**Heightened sensitivity to low-level visual information in autism during an emotional
attentional blink task.**

Adeline Lacroix^a, Marie Gomot^b, Margot Fombonne^a, Mickaël J. R. Perrier^{a,c}, Carole Peyrin^a,
Nicolas Vermeulen^{d,e}, Gwynhi Park^f, Frédéric Dutheil^g, and Martial Mermillod^a

^a Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, LPNC, 38000, Grenoble, France

^b UMR 1253, Imagerie et Cerveau, Université de Tours, Inserm, 37000 Tours, France

^c Institute for Transport Studies, University of Leeds, LS2 9JT, United Kingdom

^d Université catholique de Louvain (UCLouvain), Psychological Sciences Research Institute,
Louvain-la-Neuve, Belgium

^e Fund for Scientific Research (FNRS-FRS), Brussels, Belgium

^f Department of Psychology, Hope College, United States

^g Université Clermont Auvergne, CNRS, LaPSCo, CHU Clermont-Ferrand, WittyFit, F-63000
Clermont-Ferrand, France

Corresponding author:

Adeline Lacroix, adeline.lacroix@univ-grenoble-alpes.fr

21 **Other authors can be reached at:**

22 Marie Gomot, marie.gomot@univ-tours.fr

23 Margot Fombonne, margot.fombonne@etu.univ-grenoble-alpes.fr

24 Mickaël J. R. Perrier, tsmjrp@leeds.ac.uk

25 Carole Peyrin, carole.peyrin@univ-grenoble-alpes.fr

26 Nicolas Vermeulen, nicolas.vermeulen@uclouvain.be

27 Gwnhi Park, park@hope.edu

28 Frédéric Dutheil, fdutheil@chu-clermontferrand.fr

29 Martial Mermillod, martial.mermillod@univ-grenoble-alpes.fr

30

31

32

33

34

35

36

37

38

39

40

41

42

43

44

45

46

Abstract

Background

Impairments in facial emotion recognition have been a hallmark of autism, which may contribute to the difficulty in social engagement and interpersonal interaction. Impaired facial emotion recognition in autism could be partly due to the asymmetrical perceptual bias to High Spatial Frequencies (HSF) information observed during visual perception. While Low Spatial Frequencies (LSF) convey coarse information, which would be critical for a fast analysis and categorization of emotional faces, HSF convey local information, which may serve a critical role in visual consciousness. However, to our knowledge, the effect of HSF on visual consciousness in autism has not been specifically studied so far.

Methods

Thirty-three adult autistic participants and 35 typically developing (TD) control participants performed an emotional attentional blink paradigm. Participants had to identify and report two targets (happy faces, T1 and T2) embedded in a stream of distractors (angry faces). The distractors between T1 and T2 were unfiltered or filtered in HSF or LSF. We used ANOVA to compare the impact of spatial frequency information on visual consciousness in the two groups of participants.

Results

TD control participants showed significantly reduced T2 accuracy (i.e., accuracy for the second target given the correct report of the first target T1) after unfiltered and HSF distractors compared to LSF distractors. As predicted, reduced T2 accuracy was observed after HSF distractors in the autistic group as compared to the TD group. Although we did not hypothesized, we also found reduced T2 accuracy after LSF distractors in the autistic group. The accuracy between the two groups did not differ regarding unfiltered distractors.

Limitations

Our sample was adult, high functioning and mainly late diagnosed. Therefore, our findings may not generalize to the whole autistic population.

Conclusion

Results confirm that HSF plays a critical role in visual consciousness in both TD and autistic participants. More importantly, autistic participants demonstrated impaired target detections after filtered distractors, suggesting that they have enhanced sensitivity for low-level characteristics, such as high and low spatial frequencies filtering. These findings are discussed in the context of the Enhanced Perceptual Functioning theory and predictive coding frameworks.

Keywords: autism; low-level vision ; spatial frequencies ; visual consciousness ; emotional faces ; attentional blink ; Enhanced Perceptual Functioning ; predictive coding.

Background

Emotional face processing impairments in autism

Rapid recognition and discrimination of facial emotions play an important role in successful navigation of the social world and people demonstrate the remarkable ability to process human face and to identify emotional faces [1]. However, autistic individuals are characterized by difficulties in facial emotion recognition [2], which may significantly contribute to impaired social interaction, one of the core symptoms of Autism Spectrum Disorders¹ (ASD), together with specific interests and hyper- or hypo-reactivity to sensory input [3]. This discrepancy between autistic and typically developing (TD) individuals could be partly explained by differences in the processing of low-level visual information, such as Low and High Spatial Frequencies (LSF and HSF, respectively). In a visual stimulus, spatial frequency refers to the energy distribution along a scale, derived from the Fourier transform, and expressed in the number of cycle per degree of visual angle [4]. Coarse information of a visual percept, conveyed by LSF, below two cycles per degree, would be quickly extracted by the primary visual system and projected onto the orbitofrontal cortex (≈ 130 ms post-stimulus) via the dorsal pathway [5]. This information would be used to make top-down predictions (i.e., a subset of potential “guesses” based on holistic processing), enabling quick categorization to facilitate identification in temporal areas with the subsequent integration of HSF, above six cycles per degree [5]. This model has been supported by empirical research in object recognition [5], scene categorization [6] and face processing [7]. Despite an important role that coarse-to-fine integration played in visual consciousness [8], HSF information could be also quickly extracted and serves an integral role in visual consciousness during face identification [9]. It did not refute

¹ This term is used in keeping with the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5) but we want to mention and acknowledge that ‘autistic person’ is usually preferred by people on the spectrum. Both terms are used in the paper.

the coarse-to-fine theory but ask for a more flexible model in which the use of spatial frequency information could vary depending on types of tasks people engaged in [9–11].

