves for the *familiar* condition. Similar to the *novel* condition, visual inspection of the curves demonstrate clearly that accuracy but not reaction times changed over time. In contrast to the *novel* condition, participants with fewer subclinical autistic traits had a clear advantage in learning the visual-motor associations. *Learning time* correlated positively with overall AQ ($r(48) = 0.33$, $p = .019$; Fig. 5a). In other words, the lower the AQ score, the faster learning occurred. To further examine the relationship between subclinical autistic traits and the learning of the visual-motor associations, we also correlated the different subscales of the AQ with *learning time* (Fig. 5b-f). The Social Skill component of the AQ ($r(48) = 0.29$, $p = .041$) correlated positively with *learning time* and there was also a trend for Attention Switching ($r(48) = 0.25$, $p = .080$) to correlate positively with *learning time*. *Learning time* did not correlate as strongly with the other subscales of the AQ (p -values $> .396$; see Table 2b for all correlation coefficients). Taken together, these findings demonstrate that participants with fewer subclinical autistic traits learned the visual-motor associations faster than those who had more subclinical autistic traits following stimulus familiarisation. This effect was largely driven by the Attention Switching and Social Skill subscales of the AQ.

3.4. Differences in learning between conditions

A two-sample t-test revealed that *learning time* did not differ overall between the two conditions ($t(98) = 0.37, p = .712$). However, the manner in which this index changed as a function of overall AQ was different between the two conditions ($z = -3.06, p = .002$). This reveals a double dissociation in which participants with higher AQ scores showed a learning advantage in the *novel* condition while participants with lower AQ scores showed a learning advantage in the *familiar* condition. Further analyses comparing correlation coefficients between conditions on the AQ subscales reveal that the correlations with Attention to Detail ($z = 1.96, p = .050$), Attention Switching ($z = 2.27, p = .023$) and Social Skill ($z = 2.32, p = .020$) were different between the two conditions. Thus, the high AQ advantage in the *novel* condition was driven by the Attention to Detail subscale of the AQ while the low AQ advantage in the *familiar* condition was driven by the Social Skill and Attention Switching subscales of the AQ. For a complete list of z-scores comparing differences in correlations between the two conditions, please see Table 3.

3.5. Examination of the reaction time data

Although all participants' accuracy went in the same direction during the course of the learning phase ($b > 0$, i.e. accuracy increased as training progressed), their reaction times did not. After fitting logarithmic functions for each participant, we found that 27 (out of 50) participants in the *novel* condition and 23 (out of 50) participants in the *familiar* condition had positive slopes ($b > 0$) while all other participants had negative slopes ($b < 0$). It was quite evident from these observations that approximately half of the participants began the learning phase quickly and liberally (mean \pm SD reaction times for bin 1 for those with positive slopes: 408 ± 94 ms in the *novel* condition and 521 ± 125 ms in the *familiar* condition) while the other half began this phase of the study slowly and conservatively (mean \pm SD reaction times at bin 1 for those with negative slopes: 577 ± 133 ms in the *novel* condition and 599 ± 96 ms in the *familiar* condition).

Indeed, if one inspects the reaction times across all participants in each of the two conditions, one can see that the average does not change over time but that the variability is much greater during the first few bins relative to the rest of the training period (see Fig. 3b, d). To ascertain if the adoption of either the liberal or conservative learning strategies could be predicted by subclinical autistic traits, we carried out independent-samples t-tests to compare AQ scores for participants who had positive slopes (i.e., those who began quickly and were thus more liberal at the beginning) versus those who had negative slopes (i.e., those who began slowly and were thus more conservative at the beginning) in each condition. No statistical differences in either the *novel* ($t(48) = 0.68, p = .500$) nor *familiar* ($t(48) = 1.22, p = .228$) conditions were found. Thus, AQ had no effect on learning strategies.

3.6. Re-analysis of the data

With the three participants in the *familiar* condition removed, there were no longer significant differences between the two conditions in overall AQ and the Communication subscale of the AQ; however, the Social Skill subscale of the AQ still differed significantly between the two conditions. Distributions for the AQ and its subscales are presented in Table 1. The re-analysis of the data did not alter the significance of most results (see Tables 2 and 3). Two differences in significance were observed. Namely: the trend we observed for Attention Switching in the *familiar* condition became significant ($r(45) = 0.290, p = .048$) while the positive correlation between learning and the Social Skill subscale of the AQ no longer reached significance ($r(45) = 0.251, p = .089$).

