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Social and attention-to-detail subclusters of autistic traits differentially predict looking at eyes and face identity recognition ability

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This study distinguished between different subclusters of autistic traits in the general population and examined the relationships between these subclusters, looking at the eyes of faces, and the ability to recognize facial identity. Using the Autism Spectrum Quotient (AQ) measure in a university-recruited sample, we separate the social aspects of autistic traits (i.e., those related to communication and social interaction; AQ-Social) from the non-social aspects, particularly attention-to-detail (AQ-Attention). We provide the first evidence that these social and non-social aspects are associated differentially with looking at eyes: While AQ-Social showed the commonly assumed tendency towards *reduced* looking at eyes, AQ-Attention was associated with *increased* looking at eyes. We also report that higher attention-to-detail (AQ-Attention) was then indirectly related to *improved* face recognition, mediated by increased number of fixations to the eyes during face learning. Higher levels of socially relevant autistic traits (AQ-Social) trended in the opposite direction towards being related to *poorer* face recognition (significantly so in females on the Cambridge Face Memory Test). There was no evidence of any mediated relationship between AQ-Social and face recognition via reduced looking at the eyes. These different effects of AQ-Attention and AQ-Social suggest face-processing studies in Autism Spectrum Disorder might similarly benefit from considering symptom subclusters. Additionally, concerning mechanisms of face recognition, our results support the view that more looking at eyes predicts better face memory.

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Autism Spectrum Disorder (ASD) is a developmental disorder characterized by deficits in social communication, and restricted and repetitive behaviours or interests (American Psychiatric Association, 2013). Autistic traits also occur throughout the general population, varying along a continuum below the levels necessary for ASD diagnosis (American Psychiatric Association, 2013; Hoekstra, Bartels, Cath, & Boomsma, 2008; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). Here, we address the question of whether, in the general population, different subclusters of autistic traits are related to face recognition abilities, and if so whether such effects might be mediated via a tendency to look at, or away from, the eye region of the face.

Different clusters of autistic traits

There are a number of self-report measures that have been used to measure autistic traits in the general population. The Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) is widely used (see systematic review by Ruzich *et al.*, 2015). The AQ consists of 50 items, designed to assess the 'triad' of symptoms that were included in the clinical diagnosis of autism at the time the questionnaire was developed (social abnormalities, communication difficulties, and stereotyped and rigid behaviour) via ten questions assessing each of five different theoretical aspects (communication, social skills, imagination, attention-to-detail and attention switching; Baron-Cohen *et al.*, 2001). A total AQ score can be computed (AQ-Total), along with two factor-analytically derived subscales that we used in this study, specifically the Autism Spectrum Quotient-Social (AQ-Social), which measures socially relevant deficits (combining the highly correlated communication, social skills, imagination, and attention switching domains), and the Autism Spectrum Quotient-Attention-to-detail (AQ-Attention), which measures increased attention-to-detail (Hoekstra *et al.*, 2008). Note that while different factor analyses of the AQ have produced between two and five factors (Hoekstra *et al.*, 2008 [2]; Austin, 2005 [3]; Stewart & Austin, 2009 [4]; Kloosterman *et al.*, 2011 [5]), all include a social-interaction factor and an attention-to-detail factor. Further, a recent cluster analysis for the AQ, on a large data set of general-population adults, indicates that there is one group of people with more social difficulties and weaker detail orientation and another group of people with the opposite difficulties (Palmer, Paton, Enticott, & Hohwy, 2015).

The Broad Autism Phenotype Questionnaire (BAPQ; Hurley, Losh, Parlier, Reznick, & Piven, 2007) was also designed to assess the 'triad' of autistic symptoms, each with a 12-item subscale, which has generally been supported via factor analytic studies (Ingersoll, Hopwood, Wainer, & Donnellan, 2011). Given that diagnosis often finds the social and communication domains are inseparable, these two subfactors can also be combined into a 'Social' factor (Sasson, Nowlin, & Pinkham, 2013), leaving the rigidity subscale as a measure of non-social traits similar to the non-social AQ-Attention subscale of the AQ.

These 'Social' and 'Attention-to-Detail/Rigidity' subscales generally align with the two main symptom clusters in those with a clinical diagnosis of ASD identified by the DSM 5: social communication impairments, including deficits in social–emotional reciprocity, deficits in non-verbal communication and difficulty understanding relationships; and restricted, repetitive patterns of behaviour, interests, or activities, which may be abnormal in intensity or focus (Adolphs, Sears, & Piven, 2001; American Psychiatric Association, 2013; Frith, 1989; Pelphrey *et al.*, 2002; Shuster, Perry, Bebko, & Toplak, 2014).

Autistic traits and relation to face identity recognition

Clinically diagnosed ASD is well established to be associated with a number of face-processing difficulties (Dawson, Webb, & McPartland, 2005; Golarai, Grill-Spector, & Reiss, 2006; Hedley, Brewer, & Young, 2011; Sasson, 2006). Most relevant to the present study, these difficulties include poorer performance than controls in face identity recognition (for a review, see Weigelt, Koldewyn, & Kanwisher, 2012).

Within the general population, the question of whether higher autistic traits are similarly associated with poorer face recognition has been addressed in three recent studies. Hedley *et al.* (2011) found no significant correlation between performance on the Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006) and the AQ-Total across a general-population sample (n = 42). Rhodes, Jeffery, Taylor, and Ewing (2013) also used the CFMT and reported different patterns of associations for the different subclusters of autistic traits. Specifically, AQ-Social was *negatively* associated with a face-selective memory score (CFMT, partialling out general visual memory assessed via the Cambridge Car Memory Test; Dennett *et al.*, 2011) in a sample of undergraduate males (n = 30; although not for females, n = 82). In contrast, AQ-Attention was *positively* associated with CFMT performance in females (although not in males). Similarly, Sasson *et al.* (2013), using the BAPQ with a sample of undergraduates (n = 74), found the Social-Pragmatic Language subscale was *negatively* correlated with performance on the Benton Facial Recognition Test (Benton, Hamsher, & Varney, 1983), while the Rigidity subscale in contrast showed a small, non-significant, trend towards a *positive* association.

Together, these results suggest that analysing overall autistic traits (e.g., AQ-Total) can hide a tendency for the social aspects of autistic traits to be related to *poorer* face recognition, while the rigid personality and attention-to-detail traits tend to be related in the opposite direction, to *better* face recognition. Moreover, the results of Rhodes *et al.* (2013) above suggest there could also be sex differences in the association between face recognition and different subclusters of autistic traits. One aim of the present study was to provide additional data on these issues, using the AQ-Social and the AQ-Attention as predictors of face recognition performance (measured using the CFMT) in the general population.

The possibility of attention-to-eyes as a mediating factor linking autistic traits to face recognition

We also test a possible explanation of *why* it might be that the social and attention-to-detail clusters of autistic traits might show opposite trends of association with face recognition. Specifically, we test the novel hypothesis that these relationships might be mediated by differential effects of the autism trait subclusters on the amount of *looking at the eyes of the* face. We derive our proposals from two key ideas.

The first is that *more looking at eyes* is likely to be associated with *better face recognition* (and vice versa). This idea is supported by a correlational study in which individuals with higher face recognition ability (on an old–new task) directed their gaze to the eye region more frequently and made more saccades between the eyes during face learning, compared to those with lower face recognition ability (Sekiguchi, 2011; although note these findings were not replicated in Mehoudar, Arizpe, Baker, & Yovel, 2014). Additionally, three studies that experimentally manipulated participants' looking locations found face recognition accuracy was higher when the first fixations were on the eyes than when they were on the mouth, arguing for a causal link between more looking at the eyes and improved face recognition (Hills, Cooper, & Pake, 2013; Hills & Lewis, 2011;

Hills, Ross, & Lewis, 2011). Importantly, all of these studies were in the general population, and did not measure autistic traits.

Second, *higher autistic traits* might be associated with *reduced looking at eyes*. This proposal has received considerable attention in studies of people with a diagnosis of ASD. Current evidence is contradictory. Several studies have found that during free scanning of faces, people with ASD show fewer fixations and/or less total dwell time to internal facial features, especially the eyes, compared to controls (Cassidy, Mitchell, Chapman, & Ropar, 2015; Hernandez *et al.*, 2009; Jones, Carr, & Klin, 2008; Pelphrey *et al.*, 2002; and for dynamic faces in Speer, Cook, McMahon, & Clark, 2007). Infants later diagnosed with ASD also showed a general decline in fixation to the eyes from 2 until 24 months of age, with an increase in fixations to the mouth and objects (Klin, Shultz, & Jones, 2015). However, others have not obtained these findings (e.g., Freeth, Chapman, Ropar, & Mitchell, 2010; static faces in Speer *et al.*, 2007; Wilson, Palermo, & Brock, 2012). Moreover, a similar contradiction is present even in reviews and meta-analyses, with a conclusion of reduced looking at eyes in ASD in Papagiannopoulou, Chitty, Hermens, Hickie, and Lagopoulos (2014), but not in Falck-Ytter and von Hofsten (2011), or Guillon, Hadjikhani, Baduel, and Rogé (2014). Further, the contradiction is also present in the smaller number of studies testing the general population: for example, one study has found higher autistic traits to be associated with less eye contact in response to direct gaze (Chen & Yoon, 2011), but another found higher autistic traits showed no association with proportion of looking to the eye half of the face (i.e., the top half) compared to the non-eye half (i.e., the bottom half; Vabalas & Freeth, 2015).

Importantly, these studies have not distinguished between the separate social and attention-to-detail symptom clusters of autistic traits. We suggest it is possible that some of the variation across the literature may depend on the particular balance of symptoms in the samples, specifically whether the sample contained primarily people for whom socially relevant deficits were more prevalent, or primarily people for whom the restricted/repetitive behaviour symptoms were more prevalent. Theoretically, the idea of reduced looking at the eyes in ASD has typically been conceived as a social deficit (DSM 5; APA, 2013; Itier & Batty, 2009), reflecting a deficit in non-verbal social interaction. If so, this suggests that higher *socially* related autistic traits (e.g., as measured by AQ-Social) may be related to *reduced* looking at eyes. In contrast, concerning attention-to-detail, there seems no particular theoretical reason to think that the *non-social* aspects of ASD would be related to reduced looking at eyes. In fact, the eye region could be considered the most important local detail within the face (Emery, 2000; Gosselin & Schyns, 2001; Itier & Batty, 2009), and people with ASD often demonstrate local processing biases (Wang, Mottron, Peng, Berthiaume, & Dawson, 2007), suggesting that perhaps higher attention-to-detail (e.g., AQ-Attention) might be related to *increased* looking at eyes.

To our knowledge, no previous studies have reported looking-at-eyes data separately for the social and attention-to-detail clusters of autistic traits. However, two studies in ASD have reported data relevant to the social aspect, with results consistent with our first proposal above. Both studies correlated social awareness/responsiveness (as measured by the Social Responsiveness Scale SRS, Constantino & Gruber, 2005) with gaze behaviour, and found greater social awareness was associated with more looking at eyes (for emotionally intense film clips with multiple characters, Speer *et al.*, 2007; in structured interaction with a real person, Hanley *et al.*, 2015).

To summarize, we have developed two key ideas relevant to our study in the general population: that the social and attention-to-detail aspects of autistic traits may have opposite-direction effects on amount of looking at eyes; and that more looking at eyes is likely to be associated with better face recognition. Together, these ideas lead us to test two specific hypotheses: (1) stronger social autistic traits (higher AQ-Social) could be associated with *less* looking at eyes, which in turn could lead to *poorer* face recognition, while in contrast (2) stronger attention-to-detail (higher AQ-Attention) may be associated with *increased* looking at eyes, which in turn could lead to *better* recognition of faces.