Previous research has shown that autistic persons exhibited enhanced visual acuity [12] and perceptual bias in low-level visual processing while processing either non-social [13,14] or social visual stimuli such as emotional faces [15]. More specifically, they analyzed fine information - conveyed by HSF - faster than TD people [16] and would rely more on these frequency channels while processing emotional faces [17,18]. This could partly impair fast emotion identification in different ways as a critical mechanism allowing emotion identification would be the coarse-to-fine integration of visual information [7]. More specifically, HSF bias usually reported in autism could reduce the coarse-to-fine neurocognitive mechanisms because of enhanced bottom-up processing relying on HSF. Alternatively, HSF bias could also impair the coarse-to-fine integration by impeding predictive top-down processes that rely on the fast analysis of LSF. Both hypotheses could help understand atypical visual perception and visual consciousness in autism, which might impair emotion identification.

Studying visual consciousness with the attention blink paradigm

A Rapid Serial Visual Presentation paradigm has been utilized to study visual consciousness by manipulating the time course of attention. Participants were asked to detect two visual targets (T1 and T2) embedded among a stream of distractors presented at a frequency of about 10 items per second [19]. People typically showed high accuracy of detecting the first target T1 [20]. However, the detection of the second target T2 was inconsistent depending on the lag between the two targets [19]. When the lag between T1 and T2 was very short, the detection of the second target T2 was good, often better than the detection of the first target T1, which is called the Lag-1 sparing phenomenon [20]. On the contrary, a second target T2 occurring between 200 ms and 500 ms after T1 was usually missed [20], which is called the attentional blink (AB). The boost and bounce theory of temporal attention [20] explains both the Lag-1 sparing and the

AB. As for the Lag-1 sparing, it was assumed that a target stimulus just following T1 would receive an attentional enhancement (boost) from excitatory feedbacks elicited by the visual input whenever relevant information was processed. T1 opened a gate, which then remained opened for subsequent relevant information, which allowed it to enter into working memory. However, irrelevant stimuli would receive strong inhibitory signal that blocked the gate (bounce), thereby resulting in the AB.

Modulation of the Attentional Blink

Previous research has shown that different types of tasks and individual differences can influence T1 or T2 reports. For instance, high similarity between targets and distractors increases the AB [21], while emotional stimuli decreases it [22,23]. Also, T1 and T2 report could vary by age [24] and be modulated by individual differences in the Full Scale Intelligence Quotient [25].

There was no difference in the AB magnitude between TD and ASD participants, when letter stimuli were used [26,27]. However, when T2 were emotional words, compared to neutral words or male names, an enhancement of T2 report was observed in TD controls, i.e., reduced AB magnitude, which was attenuated in autistic individuals, i.e., less reduced AB compared to control [28]. Nonetheless, when the effect of emotional faces was explored by using angry and neutral faces as targets, no difference were found between autistic children and the control group: ASD and TD showed better T2 accuracy for angry targets compared to neutral targets, and the magnitude of the effect was similar for both groups [29]. Yerys et al. [29] made several hypothesis to explain different results in their experiment from those of Gaigg and Bowler [28]. First, the arousal levels of the stimuli might differ between the two experiments. Second, Gaigg and Bowler [28] experiment required verbal abilities as stimuli are words, while Yerys et al. [29] pictorial AB task required lower-level abilities. Finally, they hypothesized that low similarity between targets (dog for T1 and emotional or neutral face for T2) and distractors

(non-meaningful scrambled faces) in their experiment enhanced salience of targets among distractors. In other words, they supposed that low similarity between targets and distractors facilitated target detection by intensifying the emotional valence of faces, thereby enhancing performances in autistic participants and reducing differences between the groups on emotional stimuli. On the contrary, high similarity between targets and distractors can account for an increased AB as shown in TD [21,30].

Study aims and hypotheses

The goal of the current research is to examine visual consciousness of happy faces in ASD and TD participants using the AB task. In order to determine which spatial frequency channels influence preferentially visual consciousness in ASD as compared to TD, we used stimuli in different spatial frequency ranges. In our AB task, participants had to detect two unfiltered happy faces (T1 and T2) in a stream of angry faces distractors, which were either low-pass filtered (i.e., LSF), high-pass filtered (i.e., HSF) or unfiltered. We also capitalized on the finding that spatial-frequency filtered distractors would allow us to manipulate similarity between targets and distractors. In this experiment, we tested three major hypotheses. First, we predicted a strong AB effect in both groups, as distractors have a high degree of similarity with targets because they are all faces. Secondly, given a pivotal role that HSF plays in visual consciousness during face identification [9], we expected a stronger AB after HSF and unfiltered distractors (as it also contains HSF) compared to LSF distractors in both groups. Lastly, due to the perceptual bias favoring fine and detailed information observed in ASD, autistic participants would be significantly more disturbed by HSF distractors than TD participants.