3.7. Analysis of gender differences

In the novel condition, mean AQ scores were 14.74 (SD = 5.45) and 14.00 (SD = 2.00) for females and males, respectively. For the familiar condition the mean AQ scores were 16.64 (SD

= 6.41) and 18.91 (SD = 4.21) for females and males respectively when the data was first analysed while the mean AQ scores were 13.04 (SD = 4.93) and 18.91 (SD = 4.21) for females and males respectively when the data was re-analysed. These averages are comparable to the means reported for undergraduate students by Baron-Cohen et al. (2001) (females: M = 16.4, SD = 6.1, males: M = 18.6, SD = 6.6). Males and females did not differ in how fast they learned the visual-motor associations in either the novel condition ($t(48) = 0.54, p = .594$), the familiar condition from the original analysis ($t(48) = 0.18, p = .855$), or the familiar condition after re-analysis ($t(48) = 0.08, p = .938$). The lack of gender differences suggests that the results that we report in this study apply equally to males and females.

4. Discussion

Visual perception superiorities and executive functioning deficits are well documented in ASD populations and similar patterns have been extended in typical individuals with high degrees of subclinical autistic traits. However, there has been no study to date, as far as we can discern, that has teased apart these two cognitive processes within the same task. In the current study, participants in both conditions were well-matched on most metrics and performed the exact same visual-motor association learning task. The only difference between the *novel* and *familiar* conditions was that participants in the *familiar* condition had been familiarised with the visual stimuli beforehand while participants in the *novel* condition had to learn paired-associations without prior exposure to the visual stimuli.

The overall means for *learning time* between the two conditions did not differ yet the correlation analyses indicate that the effects of AQ were clearly different between the two conditions. Namely, having higher AQ scores afforded an advantage when the stimuli were novel and lower AQ scores afforded an advantage when the stimuli were familiar. Based on the correlations we observed, we make the case that certain aspects of visual perception, as indexed by the Attention to Detail subscale of the AQ, and executive functioning, as indexed by the Attention Switching and Social Skill subscales of the AQ, can operate independently as a function of subclinical autistic traits. Although the significance of the correlations between

learning time with Social Skills and Attention Switching bordered our alpha-level and reached significance depending on whether or not the three participants were excluded from the analysis, it is important to note that their contributions to learning were significantly different between conditions ($p < .025$) such that we can safely claim that these two facets explained learning better in the *familiar* relative to the *novel* condition.

For the *novel* condition, we reasoned that enhanced abilities in visual discrimination would afford an advantage in learning new visual-motor associations. This is because a person must first be able to visually discriminate between stimuli before being able to associate responses to them. Although executive functioning is certainly important for learning new visual-motor associations, these skills would be of little use prior to the participant having visually discriminated their identities. As hypothesised, having higher AQ scores afforded an advantage. This finding is somewhat similar to what Reed and colleagues (2011) found in their study. Namely, the authors showed that typical individuals with higher overall AQ scores learned to ascribe lexical labels to novel visually similar stimuli more easily than those with lower AQ scores. In our study, an assessment of the specific subscales within the AQ showed that the strongest correlation with learning was with the Attention to Detail subscale. This result illustrates that as typical adults are more attentive to detail, a cognitive style observed in ASD, the more they are afforded with an advantage for learning pair-associations between an abstract visual stimulus that they have never seen before and an action. It could have equally been the case that the participants with the lower AQ scores were impeded because they favoured more global styles of processing, making it more difficult for them to distinguish between novel stimuli on the basis of their physical attributes. Taken together, these results are consistent with the Weak Central Coherence theory of autism as well as findings that detail-focused perceptual processing is seen in individuals with higher degrees of subclinical autistic characteristics (Chouinard et al., 2013; Reed et al., 2011; Stewart et al., 2009).