Present study design

We used a regression and mediation analysis approach within the general population to examine the relationships between (1) AQ-Social and AQ-Attention as separate predictor variables representing the two core clusters of autistic traits, (2) amount of looking to eyes as a mediator variable, and (3) face identity recognition performance as the dependent variable. This design allowed us to test whether AQ-Social and AQ-Attention were directly associated with face recognition ability and, separately, whether there were any indirect associations between the subclusters of AQ traits and face recognition ability mediated by less/more looking at the eyes.

We examined two measures of the amount of looking at eyes: number of fixations and dwell time (i.e., total time spent looking at the interest area). We also examined effects separately for looking at the eyes during face *learning* (i.e., during the study phase) and during face *memory* (i.e., during the later test phase). Note Sekiguchi (2011) reported that performance (i.e., accuracy during the face memory test) was more strongly associated with having looked more at eyes while learning the faces than it was with looking more at eyes during the test phase. We also evaluated whether any mediation effects were specific to looking at eyes, rather than attention to the face more generally, by running separate analyses with amount of looking at the mouth as the mediating variable.

To measure face recognition performance, we used two tasks. First, as in Rhodes *et al.* (2013), we used the Cambridge Face Memory Task format (Duchaine & Nakayama, 2006). The CFMT involves studying six target faces and then testing participants' recognition of novel images of these faces (e.g., in different viewpoints or lighting conditions, to assess face recognition, not merely picture recognition), in a series of three-alternative-forced-choice trials. The CFMT is a well-established and widely used test that provides a reliable and valid measure of individual differences in face recognition ability (Bowles *et al.*, 2009). However, its use of multiple faces displayed simultaneously is not ideal for this kind of eye-movement study because faces are scanned and processed differently when presented simultaneously, where attention may be allocated across several faces for comparison, compared to when presented one at a time sequentially (Meissner, Tredoux, Parker, & MacLin, 2005; Stacey, Walker, & Underwood, 2005). Thus, our analysis does not use eye movements during the CFMT task, but instead is based on eye-movement results obtained from a second face recognition task, comprising an old–new recognition design in which participants learned faces during a study phase, were then tested on novel images of these 'old' faces interleaved among new distracter faces, and in both learning and test phases the faces were presented one at a time.

Method

Participants

Participants were 90 university students who were reimbursed either with course credit or with $30. (An additional three originally tested were removed – two for uncorrected visual abnormalities and another for pressing only one response button for all memory trials.) All were Caucasian (to match the race of the face stimuli); 57 were female, ranging in age from 18 to 29 years ($M = 20.0$, $SD = 2.8$), and 33 were male, ranging in age from 18 to 35 years ($M = 21.6$, $SD = 4.2$). Of these, one male and three females had missing data for one of the measures (e.g., due to computer failure) and so could not be included in mediation analyses (which require scores on all measures) but were included in analyses of bivariate associations wherever possible (i.e., they had a score on both variables). Three females scored at or above the recommended clinical cut-off of 32 on the AQ-Total in the binary scoring system (scoring 32, 40, and 41; Baron-Cohen *et al.*, 2001), suggesting these individuals could potentially meet diagnostic criteria for autism. Given there was no full diagnostic evidence that these individual do in fact have ASD, they were retained for analysis because they form part of the expected continuous distribution of AQ scores (following Rhodes *et al.*, 2013).

The study was approved by, and conducted in accordance with the guidelines of, the local Human Research Ethics Committee.

Session structure

Each participant was tested individually in two 1-hr sessions. Session 1 contained the old–new task, including eye-tracking measurements. Session 2 included: the CFMT-Aus (with eye-tracking that will not be discussed here), then a demographic questionnaire (including age, sex, race), and then the AQ (Baron-Cohen *et al.*, 2001; and some additional questionnaires that will not be discussed).

Autistic traits: The AQ subscales

Autistic traits were measured using the 50-item AQ, in which responses are on a 4-point response scale: definitely agree, slightly agree, slightly disagree, and definitely disagree (Baron-Cohen *et al.*, 2001). Following Hoekstra *et al.* (2008), we scored each item from 1 to 4, reverse scoring where necessary, such that higher scores correspond to more autistic-like behaviour (e.g., poor social skill, more attention-to-detail). AQ-total scores were summed across all items (range from 50 to 200), whereas the AQ-Social scores were the sum from 40 items and the AQ-Attention the sum of the other 10 items. Note that the 4-point scoring method is important, for example because Ingersoll *et al.* (2011) found that Baron-Cohen *et al.*'s original binary scoring method (i.e., collapsing the two 'agree' categories and the two 'disagree' categories) produced factor reliability that was less than desirable (e.g., only .58 for AQ-Attention), and also did not reveal the expected sex differences. With the 4-point scoring for our present study, reliability was satisfactory (e.g., .870 for the 40-item AQ-Social, and .786 for the 10-item AQ-Attention; Table 1), and also the expected pattern of sex differences in autistic traits was found (i.e., men scored higher than women on AQ-Total and AQ-Social; Table 2).

Measures of face identity recognition

Cambridge Face Memory Test-Australian (CFMT-Aus)

The CFMT-Australian (CFMT-Aus; McKone *et al.*, 2011 – which uses primarily British-heritage faces that are well matched to our Australian participants in ethnicity) was run using the standard CFMT procedure described in full in Duchaine and Nakayama (2006). In CFMT tasks, all faces are shown without hair, clothing, facial fair, jewellery, or glasses.

Table 1. Internal consistency results

Measure	Cronbach's α	*n* Items	*n* Participants
AQ-Total	0.868	50	88
AQ-Attention	0.786	10	88
AQ-Social	0.870	40	88
Old–New task	0.850	18	88
CFMT-Aus	0.824	72	90

Table 2. Means and *SD* for males and females for CFMT-Aus (% correct), AQ-total, and AQ subscales

	Males			Females		
	M	*SD*	*n*	*M*	*SD*	*n*
AQ-Total	110.30	11.13	33	103.27	16.38	55
AQ-Social	85.88	10.58	33	78.93	13.50	55
AQ-Attention	24.42	3.85	33	24.35	6.29	55
CFMT-Aus	83.64	9.27	32	78.81	9.29	58

Note. Based on Hoekstra *et al.* (2008), AQ scores were calculated from the original 4-point scale (definitely agree, slightly agree, slightly disagree, and definitely disagree), with approximately half of the 50 items reverse-scored. All of the items were summed, resulting in a minimum AQ-Total of 50 and a maximum of 200. The AQ-Social consists of 40 items (scale range = 40–160) and the AQ-Attention 10 items (scale range = 10–40). For each scale, a higher score indicates a higher level of autistic-like traits.

The faces in the test are all of one sex (male) and one race (here, Caucasian). In Stage 1 of the task (18 trials total), participants study six target people. Each person's face is shown in three views to encourage face rather than photograph learning. For Target 1, the face is first shown in three-quarter view looking to the left, for 2 s, followed immediately by a three-alternative-forced-choice (3AFC) test trial containing the same image of Target 1 with two distractor faces (i.e., of other people) also looking to the left; next, Target 1's face is shown front-view, with a front-view 3AFC test trial; next Target 1's face is shown three-quarter view looking to the right with a right-looking 3AFC test trial. This procedure is then repeated for Target 2–6. Most general-population participants perform at or near ceiling in Stage 1. Following completion of Stage 1, a review opportunity is provided, with all six target faces presented together simultaneously (in front view) for 20 s. In Stage 2, 30 3AFC trials test generalization of recognition to novel images of the six target faces. On a given trial, any of the six target faces could be present (with two non-target distractors), always in a novel photograph of the target (new lighting and/or viewpoint) from that studied in Stage 1. Following Stage 2, there is another review opportunity, with all six target faces simultaneously. Finally, Stage 3 presents 24 3AFC trials using novel images in which the faces have had visual noise added to increase task difficulty. Performance was scored as per cent correct (calculated from all 72 items). Internal consistency was good (Table 1).

Old–new face identity recognition task, including eye-tracking

In the old–new task (Figure 1), we required participants to study the faces of 54 people and then recognize these from among 54 new (distracter) people. During the learning phase, 18 of the 54 faces were presented in a standard unrestricted scanning condition

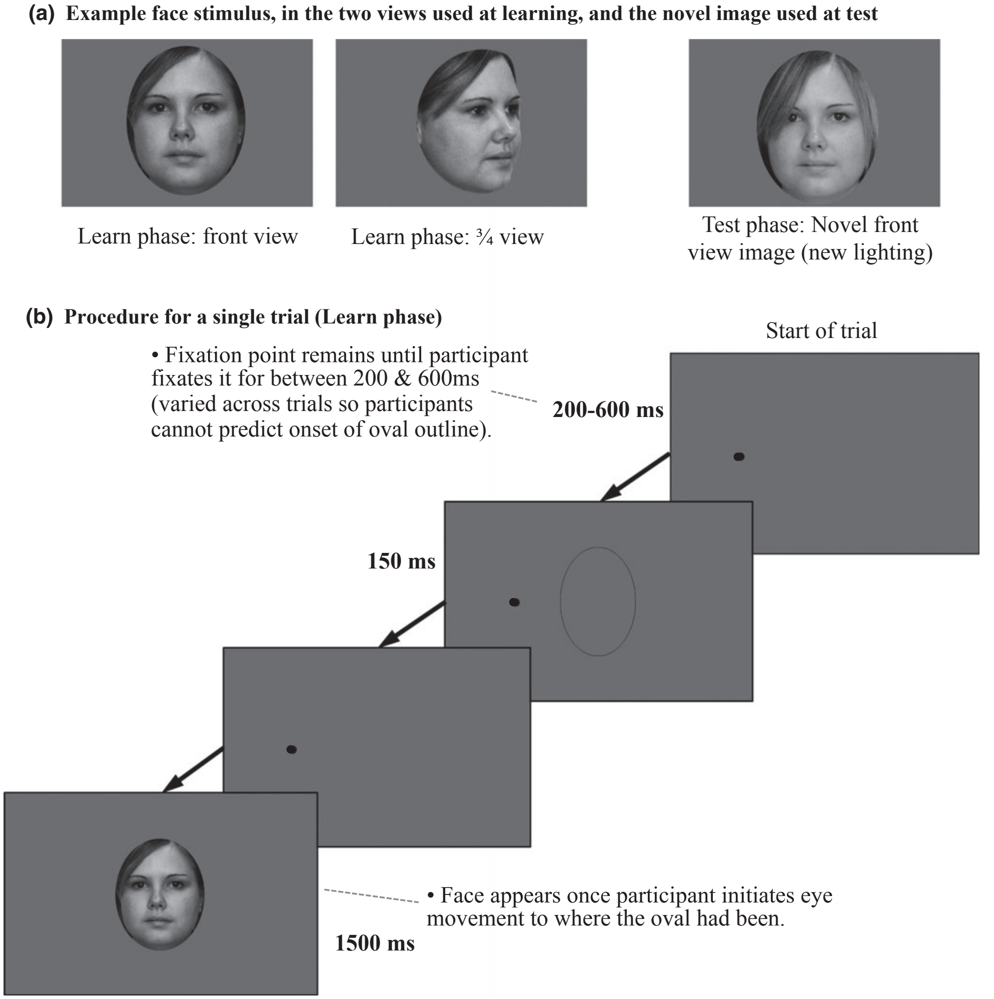

Figure 1. Old–new face memory task stimuli and procedure. (a) Example face stimulus. (b) Procedure for a single trial of the Learning phase. Face image from the GUFD (Burton, White, & McNeill, 2010).

where participants were free to scan the face as they normally would, and it is this condition for which data are reported in the present study.[1] Eye-tracking was employed during both learning and memory-test phases of the old–new task to measure where participants were looking within each face.

