Is visual metacognition associated with ASD traits? A regression analysis shows no link between visual metacognition and AQ scores.

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Abstract:
Do people with autism spectrum disorder (ASD) have altered metacognition? Despite the practical and theoretical importance of this question, the evidence is inconsistent. We ran an experiment to test the relationship between visual metacognition and ASD traits in a sample of 360 neurotypical people. We operationalized metacognition as the correspondence between accuracy in a two alternative forced choice task and the participant's reported confidence. ASD traits were assessed using the Autism-spectrum Quotient (AQ). A regression analysis has not shown statistically significant relationships between ASD traits and metacognition nor between ASD traits and confidence. In addition, no relationship was observed between the subscales of the AQ test and metacognition. Our results do not support the hypothesis that ASD traits are associated with metacognition in the general population. However, our study provides methodological and empirical evidence that may be valuable for future research aimed at identifying the relationship between ASD and metacognition.

Keywords: Metacognition, Autism Spectrum Disorder, Computational Psychiatry

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized at a behavioral level by impairment in social interaction, restricted interests, repetitive behavior, and a diminished understanding of the emotions and minds of others (American Psychiatric Association, 2013; Baron-Cohen, 1991; Capps et al., 1992; Davies et al., 1994; Hobson et al., 1988; Kanner & Lesser, 1958; Yirmiya et al., 1992). The presence of autistic traits in the general population suggests that ASD constitutes the extreme of a continuous dimension (Barttfeld et al., 2013; Constantino et al., 2003; Constantino & Todd, 2005; Lau et al., 2013). This observation led to the development of behavioral measures seeking to evaluate ASD traits in the general population, and the use of a dimensional approach to study ASD (Baron-Cohen et al., 2001).

Individuals with ASD perform better than neurotypical participants in perceptual tasks, excelling at the recognition of details and ability to find hidden figures (Dakin & Frith, 2005; Pellicano & Burr, 2012; Plaisted et al., 1998). ASD individuals seem to have a more veridical perception and a weaker influence of expectation (Karvelis et al., 2018). The idea that individuals with ASD perceive the world differently is one of the most intriguing features of ASD and might constitute one of its defining features. Some of the mainstream theories of ASD point in the direction of a strong relation between enhanced perception skills and the central disturbances of ASD (Dakin & Frith, 2005; Mottron et al., 2006; Pellicano & Burr, 2012; Plaisted et al., 1998). The relatively stronger influence of sensory information could explain hypersensitivity to sensory stimuli and extreme attention to details (Karvelis et al., 2018; Pellicano & Burr, 2012). Furthermore, this could lead to prior expectations which are too specific and which do not generalize across situations (Van de Cruys et al., 2014).

It is widely known that people with ASD have an altered theory of mind (Brunsdon & Happé, 2014), i.e. the ability to attribute mental states to others. Some authors have argued that theory of mind might rely on similar cognitive mechanisms than those we use to identify our own successful cognitive processes, an ability defined as metacognition (Carpenter et al., 2019; Grainger et al., 2016a; van der Plas et al., 2021; Flavell, 1979; Fleming et al., 2012; Metcalfe & Shimamura, 1994; Morales et al., 2018; Nelson & Narens, 1990). The link between metacognition and theory of mind suggests that ASD individuals may have a diminished metacognitive capacity. Contrary, the enhanced perceptual abilities of ASD individuals suggest that they have a more conscious perceptual mechanism, leading to an enhanced (perceptual) metacognition. However, it is debated whether people with ASD have altered metacognition (Carpenter et al., 2019; Grainger et al., 2016a, 2016b; Maras et al., 2017, 2020; Nicholson et al., 2019, 2020; Sawyer et al., 2014; van der Plas et al., 2021; Wilkinson et al., 2010; Williams et al., 2018; Wojcik et al., 2011).

Interestingly, some studies support the view that people with ASD have an altered metacognition (Grainger et al., 2016a; Nicholson et al., 2019, 2020; van der Plas et al., 2021; Wilkinson et al., 2010). Grainger et al. (2016a) compared a group of children with ASD with an IQ-age matched group of neurotypicals (NT) participants, and used judgment of confidence (JOC) after a study phase. They found a diminished metacognitive monitoring accuracy in the ASD group. Nicholson et al. (2019) performed two tasks in order to test implicit metacognition (when the accuracy of strategic behavioral reactions is assessed, without a verbal answer) and explicit metacognition (the precision with which verbal metacognitive judgments can be made, as confidence judgment). They compared adults with ASD with IQ-Age matched NT adults, and they did not observe differences in the implicit task, but they did observe it in the explicit task. Nicholson et al. (2020) observed that children/adolescents with ASD had diminished explicit metacognition regarding NT participants. Although, they found no difference in implicit metacognition, as Nicholson et al. (2019). Van der Plas et al. (2021) found that ASD traits evaluated by RAADS-14

(Eriksson et al., 2013) were not significantly related to metacognitive sensitivity in a neurotypical sample. On the other hand, their results suggest that participants who reported difficulties with social interaction in everyday life had worse metacognitive sensitivity than those who did not. Furthemore, in the last study, they compared a group of ASD participants with a group of participants with low ASD traits, and they reported evidence supporting the view that metacognition is altered in people with ASD. Interestingly, their results suggest that metacognition sensitivity is related only to social autistic traits and not to non-social ones (Van der Plas et al., 2021). Wilkinson et al. (2010) performed a memory awareness test during a face recognition task, and their results suggested that adults and children with autism have an altered metacognition regarding NT group IQ-age matched.