Similar to other AB studies, we controlled for T1 accuracy. Although previous research did not find a difference between individuals with ASD and TD in T1 accuracy when stimuli were worlds or animals [28,29] we expected reduced T1 accuracy in the ASD group because of impaired emotional face recognition usually found in individuals with ASD. Thus, we predicted

reduced T1 accuracy in ASD as compared to TD. We also assessed the Full Scale Intelligence Quotient (FSIQ), verbal Intelligence Quotient (VIQ), Performance Intelligence Quotient (PIQ), Autism spectrum Quotient (AQ) and age, to control for these variables [24,28].

Method

Participants

Sample size was determined according to studies comparing autistic and control groups during an AB task [28,29] and using *G-power*. A total of 52 participants (26 in each group) would have been required (with $\alpha = .05$, $1 - \beta = .90$ and small effect size). We decided to slightly oversize the sample (+ 25 %) in case of unusable data or overestimation of the effect size. Thirty-two adults (14 females, 15 males, 2 transgenders female-to-male) with a diagnosis of Asperger syndrome (F84.5), one adult (female) with a diagnosis of atypical autism (F84.1) and 35 TD control adults (19 females, 15 males, and 1 transgender female-to-male) were recruited for this study. One additional autistic man was enrolled but excluded as the task was too difficult for him and skipped all answers. All participants were aged from 19 to 47 years and had a FSIQ > 70, as estimated using a Wechsler Intelligence Scale (Wechsler Intelligence Scale for Children, 4th Edition - WISC-IV [31] - or Wechsler Adult Intelligence Scale, 3rd or 4th Edition -WAIS-III [32] or WAIS-IV[33]). They all reported a normal or corrected-to-normal vision.

Autistic participants were recruited through local community, with the help of either the local Expertise Centers dedicated to autism diagnosis, psychologists specialized in ASD support or associations for the autistic community. We ensured that they previously received a clinical diagnosis (by a multidisciplinary team from an Expertise Center, a regional center, or by trained psychologists and psychiatrists) by asking them the report of the diagnosis. Sixteen provided their Autism Diagnostic Observation Schedule [34] score, eight provided their Autism Diagnostic Interview-Revised [35] score and 25 provided the results of their IQ test (WAIS-III,

WAIS-IV or WISC-IV). For those who did not have available IQ data, an estimation of their FSIQ, VIQ, and PIQ was performed using four selected subtests (Vocabulary, Similarities, Block Design and Matrix) of the WAIS-IV [33,36]. The diagnosis of each participant was based on the DSM-IV-R [37] or DSM-5 [38] criteria and on the International Classification of Disease 10th revision [39]. Their age at diagnosis was situated between 10 and 45 years old (mean = 28.8, SD = 10.3). Three of them also received a diagnosis of attention deficit with or without hyperactivity disorder (one of them was treated with methylphenidate); two received a diagnosis of anxiety disorder and two had a history of traumatic brain injury. Two were receiving neuroleptic medication and six were used to take antidepressant when they were enrolled in the study but were stabilized with the treatment. Twenty-one autistic participants had neither other diagnosis nor treatment.

TD adults were recruited via advertisements and mailing list. They didn't have any neurological, neurodevelopmental or psychiatric diagnosis. As far as possible, groups were paired on sex, age and education. An estimation of their FSIQ, VIQ, and PIQ was performed.

After having checked assumptions (variance homogeneity with Levene's test and normality with histogram, density curves and qq-plot visual inspection, as well as the Shapiro-Wilk test), we performed two-sample t-test, as t-test is robust to small violation of normality. Groups did not differ on age, education, VIQ, and FSIQ. Nevertheless, it is worth noting that differences between groups on FSIQ is approaching the significance threshold and may be related to the significant difference between groups on PIQ. As predicted, groups differed on the AQ. All relevant statistics regarding groups description are set out in *Table 1*.

Table 1: Subject demographics – *Means (M)* and *standard deviations (SD)*. FSIQ = Full Scale Intelligence Quotient; VIQ = Verbal Intelligence Quotient; PIQ = Performance Intelligence Quotient ; AQ = Autism-Spectrum Quotient.

	TD (n= 35)		ASD (n= 32)		T-test	Effect size
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>p</i>	<i>Cohen's d</i>
Age	31.9	7.6	32.7	8.3	.702	
Education	15.9	2.7	14.6	2.7	.052	
FSIQ	114.5	14.6	122.5	18.2	.051	
VIQ	121.7	15.8	127.6	17.5	.242	
PIQ	103.8	14.4	113.7	15.7	<.01	.66 (medium)
AQ	15.3	6.1	35.3	8.1	<.001***	2.79 (large)
Age at diagnosis			28.8	10.5		

After a verbal instruction, written informed consent was obtained from all individual participants. Participants received a monetary compensation for their participation at the end of the study.

All procedures performed in this study involving human participants were in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved by the local ethics committee (CER-Grenoble Alps, COMUE University Grenoble Alpes, IRB00010290).