Apparatus and eye-tracking. Eye movements were recorded with an SR Research EyeLink 1000 desktop-mounted eye-tracker placed under the flat-screen monitor. Stimuli

[1] *On the remaining trials, attention was pre-cued to the location of either the eyes or the mouth (using an elliptical area of increased luminance). These conditions were included so that if it were the case that our unrestricted viewing condition showed that one (or both) of the AQ subscales was related to poorer face recognition, and that this was mediated via reduced looking at eyes, then we would be able to test whether cueing higher-AQ participants directly to look at the eyes on their first fixation would remediate their poorer face recognition. However, our results did not show the relevant mediated relationship, and thus, the issue of remediation via cueing to eyes became irrelevant; thus, results for the cueing conditions are not presented.*

were presented, and responses recorded, using the EyeLink Experiment Builder software on a 24-inch iMac (measuring 51.85 by 32.4 cm; screen resolution 1920 by 1,200 pixels, and refresh rate 60 Hz). The screen was 90 cm from participants' eyes. Head movement was restricted by a headrest. The point of gaze of the left eye was recorded at a sampling rate of 500 Hz. A standard 9-point calibration method (Cornelissen, Peters, & Palmer, 2002) was used to calibrate and validate eye-tracking before and throughout the experiment as needed.

Stimuli. Face stimuli were photographs of 108 Caucasian people, each in two viewpoints (front and 3/4), displaying neutral expression, converted to greyscale. We took images from the following: Karolinska Directed Emotional Faces (KDEF; Lundqvist, Flykt, & Öhman, 1998); Radboud Faces Database (RaFD; Langner *et al.*, 2010); Glasgow Unfamiliar Face Database (GUFD; Burton *et al.*, 2010); MIT Center for Biological and Computational Learning (MIT-CBCL; 1996) face database; and Surveillance Cameras Face Database (SCFD; Grgic, Delac, & Grgic, 2011). Faces were edited to exclude backgrounds and hair, while retaining external face contours, and then equated for mean luminance, and were approximately 11.5° tall (measured from top of forehead to base of chin) by either 7.9° wide for front view (measured between outermost point of cheeks) or 7.0° for three-quarter view (from outermost cheek to just before the ear). This approximately corresponds to the size of a real face at an ordinary conversation distance of 90 cm (i.e., our viewing distance).

Learning phase. During the learning phase, each face was seen four times in a row: in front-view, then three-quarter, then front again, and then three-quarter again. This gave a total of 216 study trials during which eye movements could be tracked (54 people in four study trials per person; of which 72 trials were in the unrestricted scanning condition). During each trial, the participant first looked at a small fixation circle to one side of the screen, which remained until the participant fixated it for between 200 and 600 ms (Figure 1). Next, an oval outline flashed for 150 ms marking one of three positions in which the face would appear and then when the participant moved their gaze towards that location the face appeared. The fixation point was located on the side of the screen so that when participants moved their eyes to the face, they could engage in their natural scanning patterns (i.e., free scanning) without having started their first 'fixation' automatically at the location of the fixation point (had this been put where a part of the face would appear). Each face image was presented for 1,500 ms, and participants were instructed to spend this time studying the face. Items were presented in the same pseudorandom order for all participants.

Recognition phase. After the study phase, participants were given a 2-min break, after which another calibration was run and the test phase began. During the recognition phase, participants were presented with all 108 (54 targets and 54 distractors) faces sequentially, with one 2-min break halfway through. Each person appeared once, in a novel unstudied image (front view, in a different specific photograph and/or different lighting conditions from those used of the person during study). These images were interleaved with images of faces that participants had not seen previously. Images were presented in the same pseudorandom order for all participants. Procedure on each test-phase trial was as follows: a small circle was fixated to one side of the screen, and then, each face was centrally presented until the participant responded old or new. Recognition accuracy was calculated as ability to discriminate old from new faces, using the Signal Detection Theory measure, d′ (Green & Swets, 1966). Internal consistency of the d′ scores was at least as high as for the CFMT (Table 1).

Practice phase. Prior to the main old–new task, a practice version allowed participants to adjust to using the eye-tracker to trigger the beginning of trials.

Measures of looking at the eyes (from old–new task), and choice of control region. To calculate looking measures, we used two interest areas (IAs), each defined as shown in Figure 2 by an elliptical region, one surrounding the eyes, and the other surrounding the mouth. Each IA was 2.8° (4.4 cm) vertical by 6.3° horizontal (9.97 cm) when viewed from a distance of 90 cm. For the eyes, the IA included part of the eyebrow and much of the upper nose (the upper nose was included due to evidence that fixating on the upper nose indicates attention being allocated to extract information from the eye region; Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006; van Belle, Ramon, Lefèvre, & Rossion, 2010). For the control mouth region, the IA extended to just below the nose and included the lower cheeks and part of the upper chin. Our choice of the mouth as the control IA was driven by three key criteria: that the control region should be based around a major facial feature; that it should be the same physical size as the eye IA (so that any random fixations would fall equally often in both areas); and that it should be sufficiently far from the eyes to avoid including extraction of eye information (e.g., exclude the top of the nose). Papers investigating eye gaze behaviour in ASD have previously used the mouth as a comparison region (Chen & Yoon, 2011; Hanley *et al.*, 2015).[2]

For each individual participant, *number of fixations* was calculated as follows: The number of separate fixations falling within the IA was computed for each face

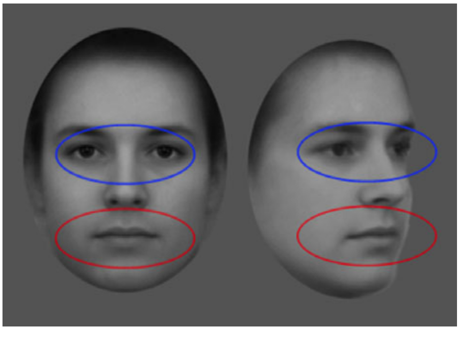

Figure 2. Interest areas (IAs) for the eyes (blue) and mouth (red) for a front-view and three-quarter-view face.

[2] *Note the results we report for the mouth control region were replicated for an alternative larger control region comprising the entire bottom half of the face (e.g., as used by Vabalas & Freeth, 2015; see Supporting information).*

image (ignoring the duration of each fixation), and the final score used in analysis was obtained by averaging this value across all images; that is, for the study stage, we summed across all four images for each of the 18 faces (then divided by 72), and for the test stage, we averaged across all 18 old plus 54 new faces. *Dwell time* within the IA was calculated as the total time spent with the eyes looking inside the IA (i.e., summing duration of all fixations) and was likewise averaged across all relevant face images.

Note that we report *absolute* number of fixations and dwell time in the IA, rather than number of fixations in the IA as a proportion of the total number of fixations made anywhere in the face. This is for theoretical reasons, namely that the construct of interest in ASD and autistic traits is the absolute amount of attention given to the eyes (which could be grossly overestimated by a relative measure if, for example, a person high on autistic traits largely ignored the face altogether, but the one short fixation they did make on the face happened to land on the eyes).

Preliminary data checks

Range and distribution

For the planned correlational and mediation analyses to be statistically valid, it is important that variables have a broad range and are normally distributed. Table 3 demonstrates this was the case. All tests of normality were non-significant (all ps > .06), and skew and kurtosis were within acceptable limits for use with parametric analyses (Stuart & Kendall, 1958). In regression analyses, there were no multivariate outliers, according to Mahalanobis distances, the assumption of linearity was fulfilled as identified by scatterplots, the assumption of homoscedasticity (homogeneity of variance) was also found to be fulfilled as identified through scatterplots and Levene's test, and collinearity diagnostic tests revealed no evidence of multicollinearity.

Table 3. Descriptive statistics

Measure	*n*	Min.	Max.	Mean	*SD*	Skew	Kurtosis
Old–New task (d′)	88	0.19	3.31	1.74	0.65	0.33	−0.14
CFMT-Aus (% correct)	90	55.6	98.6	80.9	9.5	−0.43	−0.24
AQ-Attention	88	11	37	24.4	5.4	−0.21	−0.45
AQ-Social	88	52	118	81.5	12.9	0.48	0.33
# Fixations eyes (Learn)	88	1.00	4.44	2.68	0.78	0.03	−0.54
Dwell time eyes (Learn)	88	349	1,229	823	218	−0.26	−0.69
# Fixations mouth (Learn)	88	0.01	1.15	0.35	0.25	1.11	1.05
Dwell time mouth (Learn)	88	3.2	373	96	78	1.39	2.08
# Fixations eyes (Test)	88	0.11	9.56	3.21	1.76	1.03	1.59
Dwell time eyes (Test)	88	31	3,216	894	528	1.28	3.26
# Fixations mouth (Test)	88	0.00	2.44	0.68	0.53	0.99	0.70
Dwell time mouth (Test)	88	0.00	851	196	165	1.36	2.29

Note. d′ is discrimination between old and new faces: 0 = chance memory performance; higher numbers = more accurate face recognition. AQ-Attention has a maximum possible score of 40, and a minimum possible score of 10. The AQ-Social has a maximum possible score of 160, and a minimum possible score of 40. # Fixations = number of fixations per face image in interest area. Dwell time = total number of ms per face image spent gazing in interest area.

Validating old–new task via correlation with CFMT

Validity of our old–new task as a measure of face recognition ability (rather than merely general memory) was supported via a correlation with the established CFMT format of $r = .502$, $p < .001$, $n = 87$. In the context of the upper bound correlation for the two tasks of .700, a correlation of .502 is considered a medium–high correlation. Importantly, the correlation between CFMT and general non-face visual memory is much lower ($r = .26$ for 3AFC abstract art task, $r = .37$ for Cambridge Car Memory Test; Wilmer *et al.*, 2010; Dennett *et al.*, 2011).

Results

Before turning to our core analyses concerning the relationships between AQ, looking at the eyes, and face recognition, we investigated whether those analyses should include age and sex as covariates. Also note that in the bulk of the Results section, all mention of 'looking at eyes' or 'mouth' refers to looking at these regions during *learning* the faces; results for looking at these regions during the test phase of the recognition memory task are presented in a separate section at the end of the Results. The key findings of the study are summarized in Figure 3.

Rationale for including age and sex as covariates

Results indicated age and sex each correlated significantly with one or more of the core variables. Concerning sex effects, as expected males scored higher than females for AQ-Total, $F(1, 86) = 4.752$, $MSE = 1019.394$, $p = .032$, and AQ-Social $F(1, 86) = 6.386$, $MSE = 996.673$, $p = .013$, and there were no sex differences on AQ-Attention $F(1, 86) = 0.004$, $MSE = 0.128$, $p = .948$ (Table 2; replicating the results of Baron-Cohen *et al.*, 2001; also see Rhodes *et al.*, 2013). Sex also significantly affected face recognition performance on CFMT-Aus accuracy (with males scoring more accurately than females in the 3AFC task), $F(1, 88) = 4.447$, $MSE = 386.074$, $p = .038$ (Table 2), although not on the old–new d′ measure, $F(1, 88) = 0.145$, $MSE = 0.063$, $p = .704$. Sex did not significantly affect number of fixations on the eyes $F(1, 87) = 1.689$, $MSE = 0.601$, $p = .197$, or total dwell time on the eyes, $F(1, 87) = 0.002$, $MSE = 47890.398$, $p = .969$.

We found that increasing age across our young-adult age range was associated with improved face recognition on the CFMT-Aus, $r = .324$, $p = .002$, $n = 90$ (replicating previous findings with the CFMT over this age range, Susilo, Germine, & Duchaine, 2013), and there was a similar-direction trend approaching significance for the old–new task ($r = .205$, $p = .052$, $n = 90$). Age did not significantly affect number of fixations on the eyes ($r = .022$, $p = .839$, $n = 88$), or total dwell time on the eyes ($r = -.087$, $p = .420$, $n = 88$). Age was not associated with any of the AQ measures (all ps $\geq .130$).

Overall, these results showed that sex and age each had significant correlations with the independent variables (AQ subscales) and/or the dependent variables (face memory tasks), although not with the mediator variables (looking at eyes). For fair comparison across different relationships of interest, we included age and sex as covariates for all analyses to follow.