On the other hand, several other studies found no differences between groups (Grainger et al., 2016b; Maras et al., 2017, 2020; Sawyer et al., 2014; Wojcik et al., 2011, 2014). For example, Grainger et al. (2016b) performed two experiments using a judgment of learning task (JOL), and comparing adults and adolescents with ASD and matched age and IQ NT participants. Curiously, they found an undiminished JOL accuracy in both ASD groups. Maras et al. (2017) used a math challenge task in order to compare the metacognitive monitoring of secondary children with ASD regarding NT participants, and they did not observe differences between groups. Maras et al. (2020) also found an unaltered metacognition monitoring in the autistic group compared with a matched IQ group of NT participants, using a memory task. Sawyer et al. (2014) utilized an emotion recognition and also a general knowledge task with the aim to compare people with asperger disorder and NT people. They did not find a diminished metacognitive monitoring in the asperger disorder group. Wojcik et al. (2011) compared the JOC accuracy of a memory task between children with ASD and NT (age and IQ matched), and they have not observed a significant difference. Wojcik et al. (2014) compared two groups of adolescents (ASD and NT IQ) using JOL and did not observe differences.

It even happens that some other studies found mixed results (Carpenter et al., 2019; Williams et al., 2018). Carpenter et al. (2019) used a post-decision wandering paradigm with a perceptual task, and found a negative association between ASD traits and metacognition in a NT sample, although they did not find differences in metacognition between adults with ASD and IQ-age matched NT adults. Williams et al. (2018) performed a general knowledge question task in a NT population and have not observed a significant relationship between ASD traits and JOC. They also compared NT children and IQ-age matched ASD children, although in this case they found a lower JOC in the group of children with ASD regarding the NT group.

In all these studies there are several differences at the methodological level, one of them being the way of understanding metacognition. Metacognition is a rather broad concept, which can be quantified in several ways (Fleming & Lau, 2014). A possible way to understand metacognition is to divide it into two components: metacognitive sensitivity and metacognitive bias (Fleming & Daw, 2017; Fleming & Lau, 2014). The first is operationally defined as how much can be differentiated between a participant's correct and incorrect answers based on the confidence in their answers (Fleming & Daw, 2017; Fleming & Lau, 2014). The second refers to the overall confidence in the answers (e.g. overconfidence or underconfidence). With some metacognition measures, both components could be separated, in order to control the influence of one over the other (Fleming & Lau, 2014). Nevertheless, only Nicholson et al. (2020) and Van der Plas et al. (2021) have used a bias-free measure of metacognition.

The inconsistencies between the results (Carpenter et al., 2019; Grainger et al., 2016a, 2016b; Maras et al., 2017, 2020; Nicholson et al., 2019, 2020; Sawyer et al., 2014; van der

Plas et al., 2021; Wilkinson et al., 2010; Williams et al., 2018; Wojcik et al., 2011), highlight the importance of studying the nuances of the relationship between ASD and metacognition.

In this work, we study the relationship between metacognitive sensitivity and ASD traits. With the aim of testing the robustness of the results (i.e., when the same dataset is subjected to various analyses to address the same question; Arnold et al., 2019) we used two metacognitive measures. Both measures, the type 2 ROC curve (AUROC2; Fleming & Lau, 2014) and a mixed logistic regression model (Siedlecka et al., 2016), are bias-free, in the sense that they allow separation of metacognitive bias from metacognitive sensitivity. This is important in the light of recent results that show a negative relationship between ASD traits and confidence (van der Plas et al., 2021).

Furthermore, we explore whether metacognitive sensitivity and ASD traits are related in more specific ways. With that purpose, we use the subscales of the ASD trait test (social skill, attention switching, attention to detail, communication, and imagination). Lastly, we investigate the relationship between confidence and ASD traits.

2. Material and methods

2.1 Participants

The final sample consisted of 360 participants. Participants in the final sample met the following criteria: no use of psychotropic medication, no psychiatric diagnosis, and over 18 years of age). In addition, from an initial sample of 457 participants, 97 participants were excluded. Exclusion criteria were: reporting that they had not performed the experiment carefully (6 participants), performing less than 60% (2 participants), having pressed the same confidence key more than 85% of trials (25 participants), having less than 90 trials remaining after filtering reaction times (29 participants) and having an AUROC2 (see Data analysis section) less than 1.5 standard deviations from the mean (27 participants). We also excluded participants who did not report a choice of binary male or female gender (8 participants; as they were too few to be accounted for in the regression model). The final sample consisted of 360 participants (Age: M = 32.14, SD = 11.06, range = 19 - 72), including 107 males and 253 females. Participants signed an informed consent. The present study was approved by the ethics committee of the Instituto de Investigaciones Psicológicas (CONICET, Córdoba, Argentina).

2.2 Task

The experiment was coded in JavaScript and managed using JATOS, a platform for online experiments (Lange et al., 2015). Participants were told to sit at a distance of 60 cm from the screen, to try not to be distracted, and to silence their cellphones and computer notifications. Participants completed the Autism-spectrum Quotient (AQ; Baron-Cohen et al., 2001) and a dot density task (see Figure 1), both in the same session. The dot density task consisted of 1 block of 130 trials. Each trial started with a fixation cross, followed by two horizontally aligned circles, shown for 500 ms. Participants had to decide which circle had more dots, pressing the left or right arrow keys. Next, they had to report their confidence level using a 4-point Likert scale. Circles radius was calculated as 0.15 of the browser's window width. Dots had a radius of 10 pixels. Task difficulty was controlled using a two-down/one-up staircase procedure, leading to a theoretical performance of 72% (Prins, 2016). The staircase procedure controlled the influence of performance on the AUROC2 measure (Fleming & Lau, 2014). Participants completed the experimental task in 5 minutes on average.