In the *familiar* condition, a different group of 50 participants completed a session in which they first became familiar with the stimuli's physical appearance prior to completing the visual-motor association learning task. Under this set of circumstances, any perceptual advantages that might have enhanced learning in the *novel* condition no longer applied. All participants could easily discriminate the different hiragana symbols following the

familiarisation phase. Our results show that the lower the AQ score, the faster the participant learned the paired-associations with familiar stimuli. The question then arose as to which of the AQ subscales contributed to this effect. Our results showed that it was the Attention Switching and Social Skill subscales that correlated most strongly with learning. Both depend on frontal-lobe mechanisms, as evident by the well-known case of Phineas Gage who demonstrated drastic personality changes related to inhibitory control, which were manifested in his complete disregard for social conventions, impulsivity, and poor risk assessment following his railroad maintenance accident (Harlow, 1868). We think that the Social Skill subscale of the AQ might have correlated with learning in this study because social skills do tap heavily into higher-order mechanisms that would discern conceptual meaning to a number of visual stimuli, such as a face, and select appropriate responses depending on the context. Further investigation will be required to ascertain more precisely how the Social Skill subscale of the AQ is associated with abilities to learn new visual-motor associations.

Attention switching is easier to explain given that it is essential for rule-based learning (Sullivan, Mathalon, Zipurksy, Kersteen, Knight & Pfefferbaum, 1993). In our task, participants would have to disengage their attention from one trial and shift their attention to the next in order to learn the paired associations more effectively. It would not be particularly contentious for us to say that impairments in attention switching and the presence of perseverative behaviours are pervasive features in ASD. For example, children with ASD demonstrate difficulties relative to typically developing children in Piaget's (1954) A but not B task (McEvoy et al., 1993) and in the Wisconsin Card Sorting Task (Hill, 2004). Functional neuroimaging frequently, if not always, reveals task-related activation of the prefrontal cortex when typical adults perform variants of the Wisconsin Card Sorting Task, the Go / No-Go task, and other types of tasks that demand inhibitory control and / or switching (for a meta-analysis, see Buchsbaum, Greer, Chang, & Berman, 2005).

It came as a surprise to us that the Communication subscale did not also correlate with *learning time*. After all, it is conceivable that participants in the *familiar* condition could have adopted verbal strategies to complete the learning phase. It then follows that participants with the lower AQ scores, who conceivably have better verbal and language skills, could have learned the task faster. However, our findings do not provide any evidence for this given the lack of a

significant correlation between learning and the Communication subscale. Perhaps it is the case that the AQ questions for this subscale do not probe into verbal or language processes per se but rather one's ability to engage in social communication. For example, AQ items such as "When I talk, it isn't always easy for others to get a word in edgeways." and "When I talk on the phone, I'm not sure when it's my turn to speak" are more reflective of how one engages in communication than one's ability to produce language, and thus may not have captured the use of verbal strategies in learning new visual-motor associations.

One could argue that our findings reflect differences in abilities in local versus global processing. More specifically, enhanced abilities in local processing in participants with higher AQ scores could have afforded an advantage in the *novel* condition while enhanced abilities in global processing in participants with lower AQ scores could have afford an advantage in the *familiar* condition. We think that this alternative explanation certainly contributed to the reverse patterns in learning between the *novel* and *familiar* conditions but it does not explain how abilities in attention switching and social skill could have facilitated learning in the *familiar* condition. We argue that these mechanisms were an important factor for the faster learning in typical adults with low AQ scores when visual discrimination was no longer taxing between visual stimuli in the *familiar* condition.

One could also argue that differences between conditions might arise from differences in the amount of time spent in the lab or by other generic effects of training unrelated to the question of interest, such as possible reductions in anxiety in the *familiar* compared to the *novel* conditions. However, we doubt that these possibilities could explain the results. The familiarisation phase only lasted ~5 minutes and all participants in both conditions completed all tasks within an hour. Thus, the difference in time between the two conditions was negligible. Also, if anxiety were an issue, the training in the *familiar* condition should have benefitted participants with higher as opposed to lower AQ scores. ASD is often characterised by heightened levels of anxiety (Kim, Szatmari, Bryson, Streiner, & Wilson, 2000).

Furthermore, we can rule out any speed-accuracy trade-off effects in this study and the possibility that our results could be explained by differences in learning strategies. It is important to re-emphasise that participants were not instructed at any time to prioritise reaction time or accuracy and were thus left to their own learning strategies, thereby increasing external validity

to real-world learning. Had we biased participants towards a particular learning strategy with task instructions then we would have introduced an artificial constraint on the experiments that would have made learning one more step removed from how people learn in the real world. However, the visual-motor association learning task clearly produced two distinct reaction time patterns in both the *novel* and *familiar* conditions. Approximately half of participants in each condition started off more slowly and conservatively and then showed a decrease in reaction time as learning progressed, whereas the remaining half of participants started off more quickly and liberally and then demonstrated an increase in reaction time as learning progressed. As it turned out, AQ had no bearing on whether a person started off conservatively or liberally in either the *novel* or *familiar* conditions. In addition, the AQ effects that we observed for the accuracy data cannot be explained by a speed-accuracy trade-off effect as there appears to be no relationship between AQ and reaction times.