Relationship between AQ factors and looking at the eyes during learning

Our first question was whether scores on the AQ-Attention and AQ-Social were related to looking at the eyes during face learning and, if so, in what direction. As we had hypothesized could be the case, the two different AQ subscales showed different patterns

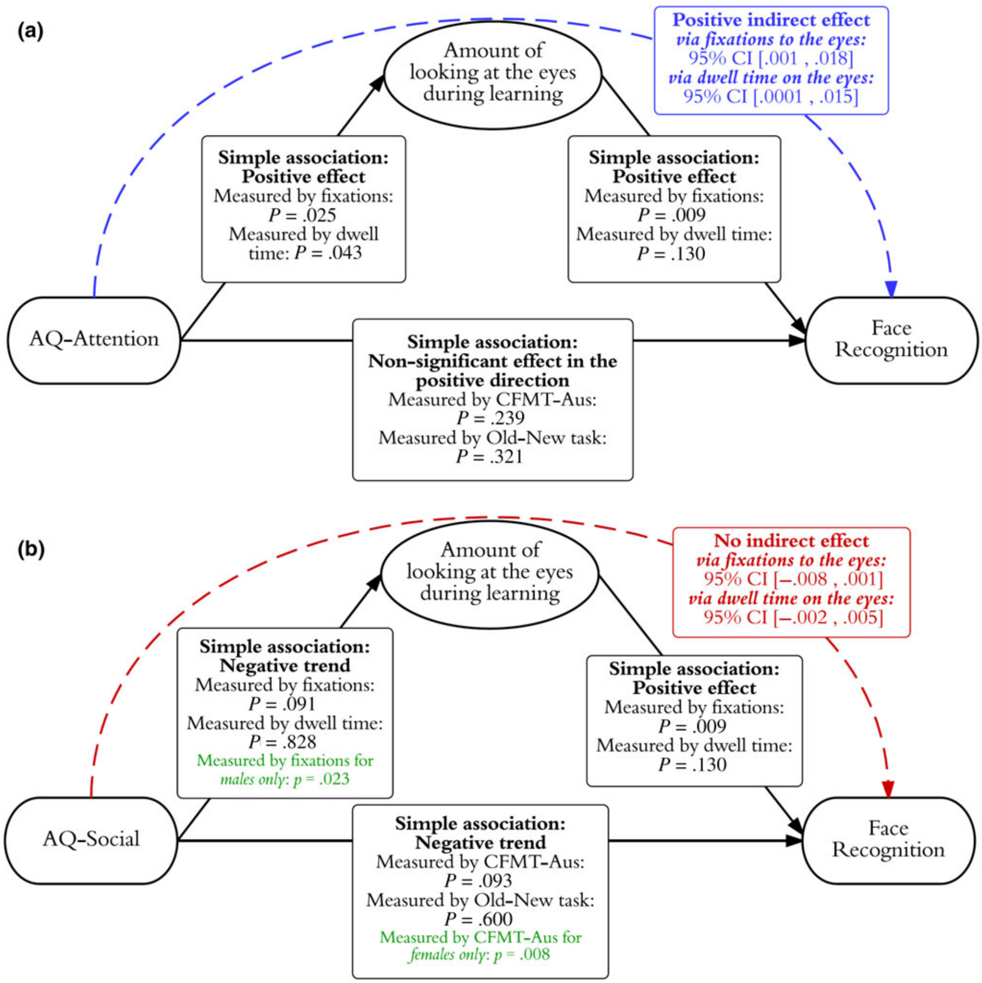

Figure 3. Summary figure of the key findings of the study. (a) Increased attention-to-detail (AQ-Attention) had a significant association with *increased looking at eyes* (partial correlation between AQ-attention and look-at-eyes measures removing covariates; see Table 4), and then with *improved* face recognition *indirectly* via increased looking at eyes (mediation analyses indirect effect; see Table 7). (b) Increased social autistic traits (AQ-Social) had a trend towards an association with *poorer* face recognition (significant for females on CFMT; partial correlation in Table 6), with no evidence of mediation by reduced looking at eyes (no indirect effect in Table 7). All results have age and sex removed as covariates (except where analysis is noted to be for a single sex of participants, where age was the only covariate). All looking-at-eyes measures refer to natural preference (unrestricted scanning) to look at the eyes during face learning.

of association with looking at the eyes. Results are presented in Table 4 (with scatterplots in Figure 4). First, higher AQ-Attention (i.e., greater attention-to-detail) was associated with significantly *greater* looking at eyes during learning, as assessed by both more fixations to the eyes (p = .025) and significantly longer dwell time on the eyes (p = .043). In contrast, higher AQ-Social (i.e., higher levels of socially relevant autistic traits) trended in the opposite direction, towards *less* looking at the eyes. On the number of fixations measure, this trend approached significance for the full sample (p = .091) and was significant within males analysed separately (i.e., males with higher AQ-Social showed fewer fixations on the eyes than males with lower AQ-Social; $p = .023$); on the total dwell time measure, dwell time on the eyes was not significantly associated with AQ-Social.

To test whether the association between AQ factors and gaze was specific to increased looking at the eyes, we also analysed looking at the mouth. Results (Table 4) revealed AQ-Social scores were not associated with looking at the mouth for either number of fixations ($p = .617$) or dwell time ($p = .725$). Likewise, AQ-Attention was not associated with looking at the mouth for either number of fixations ($p = .282$) or dwell time ($p = .291$).

Relationship between looking at the eyes and face recognition

Replicating Sekiguchi (2011), our results showed that increased looking at the eyes during learning on the old–new task was associated with improved face recognition (Table 5). This relationship was statistically significant for number of fixations on the eyes ($p = .009$), with a small non-significant trend in the same direction for total dwell time

Table 4. Regression outputs testing whether AQ subscales (AQ-Social and AQ-Attention) predict looking at eyes (and mouth) during learning

							Correlations	
DV	Model		*B*	*SE B*	β	*p*	Zero-order	Part
# Fixations eyes	1	Sex	0.222	0.182	.137	.226	.124	.133
		Age	0.012	0.025	.055	.629	.022	.053
	2	Sex	0.126	0.187	.078	.500	.124	.072
		Age	0.003	0.025	.012	.914	.022	.011
		AQ-Social	−0.012	0.007	−.199	.091	−.173	−.182
		AQ-Attention	**0.035**	**0.015**	**.248**	**.025**	**.208**	**.243**
. . .. Males only	1	Age	0.011	0.031	.063	.738	.063	.063
	2	Age	−0.037	0.032	−.220	.260	.063	−.191
		AQ-Social	**−0.028**	**0.012**	**−.426**	**.023**	**−.370**	**−.400**
		AQ-Attention	**0.069**	**0.034**	**.368**	**.051**	**.303**	**.339**
Dwell time eyes	1	Sex	−14.033	51.128	−.031	.784	−.006	−.030
		Age	−6.559	7.112	−.104	.359	−.097	−.101
	2	Sex	−15.771	53.256	−.035	.768	−.006	−.032
		Age	−6.586	7.245	−.105	.366	−.097	−.099
		AQ-Social	−0.435	1.989	−.026	.828	−.045	−.024
		AQ-Attention	**8.983**	**4.375**	**.227**	**.043**	**.225**	**.223**
# Fixations mouth	1	Sex	0.121	0.056	.237	.033	.184	.230
		Age	0.016	0.008	.223	.044	.166	.216
	2	Sex	0.110	0.059	.216	.065	.184	.198
		Age	0.015	0.008	.205	.073	.166	.193
		AQ-Social	−0.005	0.005	−.117	.282	−.136	−.115
		AQ-Attention	−0.001	0.002	−.058	.617	−.173	−.053
Dwell time mouth	1	Sex	24.010	17.771	.150	.180	.109	.146
		Age	3.857	2.472	.174	.123	.138	.169
	2	Sex	21.485	18.825	.135	.257	.109	.124
		Age	3.559	2.561	.160	.168	.138	.151
		AQ-Social	−1.645	1.546	−.118	.291	−.131	−.115
		AQ-Attention	−0.248	0.703	−.042	.725	−.128	−.038

Note. DV = dependent variable. In each case, Model 1 includes only the covariates, and Model 2 tests for significant effects of the AQ subscales over and above the covariates alone (marked in bold).

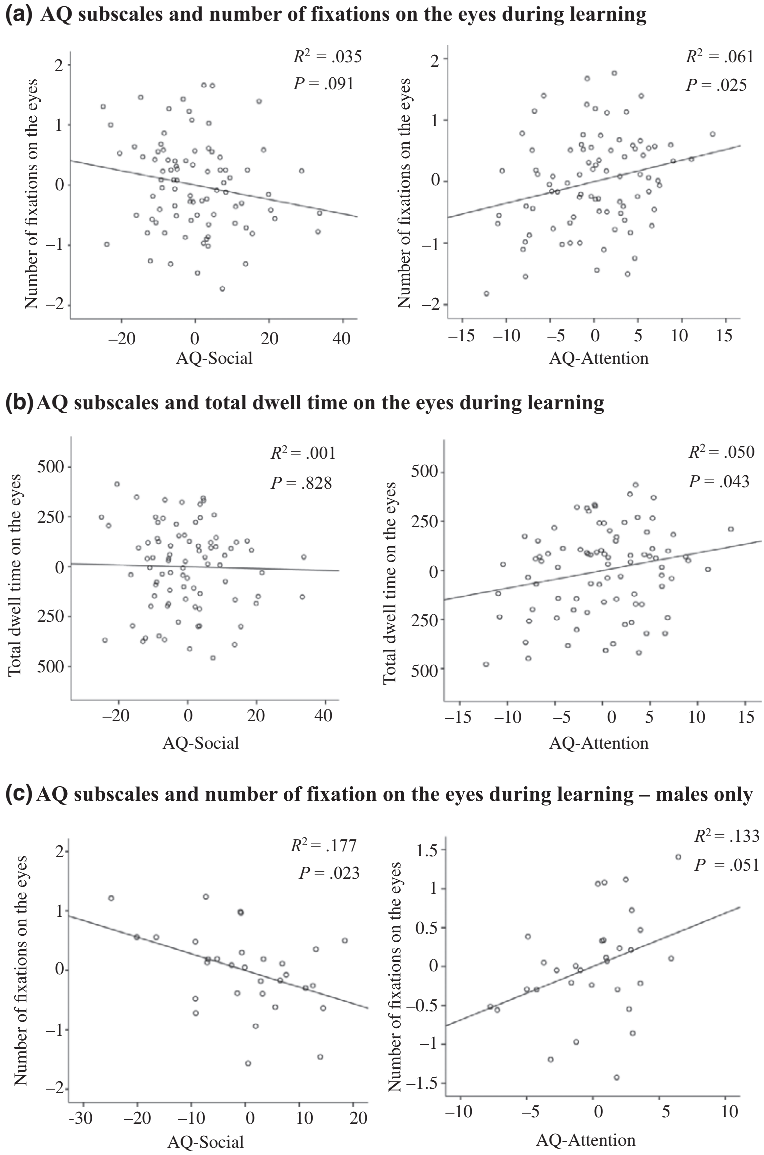

Figure 4. Partial regression plots (axes show residuals - differences from the average score) indicating relationships between the AQ subscales and looking at eyes (during learning): (a) as measured by number of fixations on the eyes; (b) as measured by total dwell time on the eyes; (c) for number of fixations for males only.

(p = .130). Increased looking at the mouth, in contrast, showed no association with better face recognition, for either number of fixations (p = .782) or dwell time (p = .854).