2.3 Data analysis.

Data were analyzed in R (Team, R., 2020). We discarded trials with reaction times (RT) greater than 5000 ms and smaller than 200 ms in the dot discrimination task (4.28% discarded), and trials with reaction times (RT) greater than 5000 ms in the confidence task

(0.07% discarded). We also discarded the first 20 trials of each participant, to allow the staircase to stabilize.

We used two methods to measure metacognition, i.e. the degree to which confidence informs about accuracy. Firstly, the area under the AUROC2 (Fleming & Lau, 2014), and secondly, a mixed logistic regression model (Siedlecka et al., 2016). In the following paragraphs, we briefly describe the procedures to calculate metacognition using each method based on the data from two fictitious participants, one with poor metacognitive sensitivity (Figures 2a) and one with relatively high metacognitive sensitivity (Figures 2b). In Figure 2a, confidence distribution is uninformative about the chance of getting it right. Contrary, Figure 2b shows a very informative confidence distribution.

The AUROC2 is a non-parametric measure that makes it possible to have a metacognitive sensitivity measure that is independent of the metacognitive bias (Fleming & Lau, 2014). This measure is a way to know how much information the confidence distribution is given about the chance of getting it right. Based on the descriptions of Fleming & Lau (2014), for each participant, it is possible to build a distribution of the reported confidence according to whether the trial was correct or incorrect (Figures 2 a and b). Considering that we have four confidence levels, we can establish three cut-off points in the distribution, one for each space between confidence levels. If considered one cut-off point at a time, one could calculate three type 2 hit rates (proportion of high confidence trials when the trial is correct) and three type 2 false alarm rates (proportion of high confidence trials when the trial is incorrect), one per cut-off point. Each type 2 hit rate is the probability of the confidence given that the trial was correct for three different cut-off points, and each type 2 false alarm rate is the probability of the confidence given that the trial was incorrect for three different cut-off points. Then, plotting the inverse cumulative type 2 hit rate points versus the inverse cumulative type 2 false alarms rate points allows us to build the ROC curve of type 2 (Figures c and d). Finally, the area under the curve is the AUROC2. Figures 2 c and d shows the AUROC2 constructed for each fictitious participant (a and b, respectively, being Figure 2a a fictitious participant with poor metacognitive sensitivity and Figure 2b a fictitious participant with high metacognitive sensitivity). The area under the curve indicates the metacognitive sensitivity. The greater the area under the curve, the higher the cognitive sensitivity score (Fleming & Lau, 2014).

Once we have a measure of metacognition for each participant, we ran a regression analysis to study the relationship between ASD traits and metacognitive sensitivity. The linear model was:

$$\text{AUROC2} = \alpha + \text{AQ score} * \beta_1 + \text{gender} * \beta_2 + \text{age} * \beta_3 + \text{AQ score} * \text{gender} * \beta_4 + \text{AQ score} * \text{age} * \beta_5 + \text{errors}$$

where AUROC2 was the predicted variable and the predictor variables were standardized AQ score, gender, standardized age, and their interactions.

Our second method to measure metacognition involves the fitting of a mixed logistic regression model. A logistic regression model would be a model suitable for predicting a binary categorical variable, i.e., whether the answer was correct or incorrect (Siedlecka et al., 2016). It has some advantages over the AUROC2 method. It does not rely on theoretical assumptions regarding the confidence distribution; it is not influenced by an imbalanced number of correct and incorrect responses, and it controls for the inter-subject variability in parameters estimation (Siedlecka et al., 2016. But see: Rausch et al., 2015; Rausch & Zehetleitner, 2017). Figures 2 e and f show the predicted line expected for each participant (a and b, respectively). The mixed logistic regression model is:

$\text{logit}(p) = \alpha + \text{MC} * \text{confidence}$, where the logit(p) as the predicted variable is the logarithm of the probabilities of the answer being correct over the probability of it being wrong, and

$MC = \beta_0 + AQ\ score * \beta_1 + gender * \beta_2 + age * \beta_3 + AQ\ score * gender * \beta_4 + AQ\ score * age * \beta_5$

The intercept varies across participants, as our only random effects factor. The predictors were the standardized AQ score, gender, standardized age, and the interactions of gender and standardized age with standardized AQ, all as fixed effects.

In order to explore whether metacognitive sensitivity is related to ASD traits in a more specific way, another linear regression was performed taking the standardized AQ subscales scores, the gender and standardized age as predictors, and metacognitive sensitivity estimated by the AUROC2 as the predicted variable. The following equation was used:

$AUROC2 = \alpha + social\ skill\ score * \beta_1 + attention\ switching * \beta_2 + attention\ to\ detail * \beta_3 + communication * \beta_4 + imagination * \beta_5 + gender * \beta_6 + age * \beta_7 + errors$

Finally, the relationship between confidence and AQ was also explored, given the following equation:

$Confidence = \alpha + AQ\ score * \beta_1 + gender * \beta_2 + age * \beta_3 + AQ\ score * gender * \beta_4 + AQ\ score * age * \beta_5 + errors$

where the confidence mean by participant was the predicted variable, and the standardized AQ, gender, standardized age and their interactions were the predictor variables.

3. Results

As expected, AUROC2 values showed great variation among participants (Figure 3a). Mean AUROC2 was 0.62 (SD = 0.057, range = 0.51 - 0.78). AQ score also showed an expected variability across participants, ranging from 16 to 37 (Figure 3b). Mean AQ score was 17.38 (SD = 5.45, range = 6 - 35), being significantly higher for males than for females (females: mean = 16.73, SD = 5.20; males: mean = 18.91, SD = 5.73; $t(183.51) = -3.386$, $p < 0.001$) consistently with the literature.