In closing, we make the case that abilities in visual discrimination and attention switching are dissociable across the degree of subclinical autistic traits in the general population, mirroring what is seen in the clinical ASD population. These findings have implications towards a greater understanding of visual-motor association learning in individuals with high degrees of subclinical autistic traits – for first degree relatives and members of the general population alike – as well as the potential for future health and educational applications for individuals with ASD. Future investigations evaluating how these mechanisms change throughout the lifespan would be of great benefit; in particular, investigating whether visual perception and executive functioning are innately dissociable or if the dissociation emerges as a function of age or experience. Information acquired from such investigations could potentially be used in the translation of educational approaches that could tailor to an individual's strengths and weaknesses.

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Table 1. Autism-Spectrum Quotient (AQ) demographic scores and sub-scale scores reported across the two experimental conditions. *Familiar* (N = 50) refers to the *familiar* condition with all participants included while *Familiar* (N = 47) refers to the *familiar* condition with the three participants removed.

	Mean (SD)			Range			<i>Novel</i> (N = 50) vs. <i>Familiar</i> (N = 50)		<i>Novel</i> (N = 50) vs. <i>Familiar</i> (N = 47)	
	<i>Novel</i> (N=50)	<i>Familiar</i> (N=50)	<i>Familiar</i> (N=47)	<i>Novel</i> (N=50)	<i>Familiar</i> (N=50)	<i>Familiar</i> (N=47)	t	p	t	p
Overall AQ	14.64 (5.10)	17.14 (6.03)	16.40 (4.93)	6 – 27	7 – 35	7 – 29	-2.24	*.027	-1.73	.087
Attention to Detail	5.56 (1.91)	6.20 (2.21)	6.13 (2.22)	1 – 9	0 – 10	0 – 10	-1.55	.125	-1.35	.179
Attention Switching	4.42 (2.57)	4.72 (2.22)	4.53 (2.14)	0 – 10	1 – 9	1 – 9	-0.62	.534	-0.23	.817
Imagination	2.14 (1.75)	2.16 (1.43)	2.13 (1.47)	0 – 7	0 – 6	0 – 6	-0.06	.950	0.04	.970
Communication	1.40 (1.16)	2.22 (2.20)	1.98 (1.96)	0 – 4	0 – 8	0 – 8	-2.33	*.022	-1.78	.078
Social Skill	1.12 (0.98)	2.06 (2.02)	1.87 (1.69)	0 – 3	0 – 9	0 – 8	-2.95	*.004	-2.70	*.008

Asterisks (*) denote significant differences.

Table 2. Learning as a function of AQ scores. The table presents the Pearson (r) correlation coefficients that were obtained between learning time and the various AQ scores in the *novel* condition (A), the *familiar* condition with all participants included (B), and the *familiar* condition with the three participants removed (C).

A. <i>Novel</i> condition (N = 50)	r	p
Overall AQ	-0.28	*.047
Attention to Detail	-0.31	*.027
Attention Switching	-0.21	.145
Imagination	0.05	.754
Communication	-0.18	.210
Social Skill	-0.18	.212
B. <i>Familiar</i> condition (N = 50)	r	p
Overall AQ	0.33	*.019
Attention to Detail	0.08	.564
Attention Switching	0.25	.078
Imagination	0.12	.396
Communication	0.12	.416
Social Skill	0.29	*.042
C. <i>Familiar</i> condition (N = 47)	r	p
Overall AQ	0.37	*.010
Attention to Detail	0.05	.730
Attention Switching	0.29	*.048
Imagination	0.12	.436
Communication	0.12	.408
Social Skill	0.25	.089

Asterisks (*) denote significant differences.

Table 3. Differences in learning between conditions. Z-scores assessing the significance difference in Pearson (r) correlation coefficients between the two conditions for various AQ scores with all participants included in the *familiar* condition (A) and with the three participants removed in the *familiar* condition (B).