Relationships between AQ-Attention and face recognition, both direct and via looking at the eyes

Figure 3a summarizes the results of the first-order and mediated associations between AQ-Attention, looking at the eyes during learning, and face recognition performance. In this

Table 5. Regression outputs testing whether amount of looking at the eyes (and mouth) during learning predict face recognition performance (old–new d′)

DV		Model	*B*	*SE B*	β	*p*	Correlations	
							Zero-order	Part
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.046	0.146	.034	.752	.025	.033
		Age	0.038	0.020	.200	.062	.198	.194
		# Fix eyes	**0.233**	**0.087**	**.276**	**.009**	**.285**	**.273**
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.108	0.148	.079	.469	.025	.077
		Age	0.044	0.021	.230	.037	.198	.223
		Dwell eyes	0.000	0.000	.161	.130	.142	.161
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.094	0.154	.069	.541	.025	.065
		Age	0.040	0.021	.210	.064	.198	.200
		# Fix mouth	0.080	0.288	.031	.782	.073	.030
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.108	0.151	.079	.479	.025	.076
		Age	0.042	0.021	.219	.052	.198	.210
		Dwell mouth	0.000	0.001	−.020	.854	.014	−.020

Note. DV = dependent variable. In each case, Model 1 includes only the covariates, and Model 2 tests for significant effects of the eye-movement measure over and above the covariates alone (marked in bold). # Fix eyes = number of fixations per face image on the eyes. Dwell eyes = total number of ms per face image spent on the eyes. # Fix mouth = number of fixations per face image on the mouth. Dwell mouth = total number of ms per face image spent on the mouth.

figure, each first-order association (straight-line link between AQ-Attention and face recognition) is the simple bivariate correlation (adjusted for covariates age and sex) between the variables. The indirect association from a separate mediation analysis is indicated by the dashed-line curve between AQ-Attention and face recognition, drawn over the top of the mediating variable of amount of looking at the eyes during learning; this is analysed separately via number of fixations to the eyes and via total dwell time on the eyes.

Results showed the following. First, considering the first-order association, increased attention-to-detail (i.e., higher AQ-Attention scores) showed small, non-significant, trends towards being associated with *improved* face recognition performance. As detailed in Table 6, this association between AQ-Attention and face recognition was in the positive direction, but for the full sample was non-significant for both CFMT-Aus (p = .239) and the old–new task (p = .321) and also remained non-significant when the analyses were repeated for each sex of participants separately.

Second, considering the indirect association, results showed a clearer positive relationship in which higher AQ-Attention (increased attention-to-detail) was significantly associated with improved face recognition via an indirect link through increased looking at the eyes during learning. We ran mediation models using the Preacher and Hayes (2008)

Table 6. Regression outputs testing whether AQ subscales (AQ-Social and AQ-Attention) predict face recognition performance (CFMT-Aus accuracy, and old–new task d′)

DV	Model		*B*	*SE B*	β	*p*	Correlations	
							Zero-order	Part
CFMT-Aus	1	Sex	−3.533	2.032	−.180	.086	−.246	−.176
		Age	**0.815**	**0.285**	**.296**	**.005**	**.336**	**.289**
	2	Sex	**−4.635**	**2.117**	**−.236**	**.031**	**−.246**	**−.219**
		Age	**0.703**	**0.290**	**.256**	**.018**	**.336**	**.242**
		AQ-Social	−0.136	0.080	−.185	.093	−.140	−.170
		AQ-Attention	0.209	0.177	.121	.239	.084	.119
. . . Females only	1	Age	0.669	0.441	.204	.135	.204	.204
	2	Age	0.572	0.432	.175	.192	.204	.169
		AQ-Social	−**0.253**	**0.092**	−**.368**	**.008**	−**.355**	−**.351**
		AQ-Attention	0.244	0.199	.165	.226	−.026	.156
. . . Males only	1	Age	**0.931**	**0.366**	**.421**	**.016**	**.421**	**.421**
	2	Age	**1.029**	**0.432**	**.465**	**.022**	**.421**	**.402**
		AQ-Social	0.202	0.152	.234	.194	.079	.220
		AQ-Attention	0.195	0.429	.082	.652	.257	.075
Old–New task d′	1	Sex	0.142	0.146	.105	.334	.051	.103
		Age	**0.047**	**0.021**	**.246**	**.026**	**.223**	**.240**
	2	Sex	0.117	0.155	.087	.452	.051	.080
		Age	**0.044**	**0.021**	**.234**	**.041**	**.223**	**.221**
		AQ-Social	−0.003	0.006	−.061	.600	−.104	−.056
		AQ-Attention	0.013	0.013	.108	.321	.092	.106
. . . Females only	1	Age	0.017	0.032	.073	.598	.073	.073
	2	Age	0.016	0.033	.069	.642	.073	.066
		AQ-Social	−0.003	0.007	−.055	.711	−.062	−.052
		AQ-Attention	0.003	0.015	.028	.852	−.003	.026
. . . Males only	1	Age	0.070	0.027	.419	.015	.419	.419
	2	Age	0.053	0.031	.319	.103	.419	.276
		AQ-Social	−0.003	0.011	−.047	.790	−.159	−.044
		AQ-Attention	0.040	0.032	.222	.225	.346	.204

Note. DV = dependent variable. In each case, Model 1 includes only the covariates, and Model 2 tests for significant effects of the AQ subscales over and above the covariates alone (marked in bold).

PROCESS macro. Results revealed a significant indirect effect of AQ-Attention on old–new d′, mediated by number of fixations on the eyes (Table 7, Model 1; indirect effect = 0.07, *SE* = 0.004, 95% CI [0.001, 0.018]), and (in a separate model) dwell time on the eyes (Table 7, Model 2; indirect effect = 0.005, *SE* = 0.003, 95% CI [0.0001, 0.015]).

Third, these patterns were specific to mediation via the eyes. Similar mediation analyses revealed that AQ-Attention did not predict face recognition through number of fixations on the mouth (indirect effect = −.0002, *SE* = 0.002, 95% CI [−0.006, 0.003]) or through dwell time on the mouth (indirect effect = 0.006, *SE* = 0.002, 95% CI [−0.001, 0.006]; see Supporting information Tables S4 and S5 for details).

Taken together, in terms of the relationship between AQ-Attention and face recognition, these findings are consistent with the proposal that higher AQ-Attention can result in greater looking at the eyes of the face during face learning and that this in turn leads to improved face recognition performance.

Table 7. Mediation models: statistics from the Preacher and Hayes (2008) process, for four mediation models, covering each AQ subscale (AQ-Attention, then separately AQ-Social) predicting face recognition (old–new d′) via mediator of looking at eyes (separately measured as number of fixations to eyes, and as total dwell time on eyes)

Model	DV	IV(s)	*B*	*SE B*	*t*	*p*	LLCI	ULCI
1. AQ-A → d′ via # fix eyes	# Fix eyes	AQ-A	0.030	0.015	1.961	.053	−0.0004	0.060
	d′	AQ-A	0.010	0.013	0.814	.418	−0.015	0.036
	d′	# Fix eyes	**0.242**	**0.090**	**2.677**	**.009**	**0.062**	**0.422**
		AQ-A	0.003	0.013	0.255	.800	−0.022	0.028
	d′	Indirect AQ-A	**0.007**	**0.004**			**0.001**	**0.018**
2. AQ-A → d′ via Dwell eyes	Dwell eyes	AQ-A	8.793	4.262	2.063	**.042**	0.312	17.274
	d′	AQ-A	0.010	0.013	0.814	.418	−0.015	0.036
	d′	Dwell eyes	0.001	0.0003	1.621	.109	−0.0001	0.001
		AQ-A	0.006	0.013	0.439	.662	−0.020	0.032
	d′	Indirect AQ-A	**0.005**	**0.003**			**0.0001**	**0.015**
3. AQ-S → d′ via # fix eyes	# Fix eyes	AQ-S	−0.009	0.007	−1.252	.214	−0.023	0.005
	d′	AQ-S	−0.002	0.006	−0.368	.714	−0.014	0.010
	d′	# Fix eyes	**0.247**	**0.089**	**2.768**	**.007**	**0.069**	**0.424**
		AQ-S	0.0000	0.006	0.002	.998	−0.011	0.011
	d′	Indirect AQ-S	−0.002	0.002			−0.008	0.001
4. AQ-S → d′ via Dwell eyes	Dwell eyes	AQ-S	0.376	1.987	0.1894	.850	−3.578	4.331
	d′	AQ-S	−0.002	0.006	−0.368	.714	−0.014	0.010
	d′	Dwell eyes	0.001	0.0003	1.772	.080	−0.0001	0.001
		AQ-S	−0.002	0.006	−0.410	.683	−0.014	0.089
	d′	Indirect AQ-S	0.0002	0.002			−0.002	0.005

Note. Significant effects are in bold. All models were run with age and sex as covariates. AQ-A = AQ-Attention. AQ-S = AQ-Social. # Fix eyes = number of fixations per face image on the eyes. Dwell eyes = total number of ms per face image spent on the eyes. Indirect AQ-A = the indirect effect of AQ-Attention (on d′), mediated by number of fixations (or dwell time) on the eyes. Indirect AQ-S = the indirect effect of AQ-Social (on d′), mediated by number of fixations (or dwell time) on the eyes. Missing *t* and *p* values are because the Preacher and Hayes (2008) process Bootstrap model does not calculate these for the indirect effect; instead, confidence intervals are used to infer the significance of the indirect effect (LLCI = lower limit for 95% confidence interval; ULCI = upper limit for 95% confidence interval; confidence intervals that do not cross zero indicate a significant indirect effect). Hayes (2013) puts forth a compelling argument for using such an approach (instead of a Sobel test, for example). Particularly, the Bootstrap confidence intervals have fewer assumptions and increased power to detect effects, producing a more accurate method of inferring significance (Hayes, 2013).

Relationships between AQ-Social and face recognition, both direct and via looking at the eyes

We repeated the analyses above using AQ-Social as the initial predictor. Results are summarized in Figure 3b. The key finding was that results for AQ-Social were quite different than for AQ-Attention. First, higher AQ-Social (i.e., increased socially relevant autistic traits) tended to be associated with *worse* face recognition (i.e., a negative association), and there was certainly no evidence of an association with *better* face recognition as revealed for AQ-Attention. Table 6 shows that the first-order association between AQ-Social and face

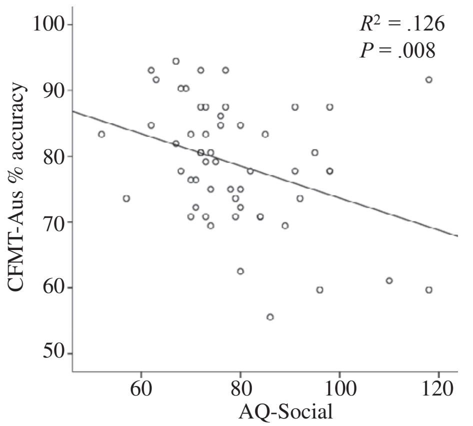

Figure 5. Scatterplot indicating negative correlation between AQ-social and face recognition ability (CFMT-Aus) for females.

recognition trended in the negative direction, for CFMT (p = .093; with a very small effect in the same negative direction for the old–new task, p = .600). The negative association reached significance for females on the CFMT (p = .008)[3] ; a scatterplot of this association is shown in Figure 5. Second, there was no mediated association between AQ-Social and old–new face recognition via looking at eyes, either for number of fixations (Table 7, Model 3; small negative effect; indirect effect = −.002, SE = 0.002, 95% CI [−0.008, 0.001]) or for dwell time (Table 7, Model 4; very small effect in positive direction; indirect effect = 0.0002, SE = 0.002, 95% CI [−0.002, 0.005]).

Again, mediation analysis showed AQ-Social did not predict face recognition through looking at the mouth (indirect effect via number of fixations on the mouth <.0001, SE = 0.001, 95% CI [−0.002, 0.002]; indirect effect via dwell time on the mouth = 0.0002, SE = 0.001, 95% CI [−0.001, 0.003]; Table S5).