The linear regression model used to study the relationship between ASD traits and metacognitive sensitivity (Figures 4 a and b; Table 1) showed that the standardized AQ score and their interaction with gender and standardized age were non-significant predictors of AUROC2.

To further confirm our results, we carried out a mixed logistic regression model (Figure 5 a; Table 2). The intercept estimates the average accuracy on the logit scale for the lowest confidence rating. We observed that the confidence significantly predicted accuracy. Nevertheless, its interaction with standardized AQ, with standardized AQ and gender, and with standardized AQ and standardized age were not significant predictors of accuracy.

To further explore the relationship between ASD traits and metacognition sensitivity, another linear regression model was conducted, taking the subscales of the AQ as predictors of AUROC2. The linear regression model (Figure 6; Table 3) showed that the standardized social skill score, standardized attention switching score, standardized attention to detail score, standardized communication score, and standardized imagination were non-significant predictors when AUROC2 is the predicted variable.

Lastly, we explored the relationship between confidence and standardized AQ (Figure 7; Table 4). It was observed that the standardized AQ score, and their interaction with gender and standardized age were non-significant predictors of the confidence mean by subject.

To observe the robustness of the results, we performed the same four regression analyses but without controlling for age and sex. In general, the results were consistent with those obtained when controlling for age and sex (see Appendix Tables A.1, B.1, C.1 and D.1).

4. Discussion

The main objective of the present study was to explore the relationship between metacognition and ASD traits. For this purpose, we ran a perceptual dot density metacognition task over a sample of neurotypical participants. Metacognition was estimated in two ways: through the AUROC2, and through a mixed logistic regression model.

Regardless of how metacognition was estimated, the results did not show a significant relationship between the AQ score and metacognition, after controlling gender and age. If we consider the ASD from a dimensional perspective (i.e. that the ASD constitutes the extreme of a continuous dimension traversing through the entire population; Barttfeld et al., 2013; Constantino et al., 2003; Constantino & Todd, 2005; Lau et al., 2013) these results seem not to support the idea that metacognition is altered in people with ASD. This observations are in line with what has been reported by other studies (Carpenter et al., 2019; Grainger et al., 2016b; Maras et al., 2017, 2020; Sawyer et al., 2014; Williams et al., 2018; Wojcik et al., 2011, 2014). Nevertheless, these results are inconsistent with other studies that report altered metacognition in people with ASD (Carpenter et al., 2019; Grainger et al., 2016a; Nicholson et al., 2019, 2020; Wilkinson et al., 2010; Williams et al., 2018).

A possible explanation for these inconsistencies is that ASD were related to metacognition in a very specific way, and some characteristics of the sample could overshadow the interaction between ASD and metacognitive sensitivity. In order to further explore the relationship between ASD traits and metacognition, each subscale of the AQ was taken into account as a predictor of metacognitive sensitivity. Nevertheless, non-significative relationships were observed. Neither the social skill subscale. These results do not support the idea that metacognitive sensitivity would be related to social autistic traits, as was found by Van der Plas et al. (2021). These differences could be due to the fact that we used different tests to measure the ASD traits in the neurotypical population. In addition, Van der Plas et al., (2021) reported a negative relation between ASD traits and confidence. We explored this relationship but we did not find a significant relationship. The relationship between ASD traits and metacognitive sensitivity, and ASD traits and confidence, remains to be considered in future studies.

Although the results of this paper do not suggest a negative relationship between metacognition and ASD traits, it is important to consider two important points. The results obtained by measuring ASD traits in the neurotypical population can not always be generalized to a diagnosed ASD population (Carpenter et al., 2019; Karvelis, 2020). Therefore, it could happen that an altered metacognition sensitivity could be observed only in the diagnosis ASD sample as Nicholson et al. (2020) and Van der Plas et al. (2021) did. Furthermore, studying whether metacognition is related to ASD in a specific way remains an important point to consider in future research, since it could explain inconsistencies in previous studies' results and shed light on the relationship between ASD and metacognition.

5. Conclusion

In the present study, the relationship between ASD traits, measured by the AQ, and metacognition was investigated in a neurotypical sample. No significant relationship was found between metacognitive sensitivity and ASD traits, or some of the AQ subscales. Nor was a significant relationship found between confidence and ASD traits. These results taken together are not in line with the idea of altered metacognition in ASD. This study contributes to the understanding of the relationship between metacognition and ASD. If there is a relationship, it appears to be more complex than previously thought, and it is possible that other variables that have not been taken into account may be involved. Future studies should investigate whether the relationship between metacognition and ASD is modulated by other characteristics of the sample. Its study has important theoretical and practical implications.

Author Statement

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Roles/Writing - original draft, Writing - review & editing; **Alberto Iorio:** Supervision, Validation, Roles/Writing - original draft, Writing - review & editing; **Pablo Barttfeld:** Conceptualization, Data curation, Formal analysis, Funding acquisition; Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Roles/Writing - original draft, Writing - review & editing; **Guillermo Solovey:** Conceptualization, Data curation, Formal analysis, Funding acquisition; Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Roles/Writing - original draft, Writing - review & editing.

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Conflict of interest

The authors declare that they have no conflict of interest.

Appendix

Table A.1

The linear regression model results used to study the relationship between ASD traits and metacognitive sensitivity without controlling for gender and age

	Beta	SE	95% CI	p-value
Intercept	0.621	0.003	0.615, 0.627	**<0.001**
AQ.std	-0.001	0.003	-0.007, 0.005	0.734
R2	0.000			
Adjusted R2	-0.002			

Note. SE = Standard Error; CI = Confidence Interval; .std = Standardized; In bold: Statistical significance.