A. <i>Novel</i> (N = 50) vs. <i>Familiar</i> (N = 50) conditions	z	p
Overall AQ	3.06	*.002
Attention to Detail	1.96	*.050
Attention Switching	2.27	*.023
Imagination	0.38	.704
Communication	1.46	.144
Social Skill	2.32	*.020
B. <i>Novel</i> (N = 50) vs. <i>Familiar</i> (N = 47) conditions	z	p
Overall AQ	3.17	*.002
Attention to Detail	1.75	.080
Attention Switching	2.40	*.017
Imagination	0.34	.737
Communication	1.44	.149
Social Skill	2.06	*.040

Asterisks (*) denote significant differences. Positive z scores denoting stronger positive correlations in the *familiar* compared to the *novel* condition.

Overview of study paradigm

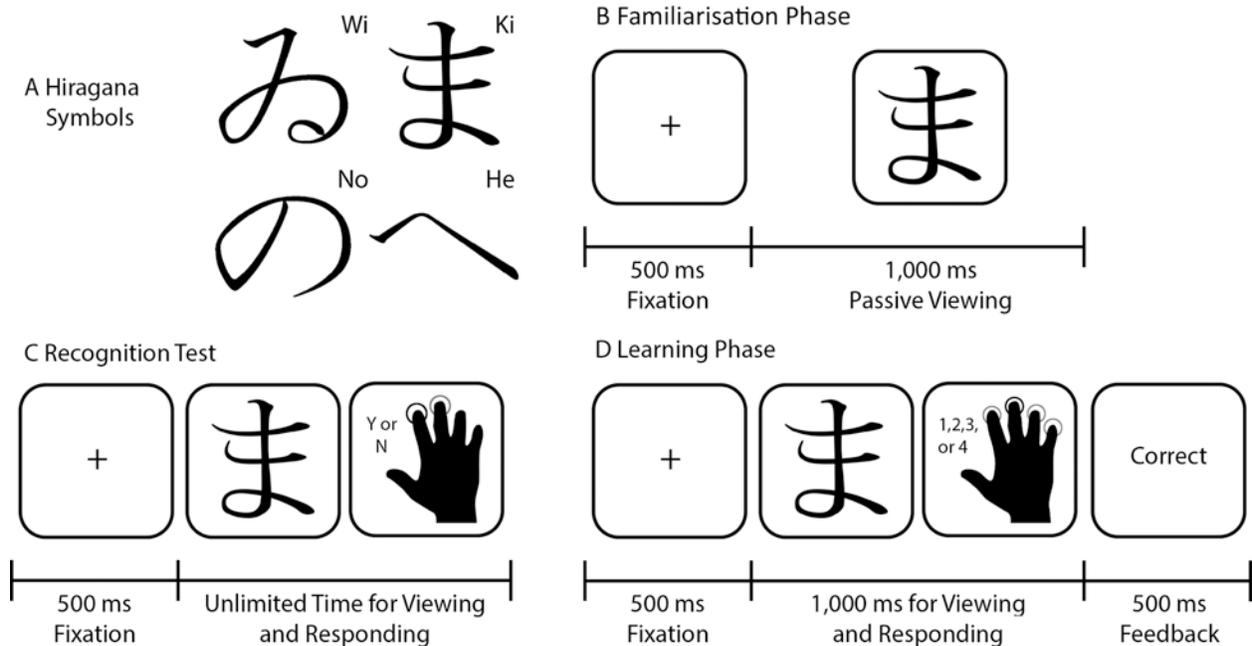


Fig. 1. Overview of study paradigm. Participants in both the *novel* and *familiar* conditions learned associations between four hiragana symbols (corresponding to the “wi”, “ki”, “no”, and “he” characters as shown in panel A) and four response buttons. Prior to this learning, participants in the *familiar* (but not the *novel*) condition underwent a familiarisation phase in which they passively viewed each stimulus so that they would become familiar with their physical attributes (panel B). Following this procedure, the participants were tested on a recognition task in which they had to indicate whether or not a visual stimulus had been presented during the familiarisation phase (panel C). Participants in both the *novel* and *familiar* conditions underwent the learning phase in which each stimulus was randomly presented one at a time in repeating chunks of four trials. The participant had to select one of four response buttons (“1”, “2”, “3”, and “Enter” on a numerical keyboard) and was then provided with visual feedback as to whether or not they had matched the correct response to the stimulus that was presented (panel D).