Overall, these results indicate an association between higher AQ-Social with poorer face recognition for females (on the CFMT), but not for males. Results also indicated no indirect effect of AQ-Social on face recognition via reduced looking at the eyes.

How reliable is the null mediation effect for AQ-Social?

We found significant indirect mediation via looking at eyes for a relationship between AQ-Attention and face recognition, but no evidence of any looking-at-eyes-mediated relationship between AQ-Social and face recognition. Given that the latter is a null effect, the question of how reliable it is arises. A number of observations about our data suggest the lack of significant indirect effect for AQ-Social is a genuine null effect rather than a weak mediation effect that might be detectable with a larger sample size.

First, it is important to note that for the indirect effect of AQ-Social on face recognition, the small trends that were present were in *opposite directions for the two measures of looking at eyes* (number of fixations, small negative trend, i.e., indirect effect = −.002,

[3] *Note this significant association could not be attributed to the inclusion of three females in our sample whose AQ-Total scores were at or above the clinical cut-off value (see Participants section) because a significant negative association was still apparent when their data were excluded (*p *= .017). This is consistent with the observation that Figure 5 shows no bivariate outliers.*

SE = 0.002, 95% CI [−0.008, 0.001]; dwell time, small positive trend, i.e., indirect effect = 0.0002, *SE* = 0.002, 95% CI [−0.002, 0.005]). This suggests that increasing sample size would be unlikely to reveal a consistent effect in one direction.

Second, we were able to detect a significant indirect effect for AQ-Attention using our sample size even though the *reliability estimate for relevant associations was lower for AQ-Attention than AQ-Social*. This is indicated by standard error values and the widths of 95% CIs. For the first-order association between AQ subscales and looking at eyes, Table 4 shows that *SE B* was approximately twice as large for the AQ-Attention-to-looking-at-eyes associations (0.015 for # fixations, 4.375 for dwell time) as it was for the AQ-Social-to-looking-at-eyes associations (*SE B* = 0.007 for # fixations, 1.989 for dwell time). It was also the case for the mediation effect, where Table 7 shows the widths of the 95% CI range for the via-eyes mediation effects were again much wider for AQ-Attention as the predictor (95% CI range = 0.017 for # fixations, calculated as ULCI of 0.018 minus LLCI of 0.001; and 0.015 for dwell time) than for AQ-Social as the predictor (95% CI range = 0.009 for # fixations; and 0.007 for dwell time). This argues that with the same sample size as for AQ-Attention, and *less* error variance (greater reliability), we had *more* power to detect indirect mediation-via-eyes effects involving AQ-Social than AQ-Attention. This suggests the lack of AQ-Social indirect effect cannot be attributed to lack of power (except to detect a very small effect, i.e., much smaller than the indirect effect found involving AQ-Attention).

Effects involving looking at the eyes during the test phase (memory retrieval)

We repeated all analyses involving the looking at the eyes where looking was computed from the memory test-phase trials. AQ subscales did not predict looking at eyes during test (*p*s > .58). Further, mediation analyses found no indirect relationships between AQ subscales and face recognition performance via looking at eyes during test (*p*s > .33; Tables S3 and S4). However, increased looking at the eyes during test was associated with improved face recognition; this was significant for both fixations on the eyes (Table 8; *p* = .003) and total dwell time (Table 8; *p* = .013).

Discussion

Our key findings, in the general population, were as follows. First, the two different subclusters of autistic traits were differentially related to eye movements to faces: Higher levels of autistic ‘attention-to-detail’ (AQ-Attention) predicted *more* looking at the eyes during learning, while higher levels of socially relevant autistic traits (AQ-Social) tended to predict *less* looking at eyes. Second, individual differences in looking at eyes then predicted face recognition performance: More fixations made to the eyes during learning were associated with better face recognition performance. Third, and consistent with the first two findings, higher levels of autistic attention-to-detail traits (AQ-Attention) were indirectly related to *improved* face recognition, mediated by increased number of fixations to the eyes. Fourth, in contrast, higher levels of socially relevant autistic traits (AQ-Social) trended in the opposite direction, towards being related to *poorer* face recognition (significantly so for females on the CFMT). Finally, there was no evidence of any mediated relationship between the social traits (AQ-Social) and face recognition via reduced looking at eyes.

Table 8. Regression outputs testing whether amount of looking at the eyes (and mouth) during test predict face recognition performance (old–new d′)

DV		Model	*B*	*SE B*	β	*p*	Correlations: Zero-order	Correlations: Part
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.101	0.142	.074	.480	.025	.072
		Age	0.047	0.020	.247	.021	.198	.239
		# Fix eyes	**0.116**	**0.038**	**.310**	**.003**	**.287**	**.308**
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.121	0.145	.089	.404	.025	.086
		Age	0.049	0.020	.258	.018	.198	.247
		Dwell eyes	**0.000**	**0.000**	**.263**	**.013**	**.224**	**.260**
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.107	0.150	.078	.479	.025	.076
		Age	0.042	0.021	.219	.051	.198	.210
		# Fix mouth	−0.035	0.134	−.028	.794	−.001	−.028
d′	1	Sex	0.104	0.149	.076	.488	.025	.074
		Age	0.041	0.021	.216	.051	.198	.210
	2	Sex	0.104	0.150	.076	.488	.025	.074
		Age	0.042	0.021	.220	.051	.198	.212
		Dwell mouth	0.000	0.000	−.029	.787	−.002	−.029

Note. DV = dependent variable. In each case, Model 1 includes only the covariates, and Model 2 tests for significant effects of the eye-movement measure over and above the covariates alone (marked in bold). # Fix eyes = number of fixations per face image on the eyes. Dwell eyes = total number of ms per face image spent on the eyes. # Fix mouth = number of fixations per face image on the mouth. Dwell mouth = total number of ms per face image spent on the mouth.

We now consider how these findings relate to, and can be integrated with, the previous literature. We first discuss results from studies of the general population. Implications for those with a diagnosis of ASD will be considered subsequently.

Are different subclusters of autistic traits differentially associated with preferences for looking at, or away from, the eyes?

To our knowledge, no previous studies have examined whether preferences to look towards, or away from, the eyes differ for the social and attention-to-detail subclusters of autistic traits (either in the general population, or in diagnosed ASD). Interestingly, and consistent with our original hypotheses, we found different effects of AQ-Social and AQ-Attention: Higher social traits were associated with *less* looking at eyes during face learning (significant for males, and approaching significance for the whole sample combined), while higher attention-to-detail traits were associated with *more* looking at eyes during learning (significant for the whole sample).

Mechanisms of face recognition: Are individual differences in face recognition ability associated with preferences for looking at eyes?

Two previous studies have used general-population individual differences studies to ask whether people who naturally look more at eyes might show better face recognition ability. Of these, Sekiguchi (2011) found this effect, while Mehoudar *et al.* (2014) did not. Our results are in agreement with Sekiguchi's, in that we found individuals who fixated more often on the eyes showed better face recognition performance. This relationship was present for eye movements during both learning and at test. Given that three other studies have found experimentally manipulating fixations to fall on the eyes improves face recognition (Hills & Lewis, 2011; Hills *et al.*, 2011, 2013), we conclude that taken together, there is now good evidence that increasing fixations on the eyes is associated with greater face recognition ability.

Are different subclusters of autistic traits associated with opposite effects on face recognition, and why?

While the 'default' expectation might be that higher levels of autistic traits are associated with poorer face recognition – as has been established in those with a diagnosis of ASD (Weigelt *et al.*, 2012) – previous studies in the general-population range have found inconsistent results (Hedley *et al.*, 2011; Rhodes *et al.*, 2013; Sasson *et al.*, 2013). Following Rhodes *et al.* (2013), we hypothesized that one reason for this might be that different subclusters of autistic traits are associated with face recognition ability in opposite directions; we also put forward the novel hypothesis that opposite-direction subcluster effects might have some mediation via looking at eyes.

Figure 6 summarizes our present results on the relationship between trait subclusters and face recognition performance, together with those of the two previous studies that have presented relevant data, namely Rhodes *et al.* (2013) who split the AQ into AQ-Social and AQ-Attention as we have done here, and Sasson *et al.* (2013) who split the BAPQ into Social-Pragmatic Language and Rigid Personality. Overall, it can be seen that although there is not a complete agreement about details of significance levels across the various studies, there appears to be a consistent pattern in terms of the direction of the trends: Higher social aspects of autistic traits tend to be associated with *poorer* face recognition, while higher attention-to-detail (AQ) or rigidity (BAPQ) aspects of autistic traits tend to be associated with *better* face recognition.

Considering each of these effects separately, the social-aspect relationship with face recognition is statistically significant in at least one sex in all three studies. This suggests that the relationship is relatively robust (even with modest sample sizes; see Figure 6). Our present results, however, provided no support for our original idea that this negative-direction relationship is mediated by less looking at eyes. Instead, our results suggest it likely has some other cause.

Turning to the attention-to-detail/rigidity aspect, Figure 6 shows the *direct* relationship with face recognition is not significant in any study; that is, there are very small effects although consistently in a positive direction. Importantly, however, the present study found that there was a significant *indirect* positive relationship between the attention/rigidity aspect and improved face recognition that operates via increased looking at the eyes. This provides support for our original hypothesis concerning attention-to-detail (AQ-Attention), namely that more attention-to-detail would lead to more looking at eyes which in turn would lead to better face recognition performance.

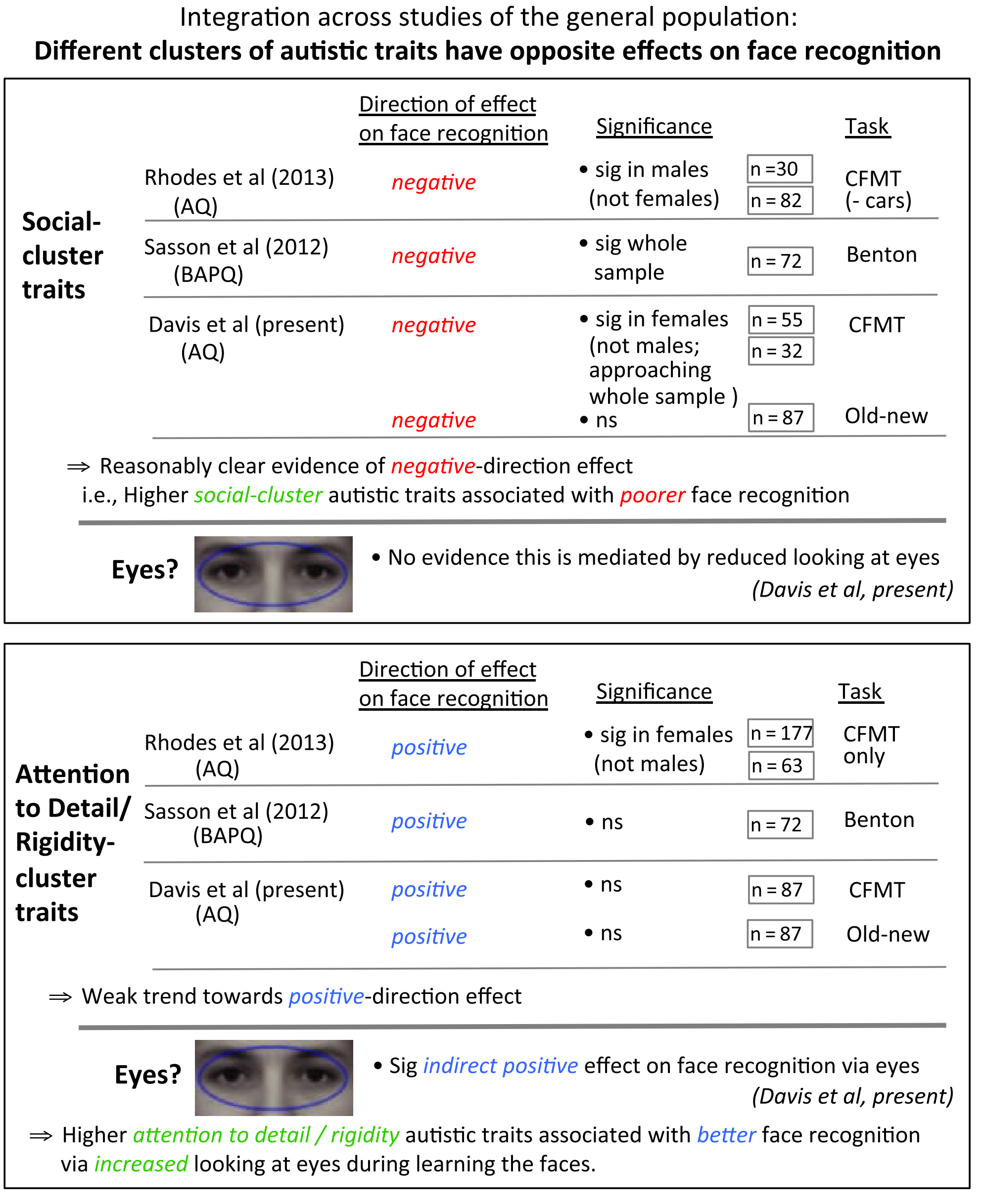

Figure 6. Integrating our present results with those of previous general-population studies. Overall, findings are consistent with the view that different clusters of autistic traits affect face recognition in opposite directions; we also found here this was mediated by more looking at eyes (during learning) with higher attention-to-detail (AQ-Attention), but not less looking at eyes with higher social autistic traits.