Material

The stimulus set comprised 80 faces on a grey background (20 females and 20 males expressing either happiness for targets or anger for distractors) from the Chicago Faces Database [40]. They were high resolution (2444 x 1718 pixels) and cropped to a 2288 x 1716 pixel size (18.4° x 13.8°). All stimuli were converted to 256 gray levels by averaging the red, green, and blue values of each pixel, then exported into a BMP format in order to standardize file size and load speed. Happy faces were the target stimuli and always presented unfiltered (i.e., in Broad Spatial Frequency – BSF). Angry faces were distractors and were presented either in BSF, LSF containing only frequencies below two cycles per degree of visual angle (corresponding to 36.89 cycles per image width, that is 10.78 cycles per face), or HSF

containing only frequencies above six cycles per degree of visual angle (corresponding 110.69 cycles per image width, that is, 31.44 cycles per face). Example of distractors can be seen on *Figure 1*. Stimuli were equalized in luminance and contrast [41]. Filtering and equalizing procedures were performed using MATLAB (Mathworks Inc., Sherborn, MA, USA). Stimuli were displayed in a darkened experimental box of the Psychology and NeuroCognition Laboratory (Grenoble Alpes University), on a 23-inch LCD monitor Dell P2319H (refresh rate = 75 Hz) at a viewing distance of 117 cm. To maintain the distance and central position, participants' head was supported by a chinrest. E-prime version 2.0 (Psychology Software Tools Inc., Pittsburg, PA) was used to exhibit stimuli and collect behavioral data. As some participants could not easily come many times to the laboratory, on the same day, after the AB task of 30 minutes duration, they also did another study (an emotional Stroop task of 15 minutes) after a break. If needed, IQ estimation was done after these tasks.

[insert Figure 1]

Figure 1. Examples of distractors used during the task. The left one is in High Spatial Frequencies (HSF), the middle one is unfiltered (BSF) and the right one is in Low Spatial Frequencies (LSF).

Procedure

Instructions were given both orally and on a written form. Each participant performed the task individually. Participants were informed that a stream of angry faces would be displayed, two happy faces would appear among them and should be memorized in order to recognize each of them among three others at the end of the stream. They were informed of the rapid presentation and were instructed to concentrate a lot for the task. A training session of 8 trials was performed by the participant before the experimental session of 180 trials, which included three breaks (every 45 trials) in order to decrease the attentional load required by the task and allow participants to rest their eyes. During the training session, the experimenter stayed with the

participant in order to ensure that instructions had been correctly understood and to reassure the
 participant if the task's difficulty generated anxiety. After this training session, the experimenter
 left the room. Each trial began with a fixation cross for approximately 1,000 milliseconds (ms),
 followed by a sequence of four, five, six or seven unfiltered angry faces followed by T1 (an
 unfiltered happy face). The second unfiltered happy face T2 appeared after a second serial of
 two (Lag 3), four (Lag 5) or six (Lag 7) distractors, which were either in BSF, LSF, or HSF.
 Lag 0 corresponds to the onset of T1. Each stimulus had a duration of 133 ms. Accordingly,
 stimulus onset asynchrony was either 399 ms (Lag 3), 665 ms (Lag 5), or 931 ms (Lag 7). As
 emotional faces are complex stimuli, longer presentation times have been required, compared
 to experiments using letters, in order to reduce task difficulty. For each trial, distractors were
 similarly filtered and five unfiltered distractors remained after T2. After this rapid serial visual
 presentation, a screen appeared for approximately 4,000 ms with three happy faces on the upper
 half. Right-handed participants had to choose which of these three faces corresponded to T1 by
 pressing one of the three corresponding buttons on the right side of the Chronos® device
 (Psychology Software Tools). Importantly, participants were instructed not to answer randomly
 and had to press the far-left button if they had no idea about the answer. For left-handed
 participants, the buttons were situated on the left side to facilitate the motor response. Then, a
 second screen appeared for the same duration with three unfiltered happy faces displayed on
 the lower half; this was made to ensure participants would notice the change in case they were
 distracted during this latter. Participants were instructed to find T2 among the three faces. The
 schematic of one trial is shown in *Figure 2*.

[Insert Figure 2]

Figure 2 Example of a trial with HSF as distractors. Target 1 has to be selected among other faces on the *Answer 1* slide
 and Target 2 has to be selected among other faces on the *Answer 2* slide.

Results

All figures and analyses were done using R version 3.6.1 and R Studio version 1.2.5019 [42].

Analysis on T2 accuracy (given a correct answer on T1)

[insert Figure 3]

Figure 3. *Mean* T2 accuracy (given a correct answer on T1) and *standard errors* by group for each Lag and in each Distractor condition. Only significant between groups differences for each Distractor type depending on Lag are represented (* = $p < .05$, ** = $p < .005$).

Table 2. *Mean* T2 accuracy (and standard errors; *SE*) for each condition.