AQ Distributions

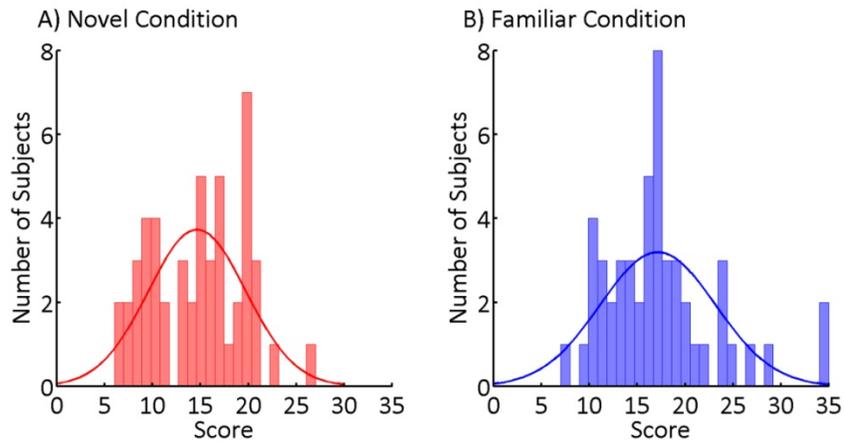


Fig. 2. AQ distributions. The figure shows the distribution of AQ scores for participants in the *novel* (panel A) and *familiar* (panel B) conditions. As shown in panel B, the *familiar* condition had two participants with high AQ scores.