Limitations and open questions

One limitation is that our participants were relatively young and would likely be of above average intelligence (university students). However, such factors are unlikely to have affected our results, given (1) AQ distributions do not differ between general-population samples and student samples (Baron-Cohen *et al.*, 2001) and (2) face recognition ability is unrelated to intelligence (for a review, see McKone & Palermo, 2010).

A more important limitation concerns sex differences. Both our study and that of Rhodes *et al.* (2013) have suggested sex differences in the relationship between autistic-trait subclusters and face recognition. However, the differences have been inconsistent across studies: We found AQ-social's relationship with face recognition to be significant for females (and not for males), while Rhodes *et al.* (2013) found it to be significant for males (and not for females). Possibly, these differences could have some theoretically interesting origin, arising perhaps from the fact that the dependent measure in Rhodes *et al.* (2013) was face-*selective* recognition ability (specifically face memory *minus* car memory) while we used simple face recognition ability, or related perhaps to evidence in the literature for sex differences in autistic symptomatology and associated difficulties (Lai *et al.*, 2013; Mandy *et al.*, 2012; Rivet & Matson, 2011). However, we urge caution in drawing such conclusions at this stage, due to the small sample sizes involved. Neither the present study nor that of Rhodes *et al.* (2013) was designed to have the sample sizes that would be required to test whether the correlation between AQ-Social and face recognition was *significantly different between males and females* (note the actual findings were simply that the correlation was significantly different from zero in one sex and not in the other). Thus, it may be that there is no genuine conflict in findings between the studies. Also, in our own study, we do not wish to conclude that there is *no* association between AQ-Social and face recognition performance for males, given our small sample size (n = 32). Future research with much larger sample sizes (e.g., 100+ males and 100+ females) would be valuable to resolve these issues.

An open question concerns whether our results would replicate with other measures of autistic traits. We have assessed autistic traits, and their subclusters, only using one measure, namely the AQ. Note we have no particular theoretical preference for this measure over alternatives such as the BAPQ, and chose the AQ because it is the most commonly used scale to measure autistic traits in the general population and we originally conceived this project as an extension of Rhodes *et al.* (2013), which used the AQ. We expect that our results would likely replicate with the 'social' and rigidity subscales of the BAPQ as predictors (given Sasson *et al.*'s (2013) results in Figure 6), but of course this remains to be confirmed.

Finally, an important point to note is that our present finding that higher attention-to-detail is associated with *more* looking at eyes has been obtained specifically in the setting of a face recognition task, that is corresponding to a real-world situation in which someone is attempting to learn and recognize the identity of a set of new people. An interesting open question is whether individuals with higher attention-to-detail would also look more at eyes in other situations, such as when processing facial emotion, when interacting socially with an already-familiar individual, or when faces form a more incidental part of a natural scene containing a mix of people and objects (e.g., noting that Sasson, Turner-Brown, Holtzclaw, Lam, and Bodfish (2008) found that higher levels of repetitive behaviour in ASD were linked with *reduced* looking to faces when scanning a mixed face-and-object display).

Implications for ASD

The present article has focused on the range of autistic traits found in the general population. Our findings, however, have potentially important implications for the study of ASD. First, they imply that the currently contradictory evidence regarding whether ASD is, or is not, associated with reduced looking at the eyes of faces might be resolved if future studies examine separately the clusters of social, and non-social autistic traits: It might be only the *social* aspects of ASD that are associated with reduced looking at eyes, while restricted and repetitive behaviours (to the extent these are related to increased attention-to-detail) might be associated with the opposite pattern of *more* looking at eyes. Second, our results suggest that, similarly, it would be of interest to examine whether the ASD deficits in face identity recognition vary depending on symptom cluster and, if so, whether this variation is mediated by differential patterns of looking towards, or away from, the eyes.

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Author contributions

JD, RP, and EM contributed to research question and design of the study. JD, RP, MZ, and TM involved in stimulus preparation and experiment programming including the eye-tracking. JD and research assistants tested participants. JD, DA, RP, and MZ extracted data. JD, DA, RP, EM, and RO'K performed statistical analysis. JD, EM, and RP prepared the manuscript with contributions from all authors.

References

Adolphs, R., Sears, L., & Piven, J. (2001). Abnormal processing of social information from faces in autism. *Journal of Cognitive Neuroscience*, *13*(2), 232–240.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders: DSM 5*. Arlington, VA: Author.

Austin, E. J. (2005). Personality correlates of the broader autism phenotype as assessed by the Autism Spectrum Quotient (AQ). *Personality and Individual Differences*, *38*, 451–460. doi:10.1016/j.paid.2004.04.022

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders*, *31*(1), 5–17. doi:10.1068/p5547

Barton, J. J., Radcliffe, N., Cherkasova, M. V., Edelman, J., & Intriligator, J. M. (2006). Information processing during face recognition: The effects of familiarity, inversion, and morphing on scanning fixations. *Perception*, *35*, 1089–1105. doi:10.1068/p5547

Benton, A. L., Sivan, A. B., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Benton test of facial recognition*. New York, NY: Oxford University Press.

Bowles, D. C., McKone, E., Dawel, A., Duchaine, B., Palermo, R., Schmalzl, L., . . . Yovel, G. (2009). Diagnosing prosopagnosia: Effects of ageing, sex, and participant–stimulus ethnic match on the Cambridge Face Memory Test and Cambridge Face Perception Test. *Cognitive Neuropsychology*, *26*, 423–455. doi:10.1080/02643290903343149

Burton, A.M., White, D., & McNeill, A. (2010). The Glasgow Face Matching Test. *Behavior Research Methods*, *42*(1), 286–291. doi:10.3758/BRM.42.1.286

Cassidy, S., Mitchell, P., Chapman, P., & Ropar, D. (2015). Processing of spontaneous emotional responses in adolescents and adults with autism spectrum disorders: Effect of stimulus type. *Autism Research*, *8*(5), 534–544. doi:10.1002/aur.1468

Chen, F., & Yoon, J. (2011). Brief Report: Broader autism phenotype predicts spontaneous reciprocity of direct gaze. *Journal of Autism and Developmental Disorders*, *41*, 1131–1134. doi:10.1007/s10803-010-1136-2

Constantino, J. N., & Gruber, C. P. (2005). *Social responsiveness scale*. Los Angeles, CA: Western Psychological Services.

Cornelissen, F. W., Peters, E. M., & Palmer, J. (2002). The Eyelink Toolbox: Eye tracking with MATLAB and the Psychophysics Toolbox. *Behavior Research Methods, Instruments, & Computers*, *34*, 613–617. doi:10.3758/BF03195489

Dawson, G., Webb, S. J., & McPartland, J. (2005). Understanding the nature of face processing impairment in autism: Insights from behavioral and electrophysiological studies. *Developmental Neuropsychology*, *27*, 403–424. doi:10.1207/s15326942dn2703_6

Dennett, H. W., McKone, E., Tavashmi, R., Hall, A., Pidcock, M., Edwards, M., & Duchaine, B. (2011). The Cambridge Car Memory Test: A task matched in format to the Cambridge Face Memory Test, with norms, reliability, sex differences, dissociations from face memory, and expertise effects. *Behavior Research Methods*, *44*, 587–605. doi:10.3758/s13428-011-0160-2

Duchaine, B., & Nakayama, K. (2006). The Cambridge Face Memory Test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia*, *44*, 576–585. doi:10.1016/j.neuropsychologia.2005.07.001

Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. *Neuroscience & Biobehavioral Reviews*, *24*, 581–604. doi:10.1016/S0149-7634(00)00025-7

Falck-Ytter, T., & von Hofsten, C. (2011). How special is social looking in ASD: A review. *Progress in Brain Research*, *189*, 209–222. doi:10.1016/B978-0-444-53884-0.00026-9

Freeth, M., Chapman, P., Ropar, D., & Mitchell, P. (2010). Do gaze cues in complex scenes capture and direct the attention of high functioning adolescents with ASD? Evidence from eye-tracking. *Journal of Autism and Developmental Disorders*, *40*, 534–547. doi:10.1007/s10803-009-0893-2

Frith, U. (1989). *Autism: Explaining the enigma*. Oxford, UK: Blackwell.

Golarai, G., Grill-Spector, K., & Reiss, A. L. (2006). Autism and the development of face processing. *Clinical Neuroscience Research*, *6*(3), 145–160.

Gosselin, F., & Schyns, P. G. (2001). Bubbles: A technique to reveal the use of information in recognition tasks. *Vision Research*, *41*, 2261–2271. doi:10.1016/S0042-6989(01)00097-9

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics* (Vol. 1). New York, NY: Wiley.

Grgic, M., Delac, K., & Grgic, S. (2011). SCface – surveillance cameras face database. *Multimedia Tools and Applications*, *51*, 863–879. doi:10.1007/s11042-009-0417-2

Guillon, Q., Hadjikhani, N., Baduel, S., & Rogé, B. (2014). Visual social attention in autism spectrum disorder: Insights from eye tracking studies. *Neuroscience & Biobehavioral Reviews*, *42*, 279–297. doi:10.1016/j.neubiorev.2014.03.013

Hanley, M., Riby, D. M., Carty, C., Melaugh McAteer, A., Kennedy, A., & McPhillips, M. (2015). The use of eye-tracking to explore social difficulties in cognitively able students with autism spectrum disorder: A pilot investigation. *Autism: The International Journal of Research and Practice*, *19*, 868–873. doi:10.1177/1362361315580767

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York, NY: Guilford Press.