	TD			ASD			All			
Distractor	Lag 3	Lag 5	Lag7	Lag 3	Lag 5	Lag7	Lag 3	Lag 5	Lag7	Mean for each Distractor
BSF	26.3 % (3.1)	36.8 % (3.2)	47.4 % (3.2)	21.1 % (3.8)	30.7 % (4.3)	41.1 % (4.3)	23.8 % (2.4)	33.9 % (2.7)	44.4 % (2.7)	34.0 % (1.6)
LSF	23.4 % (2.9)	45.9 % (3.1)	57.1 % (2.7)	19.0 % (3.6)	34.0 % (4.3)	41.7 % (4.5)	21.3 % (2.3)	40.2 % (2.7)	49.7 % (2.7)	37.1 % (1.7)
HSF	21.5 % (3.1)	33.8 % (3.0)	44.8 % (3.8)	16.2 % (3.3)	25.4 % (4.2)	33.4 % (4.8)	19.0 % (2.3)	29.8 % (2.6)	39.3 % (3.1)	29.4 % (1.6)
Mean for each Lag	23.7 % (1.7)	38.8 % (1.9)	49.7 % (1.9)	18.8 % (2.0)	24.2 % (2.5)	38.7 % (2.6)	21.4 % (1.3)	34.6 % (1.6)	44.5 % (1.7)	
General mean	37.4 % (1.2)			29.2 % (1.5)			33.5 % (0.9)			

We calculated the correct response rate (accuracy) for T2 given that T1 was correctly reported [19,28,29] for each of the experimental conditions. This latter is abbreviated “T2 accuracy” in the following text. *Figure 3* represents the T2 accuracy for each group (ASD, TD) as a function of Lag (3, 5, and 7) and Distractor (BSF, HSF, and LSF). All means and standard errors for T2 accuracy are reported in *Table 2*. We conducted a mixed-design ANOVA with Group (ASD vs

TD participants) as a between subject factor, and Lag (3, 5 or 7) and Distractor (BSF, LSF or HSF) as within-subject factors. Assumptions of sphericity were tested with Mauchly Test. As there was no violation of sphericity, no correction was required. Normality assumption on residuals were visually inspected with histogram and qq-plot, and tested with a Shapiro-Wilk test.

The analysis revealed three significant main effects. The main effect of Group ($F(1, 65) = 4.14$, $p < .05$, $\eta^2 = .04$), indicated that overall T2 accuracy of ASD participants was significantly lower than overall T2 accuracy of TD participants. A main effect of Lag ($F(1, 85) = 104.8$, $p < .001$, $\eta^2 = .17$) was also found. Post-hoc paired t-test with Tukey adjustment showed that T2 accuracy at Lag 3 was worse than T2 accuracy at Lag 5 ($t(130) = -8.27$, $p < .001$, $d = -0.65$), which was also worse than T2 accuracy at Lag 7 ($t(130) = -6.15$, $p < .001$, $d = -0.43$). These findings demonstrate the expected AB phenomenon in our paradigm (both group taken together). Finally, we observed a main effect of Distractor ($F(1, 88) = 17.68$, $p < .001$, $\eta^2 = .02$). Post-hoc paired t-test with Tukey adjustment revealed that T2 accuracy after HSF distractors was lower than after BSF distractors ($t(130) = 3.61$, $p < .005$, $d = -0.21$), and lower than after LSF distractors ($t(130) = -5.90$, $p < .001$, $d = -0.32$). These findings revealed that HSF produced a greater AB than other distractors when groups were taken together. However, the difference between T2 accuracy after BSF distractors and after LSF distractors was not significant.

There was also a significant Lag $\times$ Distractor interaction ($F(3, 85) = 2.96$, $p < .05$, $\eta^2 = .007$), attesting that the effects of distractors were different depending on the Lag. Paired t-test with Tukey adjustment revealed that T2 accuracy was lower for HSF than LSF at Lag 5 ($t(390) = -4.66$, $p < .001$, $d = -0.48$) and at Lag 7 ($t(390) = -4.61$, $p < .001$, $d = -0.43$). This was not observed at Lag 3, suggesting that the greater AB followed by HSF compared to LSF appeared only at longer lags (5 and 7). Moreover, T2 accuracy was significantly lower for BSF

than LSF at Lag 5 ($t(390) = -2.79, p < .02, d = -0.29$), but not at Lag 3, and only marginally significant at Lag 7 ($t(390) = -2.29, p = .058, d = -0.24$). Hence, BSF distractors also produced a greater AB than LSF distractors at longer lags.

The data set out in *Figure 3* suggests that the lack of significance difference between BSF and LSF at Lag 7, which was not expected, could be explained by a different pattern in each group. This led us to perform within-group paired t-test with Tukey adjustment although the foregoing analysis provided no interaction involving the group factor. In the TD group, a significant difference in T2 accuracy exists between HSF and LSF at Lag 5 ($t(390) = -3.94, p < .001, d = -0.67$) and at Lag 7 ($t(390) = -3.99, p < .001, d = -0.62$), and between BSF and LSF at Lag 5 ($t(390) = -2.95, p < .01, d = -0.48$) and at Lag 7 ($t(390) = -3.14, p < .01, d = -0.55$). These findings indicate that, as expected, HSF and BSF distractors produce a greater AB than LSF distractors at longer lags (5 and 7) in TD participants. In the ASD group there is a difference in T2 accuracy between HSF and LSF at lag 5 ($t(390) = -2.68, p < .05, d = -0.36$) and at Lag 7 ($t(390) = -2.56, p < .05, d = -0.31$). However, there is no significant difference between BSF and LSF, neither at Lag 5, nor at Lag 7. Hence, in the ASD group, only HSF distractors produced a greater AB than LSF distractors at longer lags (5 and 7). These differences between groups could therefore explain the lack of significance previously found at Lag 7 between BSF and LSF in the main effect and in the interaction. Moreover, the analysis showed a difference in T2 accuracy between BSF and HSF at Lag 7 ($t(390) = 2.39, p < .05, d = 0.30$) for the ASD group, suggesting greater AB after HSF distractors compared to BSF distractors at the longest lag.