Table B.1

The mixed logistic regression model results to study of the relationship between ASD traits and metacognitive sensitivity without controlling for gender and age

	log(OR)	SE	95% CI	p-value
Intercept	0.285	0.028	0.231, 0.340	**<0.001**
Confidence.norm	1.452	0.048	1.357, 1.546	**<0.001**
Confidence.norm * AQ.std	-0.044	0.025	-0.093, 0.006	0.087
Subjects SE(intercept)	0.202			
Deviance	43,050			

Note. OR = Odds Ratio; SE = Standard Error; CI = Confidence Interval; Statistical significance; .norm = normalized; .std = Standardized.

Table C.1

The linear regression model results used to study the relationship between the subscales of the AQ and metacognitive sensitivity without controlling for gender and age

	Beta	SE	95% CI	p-value
Intercept	0.621	0.003	0.615, 0.627	**<0.001**
Social Skill.std	-0.004	0.004	-0.011, 0.003	0.290
Attention Switching.std	-0.003	0.003	-0.009, 0.003	0.368
Attention to Detail.std	-0.000	0.003	-0.006, 0.006	0.923
Communication.std	0.007	0.004	0.000, 0.015	**0.044**
Imagination.std	-0.004	0.003	-0.010, 0.002	0.190
R2	0.017			
Adjusted R2	0.004			

Note. SE = Standard Error; CI = Confidence Interval; .std = Standardized; In bold: Statistical significance.

Table D.1

The linear regression model results used to study the relationship between ASD traits and confidence without controlling for gender and age

	Beta	SE	95% CI	p-value
Intercept	0.000	0.053	-0.104, 0.104	0.999
AQ.std	0.062	0.053	-0.042, 0.166	0.241
R2	0.004			
Adjusted R2	0.001			

Note. SE = Standard Error; CI = Confidence Interval; .std = Standardized.

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Tables:

Table 1

The linear regression model results used to study the relationship between ASD traits and metacognitive sensitivity

	Beta	SE	95% CI	p-value
Intercept	0.620	0.004	0.613, 0.627	**<0.001**
AQ.std	-0.001	0.004	-0.008, 0.006	0.787
Gender[m]	0.007	0.007	-0.006, 0.021	0.287
Age.std	-0.006	0.003	-0.012, 0	0.063
AQ.std * Gender[m]	-0.003	0.006	-0.016, 0.009	0.607
AQ.std * Age.std	0.004	0.003	-0.003, 0.010	0.266
R2	0.018			
Adjusted R2	0.004			

Note. SE = Standard Error; CI = Confidence Interval; [m] = male; .std = Standardized; In bold: Statistical significance.

Table 2

The mixed logistic regression model results to study of the relationship between ASD traits and metacognitive sensitivity

	log(OR)	SE	95% CI	p-value
Intercept	0.286	0.028	0.232, 0.341	**<0.001**
Confidence.norm	1.426	0.051	1.327, 1.525	**<0.001**
Confidence.norm * AQ.std	-0.047	0.031	-0.108, 0.014	0.134

Confidence.norm * Gender[m]	0.094	0.058	-0.020, 0.208	0.104
Confidence.norm * Age.std	-0.003	0.026	-0.054, 0.048	0.916
Confidence.norm * AQ.std * Gender[m]	-0.008	0.055	-0.116, 0.100	0.889
Confidence.norm * AQ.std * Age.std	0.019	0.028	-0.037, 0.075	0.505
Subjects SE(intercept)	0.201			
Deviance	43,050			

Note. OR = Odds Ratio; SE = Standard Error; CI = Confidence Interval; [m] = male; Statistical significance; .norm = normalized; .std = Standardized.

Table 3

The linear regression model results used to study the relationship between the subscales of the AQ and metacognitive sensitivity

	Beta	SE	95% CI	p-value
Intercept	0.620	0.004	0.613, 0.627	**<0.001**
Social Skill.std	-0.003	0.004	-0.011, 0.004	0.362
Attention Switching.std	-0.004	0.003	-0.010, 0.003	0.246
Attention to Detail.std	-0.001	0.003	-0.007, 0.005	0.787
Communication.std	0.007	0.004	-0.001, 0.014	0.069
Imagination.std	-0.004	0.003	-0.010, 0.002	0.232
Gender[m]	0.006	0.007	-0.008, 0.019	0.410
Age.std	-0.005	0.003	-0.011, 0.001	0.082
R2	0.028			
Adjusted R2	0.009			

Note. SE = Standard Error; CI = Confidence Interval; [m] = male; .std = Standardized; In bold: Statistical significance.

Table 4

The linear regression model results used to study the relationship between ASD traits and confidence