Hedley, D., Brewer, N., & Young, R. (2011). Face recognition performance of individuals with Asperger syndrome on the Cambridge face memory test. *Autism Research*, *4*, 449–455. doi:10.1002/aur.214

Hernandez, N., Metzger, A., Magné, R., Bonnet-Brilhault, F., Roux, S., Barthelemy, C., & Martineau, J. (2009). Exploration of core features of a human face by healthy and autistic adults analyzed by visual scanning. *Neuropsychologia*, *47*, 1004–1012. doi:10.1016/j.neuropsychologia.2008.10.023

Hills, P. J., Cooper, R. E., & Pake, J. M. (2013). First fixations in face processing: The more diagnostic they are the smaller the face-inversion effect. *Acta Psychologica*, *142*, 211–219. doi:10.1016/j.actpsy.2012.11.013

Hills, P. J., & Lewis, M. B. (2011). Reducing the own-race bias in face recognition by attentional shift using fixation crosses preceding the lower half of a face. *Visual Cognition*, *19*, 313–339. doi:10.1080/13506285.2010.528250

Hills, P. J., Ross, D. A., & Lewis, M. B. (2011). Attention misplaced: The role of diagnostic features in the face-inversion effect. *Journal of Experimental Psychology: Human Perception and Performance*, *37*, 1396–1406. doi:10.1037/a0024247

Hoekstra, R. A., Bartels, M., Cath, D. C., & Boomsma, D. I. (2008). Factor structure, reliability and criterion validity of the Autism-Spectrum Quotient (AQ): A study in Dutch population and patient groups. *Journal of Autism and Developmental Disorders*, *38*, 1555–1566. doi:10.1007/s10803-008-0538-x

Hurley, R. S., Losh, M., Parlier, M., Reznick, J. S., & Piven, J. (2007). The broad autism phenotype questionnaire. *Journal of Autism and Developmental Disorders*, *37*, 1679–1690. doi:10.1007/s10803-006-0299-3

Ingersoll, B., Hopwood, C. J., Wainer, A., & Donnellan, M. B. (2011). A comparison of three self-report measures of the broader autism phenotype in a non-clinical sample. *Journal of Autism and Developmental Disorders*, *41*(12), 1646–1657.

Itier, R. J., & Batty, M. (2009). Neural bases of eye and gaze processing: The core of social cognition. *Neuroscience & Biobehavioral Reviews*, *33*, 843–863. doi:10.1016/j.neubiorev.2009.02.004

Jones, W., Carr, K., & Klin, A. (2008). Absence of preferential looking to the eyes of approaching adults predicts level of social disability in 2-year-old toddlers with autism spectrum disorder. *Archives of General Psychiatry*, *65*, 946–954. doi:10.1001/archpsyc.65.8.946

Klin, A., Shultz, S., & Jones, W. (2015). Social visual engagement in infants and toddlers with autism: Early developmental transitions and a model of pathogenesis. *Neuroscience & Biobehavioral Reviews*, *50*, 189–203. doi:0.1016/j.neubiorev.2014.10.006

Kloosterman, P. H., Keefer, K. V., Kelley, E. A., Summerfeldt, L. J., & Parker, J. D. (2011). Evaluation of the factor structure of the Autism-Spectrum Quotient. *Personality and Individual Differences*, *50*(2), 310–314.

Lai, M. C., Lombardo, M. V., Suckling, J., Ruigrok, A. N., Chakrabarti, B., Ecker, C., . . . Baron-Cohen, S. (2013). Biological sex affects the neurobiology of autism. *Brain*, *136*, 2799–2815. doi:10.1093/brain/awt216

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H. J., Hawk, S. T., & van Knippenberg, A. (2010). Presentation and validation of the Radboud Faces Database. *Cognition & Emotion*, *24*, 1377–1388. doi:10.1080/02699930903485076

Lundqvist, D., Flykt, A., & Öhman, A. (1998). *The Karolinska Directed Emotional Faces – KDEF, CD ROM from Department of Clinical Neuroscience, Psychology section*. Stockholm: Karolinska Institutet.

Mandy, W., Chilvers, R., Chowdhury, U., Salter, G., Seigal, A., & Skuse, D. (2012). Sex differences in autism spectrum disorder: Evidence from a large sample of children and adolescents. *Journal of Autism and Developmental Disorders*, *42*, 1304–1313. doi:10.1007/s10803-011-1356-0

McKone, E., Hall, A., Pidcock, M., Palermo, R., Wilkinson, R. B., Rivolta, D., . . . O'Connor, K. B. (2011). Face ethnicity and measurement reliability affect face recognition performance in developmental prosopagnosia: Evidence from the Cambridge Face Memory Test-Australian. *Cognitive Neuropsychology*, *28*(2), 109–146. doi:10.1080/02643294.2011.616880

McKone, E., & Palermo, R. (2010). A strong role for nature in face recognition. *Proceedings of the National Academy of Sciences*, *107*, 4795–4796. doi:10.1073/pnas.1000567107

Mehoudar, E., Arizpe, J., Baker, C. I., & Yovel, G. (2014). Faces in the eye of the beholder: Unique and stable eye scanning patterns of individual observers. *Journal of Vision*, *14*, 1–11. doi:10.1167/14.7.6

Meissner, C. A., Tredoux, C. G., Parker, J. F., & MacLin, O. H. (2005). Eyewitness decisions in simultaneous and sequential lineups: A dual-process signal detection theory analysis. *Memory & Cognition*, *33*, 783–792. doi:10.3758/BF03193074

MIT Center for Biological and Computation Learning (1996). *CBCL Face Database #1*. Retrieved from http://www.ai.mit.edu/projects/cbcl

Palmer, C. J., Paton, B., Enticott, P. G., & Hohwy, J. (2015). 'Subtypes' in the presentation of autistic traits in the general adult population. *Journal of Autism & Developmental Disorders*, *45*, 1291–1301. doi:10.1007/s10803-014-2289-1

Papagiannopoulou, E. A., Chitty, K. M., Hermens, D. F., Hickie, I. B., & Lagopoulos, J. (2014). A systematic review and meta-analysis of eye-tracking studies in children with autism spectrum disorders. *Social Neuroscience*, *9*, 610–632. doi:10.1080/17470919.2014.934966

Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Paul, G., Goldman, B. D., & Piven, J. (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders*, *32*, 249–261. doi:10.1023/A:1016374617369

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, *40*, 879–891. doi:10.3758/BRM.40.3.879

Rhodes, G., Jeffery, L., Taylor, L., & Ewing, L. (2013). Autistic traits are linked to reduced adaptive coding of face identity and selectively poorer face recognition in men but not women. *Neuropsychologia*, *51*, 2702–2708. doi:10.1016/j.neuropsychologia.2013.08.016

Rivet, T. T., & Matson, J. L. (2011). Review of gender differences in core symptomatology in autism spectrum disorders. *Research in Autism Spectrum Disorders*, *5*, 957–976. doi:10.1016/j.rasd.2010.12.003

Ruzich, E., Allison, C., Smith, P., Watson, P., Auyeung, B., Ring, H., & Baron-Cohen, S. (2015). Measuring autistic traits in the general population: A systematic review of the Autism-Spectrum Quotient (AQ) in a nonclinical population sample of 6,900 typical adult males and females. *Molecular Autism*, *6*, 2. doi:10.1186/2040-2392-6-2

Sasson, N. J. (2006). The development of face processing in autism. *Journal of Autism and Developmental Disorders*, *36*, 381–394. doi:10.1007/s10803-006-0076-3

Sasson, N. J., Nowlin, R. B., & Pinkham, A. E. (2013). Social cognition, social skill, and the broad autism phenotype. *Autism: The International Journal of Research and Practice*, *17*, 655–667. doi:10.1177/1362361312455704

Sasson, N. J., Turner-Brown, L. M., Holtzclaw, T. N., Lam, K. S., & Bodfish, J. W. (2008). Children with autism demonstrate circumscribed attention during passive viewing of complex social and nonsocial picture arrays. *Autism Research*, *1*(1), 31–42. doi:10.1002/aur.4

Sekiguchi, T. (2011). Individual differences in face memory and eye fixation patterns during face learning. *Acta Psychologica*, *137*(1), 1–9. doi:10.1016/j.actpsy.2011.01.014

Shuster, J., Perry, A., Bebko, J., & Toplak, M. E. (2014). Review of factor analytic studies examining symptoms of autism spectrum disorders. *Journal of Autism & Developmental Disorders*, *44*(1), 90–110. doi:10.1007/s10803-013-1854-3

Speer, L. L., Cook, A. E., McMahon, W. M., & Clark, E. (2007). Face processing in children with autism effects of stimulus contents and type. *Autism: The International Journal of Research and Practice*, *11*, 265–277. doi:10.1177/1362361307076925

Stacey, P. C., Walker, S., & Underwood, J. D. (2005). Face processing and familiarity: Evidence from eye-movement data. *British Journal of Psychology*, *96*, 407–422. doi:10.1348/000712605X47422

Stewart, M. E., & Austin, E. J. (2009). The structure of the Autism-Spectrum Quotient (AQ): Evidence from a student sample in Scotland. *Personality and Individual Differences*, *47*(3), 224–228.

Stuart, A., & Kendall, M. G. (1958). *Advanced theory of statistics* (Vol. *1*). London, UK: Charles Griffin.

Susilo, T., Germine, L., & Duchaine, B. (2013). Face recognition ability matures late: Evidence from individual differences in young adults. *Journal of Experimental Psychology: Human Perception and Performance*, *39*, 1212–1217. doi:10.1037/a0033469

Vabalas, A., & Freeth, M. (2015). Brief Report: Patterns of eye movements in face to face conversation are associated with autistic traits: Evidence from a student sample. *Journal of Autism and Developmental Disorders*, *46*(1), 305–314. doi:10.1007/s10803-015-2546-y

van Belle, G., Ramon, M., Lefèvre, P., & Rossion, B. (2010). Fixation patterns during recognition of personally familiar and unfamiliar faces. *Frontiers in Psychology*, *1*, 20. doi:10.3389/fpsyg.2010.00020

Volkmar, F. R., Lord, C., Bailey, A., Schultz, R. T., & Klin, A. (2004). Autism and pervasive developmental disorders. *Journal of Child Psychology and Psychiatry*, *45*(1), 135–170. doi:10.1046/j.0021-9630.2003.00317.x

Wang, L., Mottron, L., Peng, D., Berthiaume, C., & Dawson, M. (2007). Local bias and local-to-global interference without global deficit: A robust finding in autism under various conditions of attention, exposure time, and visual angle. *Cognitive Neuropsychology*, *24*, 550–574. doi:10.1080/13546800701417096

Weigelt, S., Koldewyn, K., & Kanwisher, N. (2012). Face identity recognition in autism spectrum disorders: A review of behavioral studies. *Neuroscience & Biobehavioral Reviews*, *36*, 1060–1084. doi:10.1016/j.neubiorev.2011.12.008

Wilmer, J. B., Germine, L., Chabris, C. F., Chatterjee, G., Williams, M., Loken, E., . . . Duchaine, B. (2010). Human face recognition ability is specific and highly heritable. *Proceedings of the National Academy of Sciences*, *107*, 5238–5241. doi:10.1073/pnas.0913053107

Wilson, C. E., Palermo, R., & Brock, J. (2012). Visual scan paths and recognition of facial identity in autism spectrum disorder and typical development. *PLoS One*, *7*(5), e37681. doi:10.1371/journal.pone.0037681.g004

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Supporting Information

The following supporting information may be found in the online edition of the article:

Appendix S1. Supplementary Information.
Table S1. Correlation matrix for age, sex and eye movement measures.
Table S2. No sex differences for eye movement measures.
Table S3. Regression outputs testing whether AQ subscales (AQ-Social and AQ-Attention) predict looking at eyes (and mouth) during recognition test.
Table S4. Mediation models for eye movements during test phase: statistics from Preacher and Hayes (2008) process, for eight mediation models, covering each AQ subscale predicting face recognition (old-new d′) via mediator of looking at eyes (separately measured as number of fixations to eyes, and as total dwell time on eyes), and via mediator of looking at mouth (separately measured as number of fixations to mouth, and as total dwell time on mouth) during the *test phase*.
Table S5. Mediation models: statistics from Preacher and Hayes (2008) process, for four mediation models, covering each AQ subscale predicting face recognition (old-new d′) via mediator of looking at mouth *during learning* (separately measured as number of fixations to mouth, and as total dwell time on mouth).
Figure S1. Interest area (IA) for the analysis of the entire bottom half of the face (including tip of nose, cheeks, chin), shown as bright green rectangle, for a front-view and three-quarter-view face.