Learning Curves

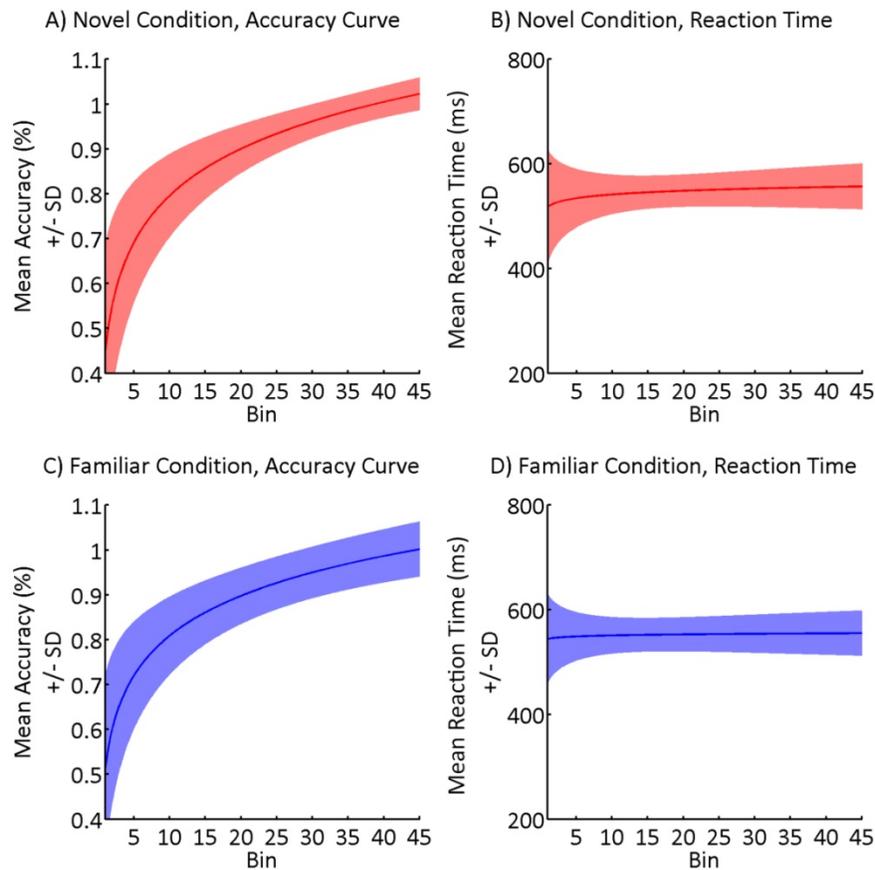


Fig. 3. Learning curves. For data analysis, we fit logarithmic curves for each participant's accuracy and reaction time data. In this figure we show the average and standard deviations across subjects in the *novel* (panel A: accuracy; panel B: reaction time) and *familiar* (panel C: accuracy; panel D: reaction time) conditions. In terms of accuracy, we found that all participants displayed positive slopes; namely, every participant became more accurate during the course of the training (panels A and C). Based on each participant's interpolated accuracy curve, we calculated when accuracy reached 90%, which served as our index of *learning time*. The smaller this value, the faster the participant learned the associations. In terms of reaction time, some participants had adopted a conservative strategy in which they started slowly and got faster while other participants adopted a liberal strategy in which they started quickly and got slower. This difference in strategy was reflected by a relatively constant average reaction time across time and a greater amount of variability at the beginning of training (panels B and D).

Novel Condition

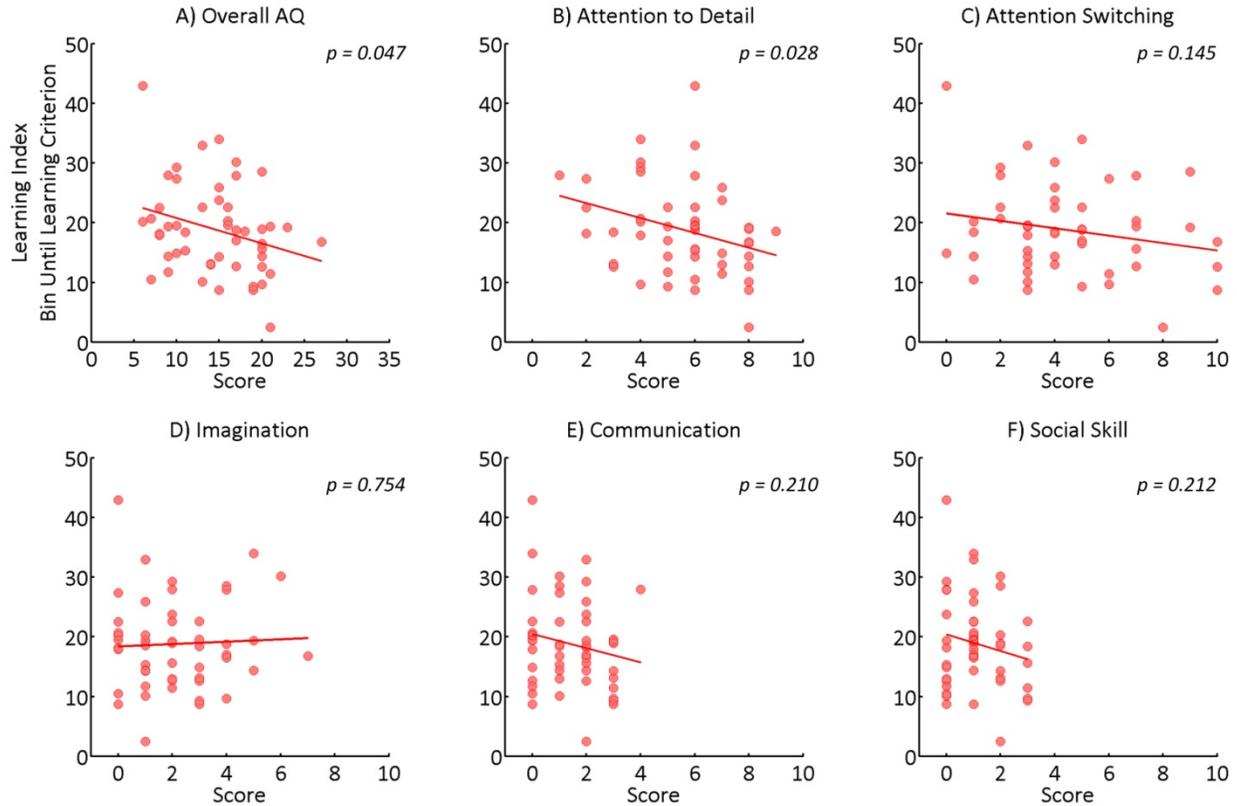


Fig. 4. Correlations in the *novel* condition. The figure shows how learning abilities in the *novel* condition changed as a function of Overall AQ (panel A) as well as how these abilities changed as a function of the Attention to Detail (panel B), Attention Switching (panel C), Imagination (panel D), Communication (panel E), and Social Skill (panel F) subscales of the AQ. The negative correlations for Overall AQ and Attention to Detail (panels A and B) show how participants with these higher AQ scores learned the visual-motor associations in a fewer number of trials. In other words, a greater presence of autistic characteristics in these measures correlated with learning abilities in the *novel* condition.