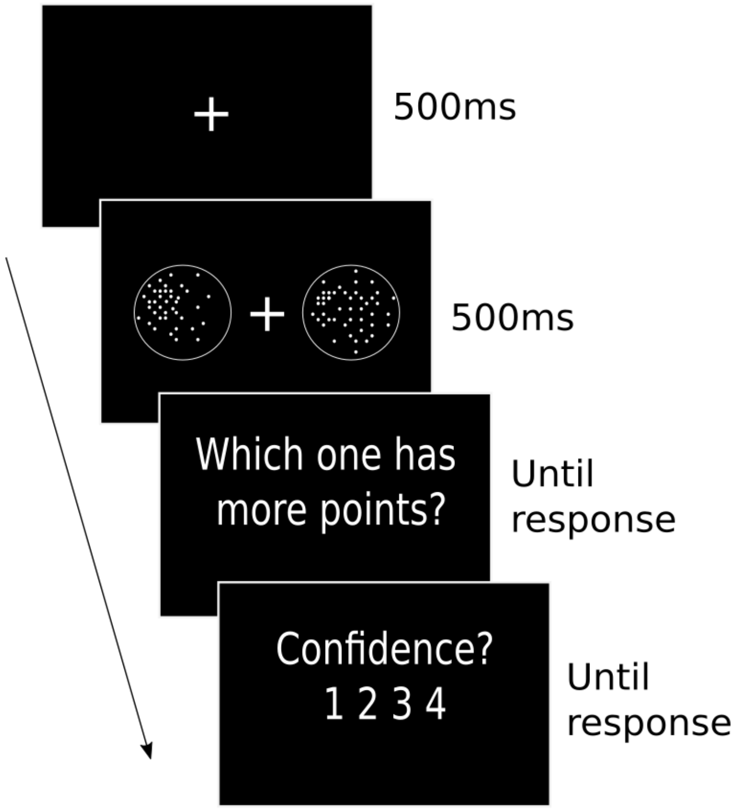
	Beta	SE	95% CI	p-value
Intercept	0.048	0.064	-0.077, 0.173	0.452
AQ.std	0.102	0.066	-0.028, 0.232	0.124
Gender[m]	-0.134	0.119	-0.369, 0.100	0.259
Age.std	-0.031	0.053	-0.136, 0.074	0.562
AQ.std * Gender[m]	-0.092	0.114	-0.315, 0.132	0.421
AQ.std * Age.std	0.004	0.058	-0.110, 0.117	0.951
R2	0.011			
Adjusted R2	-0.003			

Note. SE = Standard Error; CI = Confidence Interval; [m] = male; .std = Standardized.

Figures:

Figure 1

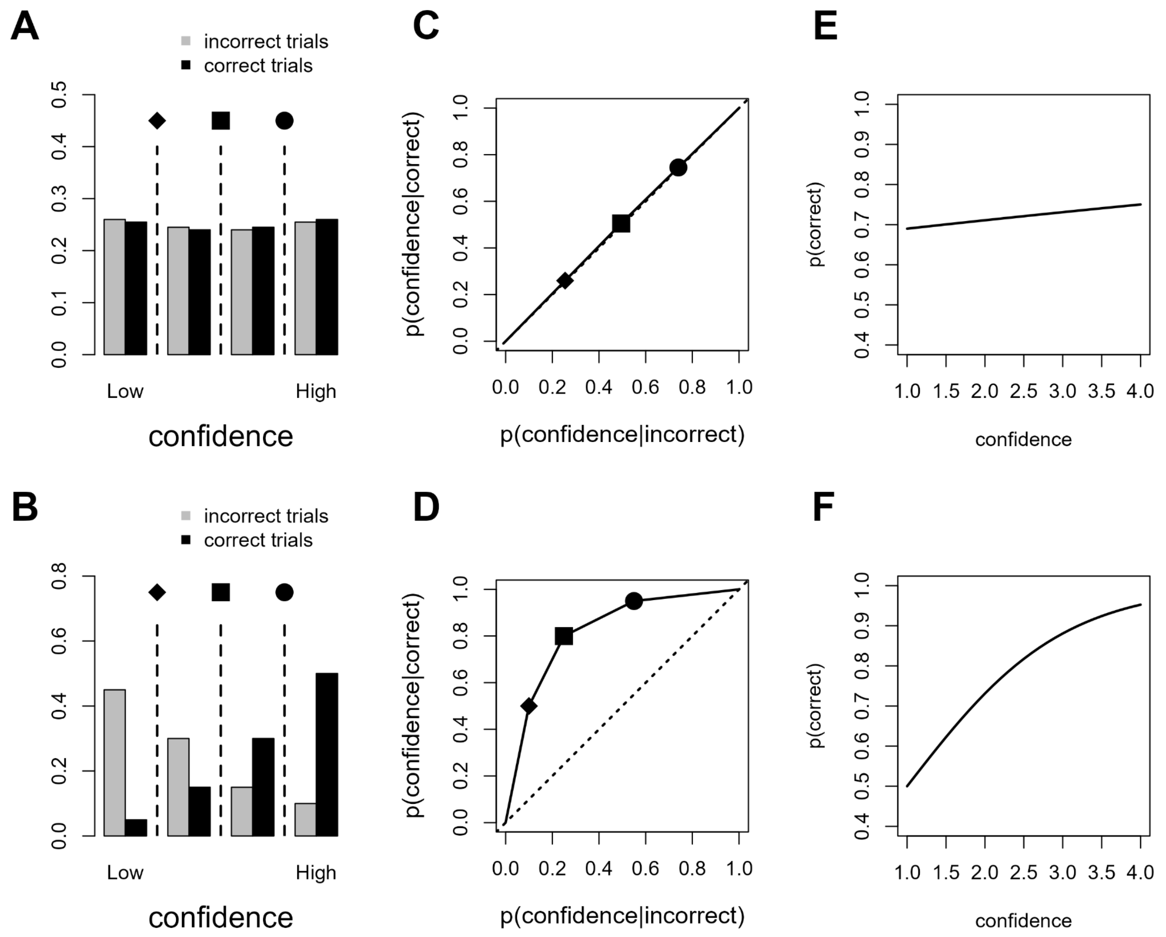
Task procedure



Note. Sequence of events during one trial of the experimental task with their respective times. Participants had to decide which circle had more dots, pressing the left or right arrow keys. After that, they had to report their confidence level using a 4-point Likert scale.