Finally, we tested our main hypothesis: HSF distractors would produce a greater AB than LSF distractors for the ASD group as compared to the control group. We performed between-group paired t-tests with Tukey adjustment for each distractor type and within each Lag. The expected between-group difference on T2 accuracy after HSF distractors was only found at

Lag 7 ($t(161) = -2.21, p < .03, d = -0.46$). Differences between groups on T2 accuracy were also found after LSF distractors at Lag 5 ($t(161) = -2.31, p < .03, d = -0.55$) and at Lag 7 ($t(161) = -3.00, p < .005, d = -0.73$). These unexpected findings indicate that LSF distractors also produce a greater AB for the ASD group as compared to the TD group at longer lags (5 and 7). No between-group differences in T2 accuracy were found after BSF distractors. These results are represented on *Figure 3*.

Analysis on T1

[insert Figure 4]
Figure 4: Box plot and mean T1 accuracy (in red) by group

We calculated a correct response rate for T1 for each participant. The latter is abbreviated by “T1 accuracy” in the text. *Figure 4* represent T1 accuracy by group (ASD, TD). As variances were unequal, we performed a Mann-Whitney-Wilcoxon test. Contrary to our prediction, the test was not significant, indicating that T1 accuracy of autistic participants ($M = 52.7, SE = 1.4$) does not significantly differ from T1 accuracy of TD participants ($M = 58.0, SE = 0.8$).

Correlation analysis

Correlations plots between AQ, Age, as well as the estimations of FSIQ, VIQ, and PIQ with the T2 accuracy and the T1 accuracy are represented on *Figure 5a* and *Figure 5b*, respectively. We did not find any significant correlation between T2 accuracy and AQ, FSIQ, nor VIQ. A significant negative correlation between age and T2 accuracy was found for the TD group only ($r = -.43, p < .01$), indicating that the older the TD participants are, the stronger is the AB. We also found a significant negative correlation between age and T1 accuracy in the TD group

($r = -.35, p < .05$), revealing that the older TD participants are, the lower is their T1 accuracy. Finally, we found a significant positive correlation between T1 accuracy and FSIQ in the TD group ($r = .41, p < .05$) and in the ASD group ($r = .39, p < .05$), indicating that the higher FSIQ is, the better is the T1 accuracy. We also found significant positive correlations between T1 accuracy and PIQ in the TD group ($r = .46, p < .01$) and in the ASD group ($r = .40, p < .05$), revealing that the higher the PIQ is, the better is the T1 accuracy.

[insert Figure 5]

Figure 5. a. Correlation plots between T2 accuracy (given correct answer on T1) and Autism-Spectrum Quotient (AQ), age, as well as estimations of Full Scale Intelligence Quotient (FSIQ), Verbal Intelligence Quotient (VIQ), and Performance Intelligence Quotient (PIQ). b. Correlation plots between T1 accuracy and AQ, age, as well as estimations of FSIQ, VIQ and PIQ.

Discussion

The current study used an AB paradigm with spatial-frequency filtered distractors to investigate the influence of spatial frequencies on visual consciousness in autistic adults compared to TD control participants.

The Attentional Blink and the influence of HSF in visual consciousness

Replicating previous results on AB in TD people [19,20] and in ASD [26–29], our results elicited a strong AB, as T2 accuracy was reduced for shorter lags and increased with longer lags. This finding is consistent with the first hypothesis. We also found a stronger AB after HSF distractors and after BSF distractors as compared to LSF distractors, at Lag 5 and at Lag 7 in both groups taken together, which is consistent with our second hypothesis. This result further confirms that HSF plays a primary role in visual consciousness. As HSF are mainly conveyed by the ventral stream, our findings supports the idea that visual consciousness emerged from the temporal pathway processing, as suggested by other studies [43–45]. For instance, a correlation has been shown between event-related potential in the occipito-temporal cortex

(N170) and conscious perception of faces [43]. It should be noted that the difference between BSF and LSF at Lag 7 was only marginally significant. This could be explained by differences between groups on LSF distractors, which will be further discussed. No difference between distractors at Lag 3 can be explained by the strength of the AB at that lag.

Increased sensitivity to filtered distractors suggests enhanced low-level visual processing in autism