Familiar Condition

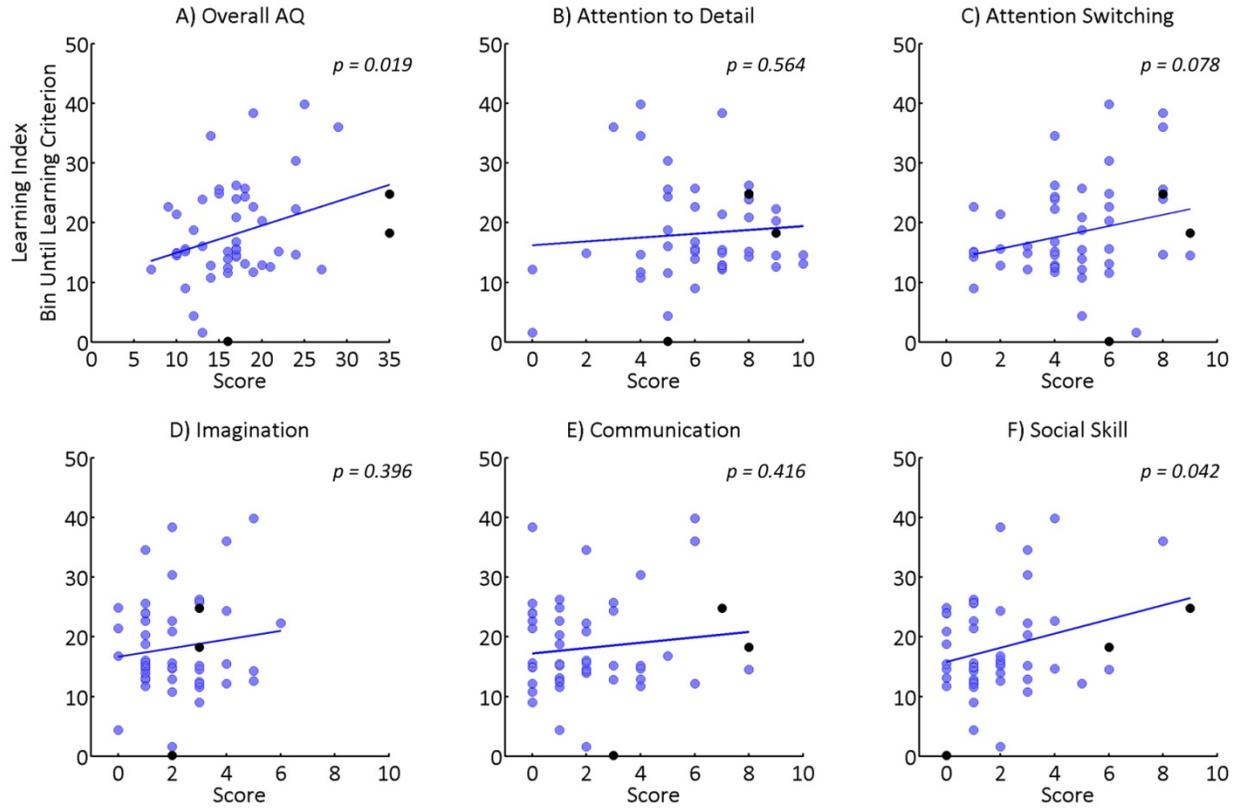


Fig. 5. Correlations in the *familiar* condition. The figure shows how learning abilities in the *familiar* condition changed as a function of Overall AQ (panel A) as well as how these abilities changed as a function of the Attention to Detail (panel B), Attention Switching (panel C), Imagination (panel D), Communication (panel E), and Social Skill (panel F) subscales of the AQ. The positive correlations for Overall AQ, Attention Switching (being close to significance), and Social Skill (panels A, C, and F) show how participants with these lower AQ scores learned the visual-motor associations in a fewer number of trials. In other words, less autistic characteristics in these measures correlated with learning abilities in the *familiar* condition. The darker circles indicate the three participants that were removed in the re-analysis of the data.