Figure 2

Estimation of metacognitive sensitivity using the AUROC2 and logistic regression model of two fictitious participants

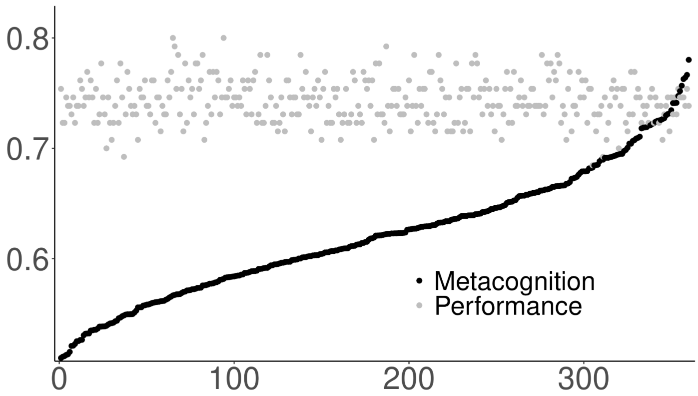


Note. First (second) row corresponds to a fictional participant with low (high) metacognitive sensitivity. A and B show the distribution of confidence for correct and incorrect trials. C and D: AUROC2 for each participant. E and F show the inferred probability of choosing the correct response as a function of confidence using a logistic regression model. The slope of the curve is greater in F than in E, which shows that confidence is a better predictor of the probability of getting it right in the first case (i.e., greater metacognitive sensitivity).

Figure 3

A

Metacognitive sensitivity and performance per participant



Note. Performance remained relatively constant due to the staircase procedure. Metacognition varied quite a bit per participant.

B

AQ score for female and male participants

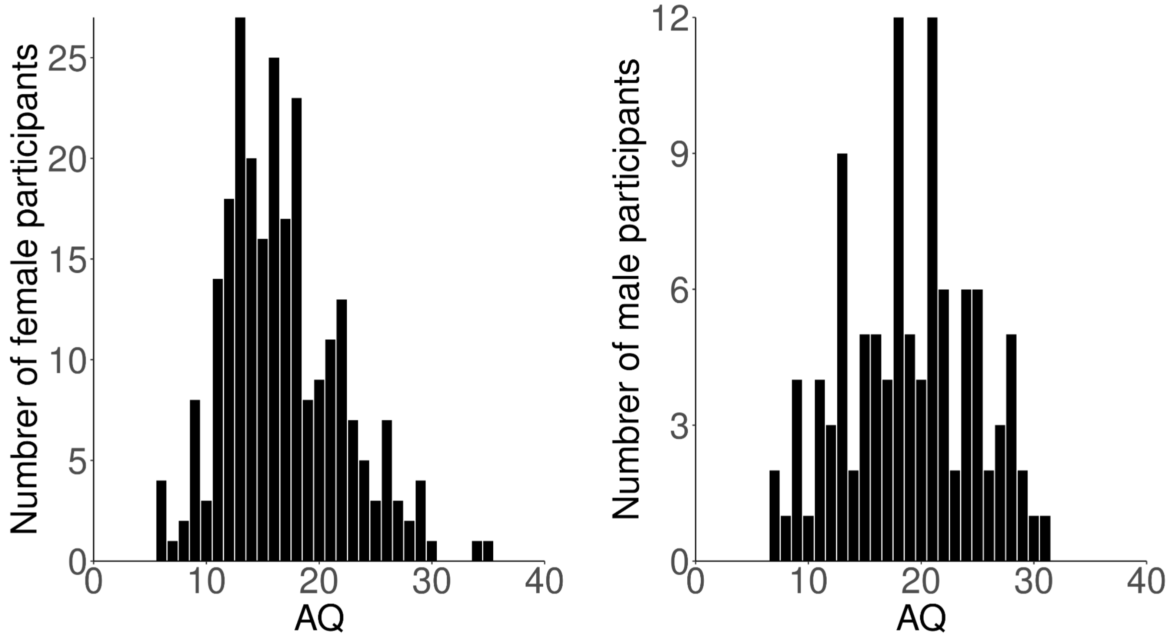
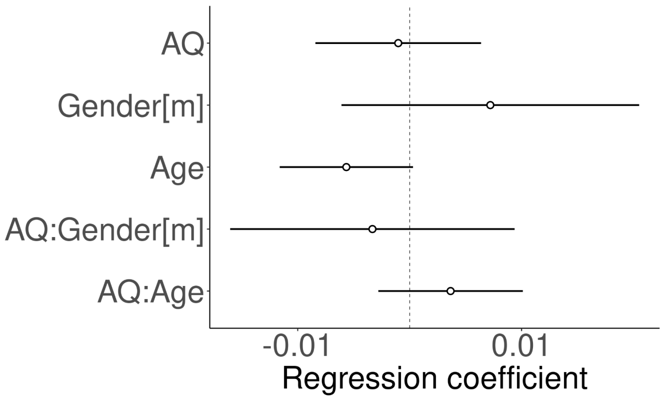


Figure 4

A

Linear regression model used to study the relationship between ASD traits and metacognitive sensitivity



Note. [m] = male.