Based on previous findings of perceptual bias favoring HSF information in autism [14–16] we predicted that autistic participants would show significantly reduced T2 accuracy in response to the HSF content of inter-target distractors compared to TD control participants. While there was no difference between groups on T2 accuracy according to distractor types at Lag 3, probably due to the strong AB effect at lag 3 for both groups, group differences emerged at Lags 5 and 7. Of particular importance is lower T2 accuracy for autistic participants, compared to TD, after HSF distractors at Lag 7, which partially support our hypothesis. Interestingly, at Lags 5 and 7, our analysis also revealed unexpected lower T2 accuracy for the ASD group after LSF distractors as compared to the TD group. Additionally, we did not observed differences between groups on BSF. The latter finding indicate that the main effect of group observed on T2 accuracy in our experiment appears to be related to the filtered nature of the distractors. Thus, it is not likely to be due to the emotional content, which might have reduced the AB in TD participants compared to ASD as it has been observed sometimes [28]. Taken together, these results suggest an increased sensitivity to low-level visual characteristics (i.e., HSF and LSF information) in ASD participants compared to TD control. No difference between groups after BSF could be questionable as BSF contain LSF and HSF. However, BSF also contain other spatial frequency bands. Hence, processing LSF and HSF in BSF stimuli might differ from processing them independently in low-passed or high-passed stimuli, as suggested by other experiments [4]. The sensitivity to low-level visual characteristics in autism found here

supports the Enhance Perceptual Functioning theory of autism [14]. According to this theory, the local bias observed in autism should be attributed to enhanced low-level perception, which could explain, in our experiment, the sensitivity to both HSF and LSF, rather than to deficits in processing global information, as suggested by the Weak Central Coherence theory [46]. Indeed, it has already been showed that autistic children are perfectly able to perform global processing in some conditions, depending on the task demands [47]. Our findings are also congruent with the enhanced visual acuity found in autism [12]. Enhanced low-level characteristics processing in autism could partially explain some inconsistencies found in studies implicating spatial frequency filtering, as some found that autistic participants were more sensitive to HSF [17,48] and other to LSF [49]. At a neural level, enhanced low-level visual perception in autism could be related to superior functioning of the most posterior region of the visual brain [14]. At a behavioral level, it could also be related to atypical attention pattern usually reported in autism for social [50] but also non-social stimuli [51]. As eye-tracking experiments demonstrate atypical pattern of attention orientation in autistic participants when processing visual scenes, we can hypothesize that their gaze might be attracted by low-level characteristics of the scene.

The predictive coding hypothesis: an alternative framework for explaining our results

The sensitivity of autistic participants to filtered distractors could also provide evidence to support predictive coding theories. Predictive coding theoretical frameworks hypothesize hypoactive top-down modulations or hyperactive low-level bottom-up information processing in autistic individuals would result in increased prediction errors. Higher prediction errors could be used as feed-forward inputs for the next stage of processing, whereas those errors should normally be minimized to allow adaptation to an environment [52–55]. In our experiment, the second target appeared after a stream of distractors containing the same low-level characteristics (i.e., the same type of filtering was used for each distractor). It is reasonable to

assume that ASD participants became used to the characteristics of the distractors (at Lag 5 and 7) and made strong predictions for the next image, based on the current input. Hence, we assume that when distractors were low-pass or high-pass filtered, the appearance of the unfiltered second target T2 violated the expectation generated by the statistical regularity of the stream, leading to greater prediction errors. This mechanism could impair T2 accuracy in autistic participants more than TD as the latter seem more likely to adapt to this change. In the case of BSF distractors, targets and distractors had the same low-level content. Thus, it is possible that autistic people did not make prediction error related to low-level characteristics of the stimuli (i.e., spatial frequencies filtering), explaining the absence of between-group differences for BSF distractors. The predictive coding hypothesis for our results is supported by electrophysiological studies on Mismatch Negativity in autistic adults. The Mismatch Negativity paradigm is used to study brain reactions to an unexpected event occurring among regular events and can be seen as an electrophysiological signal of perceptual prediction errors [56]. Autistic people often elicit faster or stronger reactions to deviant stimuli, either in auditory or in the visual modality [57]. It indicates the ability of autistic person to make accurate predictions in some situations, but overweight them [58], consequently having a stronger reaction to what is unpredicted.

Attentional blink modulation

Less importantly, T2 accuracy appear reduced in our experiment (i.e., $M = 33.5\%$) as compared to other experiments (where T2 accuracy range from approximately 60 % to 90 %), even if they implied autistic participants [28,29]. It could be surprising as an attenuation of the AB (i.e., better T2 accuracy) is usually observed when targets are emotional faces [22,23]. However, the similarity between targets and distractors, which were all emotional faces in our experiment, can explain this result. It confirms past findings that target-distractor similarity would reduce salience of targets among distractors thus increasing the AB [21,29,59]. In addition, the answer

choice in our task was presumably harder as compared to other similar tasks and may affect performances. Indeed, our participants have to identify the T1 face between three happy faces (and the same for T2), with the instruction not to answer by chance, having the possibility to choose “*I don’t know*” (thus, the chance level here is much less than 33%). We assume that finding a target face among other is more difficult than a dichotomous yes/no answer on a question such as “*Did you see a face?*” (chance level = 50 %).

The task difficulty could also explain the longer AB observed in our experiment. Despite AB usually occur between 200 ms and 500 ms after T1 onset, it appears to still occur at Lag 5 (665 ms) and maybe even at Lag 7 (931 ms). Nevertheless, longer lags would be required to determine the actual duration of the AB. This can extend previous findings showing that the AB magnitude can be modulated by various factors such as task demands [60,61].

T1 accuracy and correlations

The task difficulty probably impaired T1 recognition as well. Indeed, we observed apparent poorer T1 accuracy in our experiment with greater variability as compared to T1 accuracy usually observed in other experiments.