B

Predicted values for AUROC2

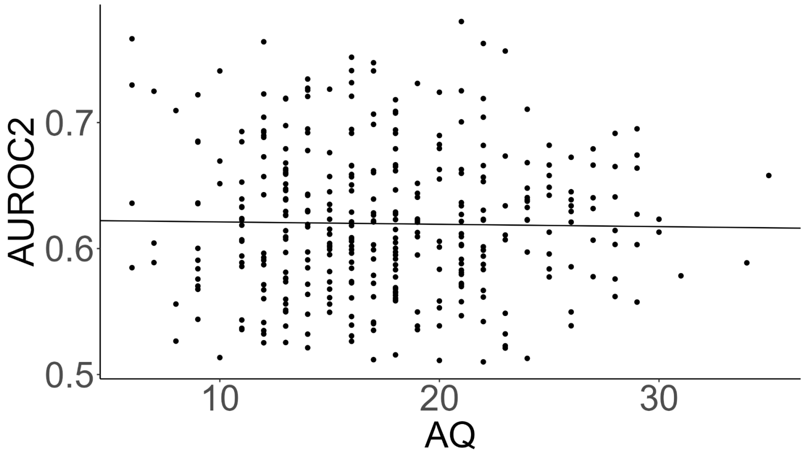
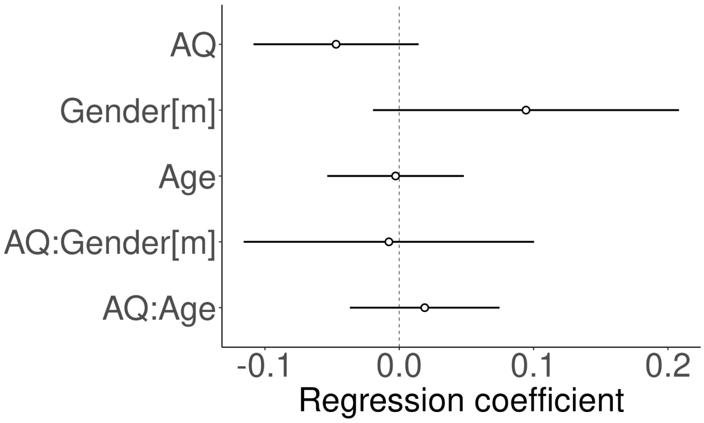


Figure 5

The mixed logistic regression model result to study of the relationship between ASD traits and metacognitive sensitivity



Note. [m] = male.

Figure 6

The linear regression model result used to study the relationship between the subscales of the AQ and metacognitive sensitivity

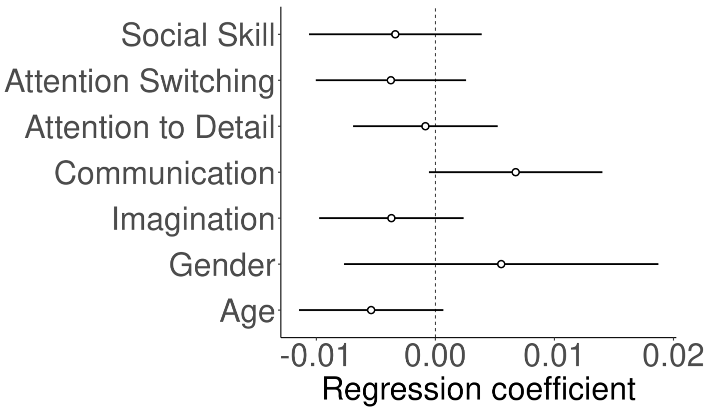
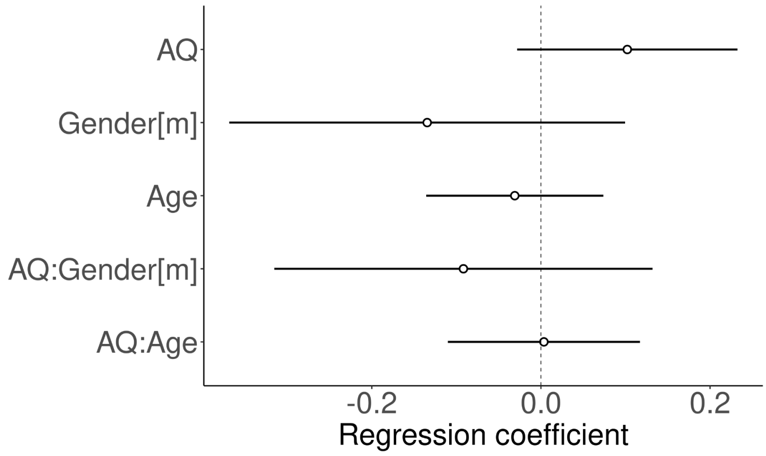


Figure 7

A

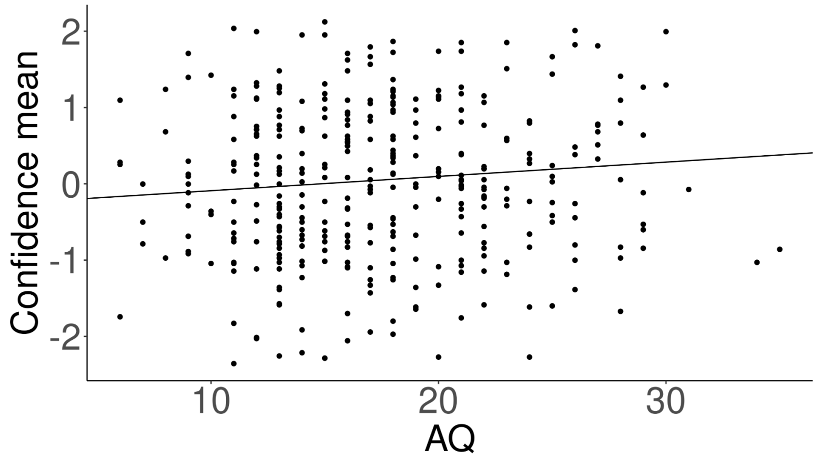
The linear regression model result used to study the relationship between ASD traits and confidence



Note. [m] = male.

B

Predicted values for confidence mean



Supplemental materials:

All data used in this study, the code to run the experiment and the code to perform data analysis and to reproduce all figures is available at:
https://github.com/iair-embon/metacog-asd-traits-2022