We predicted that T1 accuracy would differ between groups, because the task involved emotional faces which are difficult to process by autistic people [2]. However, T1 accuracy was similar in both groups. A meta-analysis on emotions recognition in autism suggests the intact recognition of happiness in autistic individuals [2]. Since our targets were happy faces, autistic participants might have no difficulty in identifying them, which could explain similar T1 accuracy in both groups. Alternatively, this result could be related to IQ performances. A correlation exists between T1 accuracy and FSIQ, as well as between T1 and PIQ for both groups, which is in line with previous studies showing that higher IQ can enhance emotion recognition in both TD and ASD participants [62,63]. Thus it is possible that higher IQ of ASD

participants compared to the TD control group (statistically significant difference for PIQ, marginally significant difference for FSIQ), can possibly compensate emotion recognition impairment usually found in ASD and mask between-groups differences. Nevertheless, when we remove the few outliers in term of IQ performances (group means $\pm 2SD$), correlations between T1 accuracy and FSIQ and PIQ were not significant anymore. This is in favor of weak FSIQ and PIQ weights in the task. It should be mentioned that correlation between IQ and T2 accuracy is not significant, which is coherent as the calculation of T2 accuracy is based on trials where T1 have been correctly reported. It is also congruent with previous research [25]. Moreover, we didn't find any correlation between VIQ and T2 accuracy in ASD (nor in TD), contrary to another study [28]. It may be explained by differences in our paradigm: their targets and distractors were emotional and non-emotional words, which could more imply VIQ than our task based on emotional faces. Taken together, these findings support the fact that IQ variations among our subjects have not impaired our results. Finally, we found a significant negative correlation between accuracy (for T1 and for T2) and age in TD, performances becoming weaker with age, but this is not found in ASD. AB performances tend to improve between 18 and 39 years old, and then to decline [24]. Hence, the negative correlation could be at odds with the fact that only 9 TD participants are aged 39 and above. However, a fast decrease of performances after 39 might explain this result. Surprisingly, this decline is not observed in ASD participants despite they are a bit older than TD participants in our study (ASD age rank = 19 – 47, median = 33.5; TD age rank = 19 – 44, median = 31.0). Two hypotheses can be brought up. First, it may be related to high IQ of ASD participants as compared to TD in our study. Indeed, higher IQ is usually associated with less cognitive decline [64]. Second, ASD might also partially protect against a cognitive decline related to age [65], which is yet to be determined.

Limitations

Our study has some limitations pertaining to participants. First our autistic participants are adults, who were mainly diagnosed late and have high intellectual abilities. Moreover, all except one have been diagnosed with Asperger syndrome and can have a different cognitive profile of those with High Functioning Autism, even if those categories can be debated. Particularly, emotion recognition can be enhanced in Asperger syndrome as compared to High Functioning Autism [66]. Our ASD group represents a small subset of autistic adults and are not representative of the ASD population. Hence, the results found here cannot be generalized to the whole spectrum. It would be interesting to conduct similar task with autistic participants with IQ in the normal range, or with low IQ or with participants with typical autism, but the task should be adapted because of its difficulty. Moreover, there is a high variability in performances of autistic participants, probably reflecting the highly heterogeneous autism spectrum. Data driven analysis might be conducted to distinguish autistic subgroups [67], but would probably require larger sample size. Another limitation is that a small portion of our autistic participants has comorbidities and/or treatment, which might have affected their performances. Nevertheless, in this case, we can hypothesize that all performances would have been affected, and not only those after LSF and HSF distractors. To confirm or infirm this hypothesis, similar studies should be conducted with other clinical populations. Finally, the correlation found with age could potentially have a slight impact on the result and should conduct to lower the maximal age in further studies.

Other limitations are related to the task. Our task was designed to detect happy faces target among angry faces distractors. Hence, it cannot be generalized to other emotional faces. Moreover, the task was difficult and we are aware that accuracy is quite low; nevertheless, as participants were instructed not to answer by chance and to use the “*I don’t know*” button when they were not sure, we think that our results are reliable.

Conclusion

The present study shed light on the influence of spatial frequencies on visual consciousness in both autistic and TD persons. The results of the study extend our understanding of the attentional blink phenomenon. Moreover, our findings suggest increased sensitivity to low-level visual characteristics in autism. If HSF sensitivity was expected in autism, LSF sensitivity was more surprising. These results can be explained by the Enhanced Perceptual Functioning framework, which is an influential model of autism, and by superior visual abilities in autism. They can be also explained by predictive coding frameworks, which are emerging models for explaining autism characteristics. However, further studies are required to tease apart low-level processing from predictive coding processing in autism. Results of the current research could have important implications for our understanding of atypical visual processing in autism, which can partly contribute to social deficits.

List of abbreviations

ASD = Autism Spectrum Disorder

BSF = Broad Spatial Frequencies

cpd = cycle per degree

DSM = Diagnostic and Statistical of Mental Disorder

FSIQ = Full Scale Intelligence Quotient

HSF = High Spatial Frequencies

605 IQ = Intelligence Quotient

606 LSF = Low Spatial Frequenciesms

607 ms = milliseconds

608 PIQ = Performance Intelligence Quotient

609 TD = Typically Developing

610 VIQ = Verbal Intelligence Quotient

611 WAIS = Wechsler Adult Intelligence Scale

612 WISC = Wechsler Intelligence Scale for Children

613

614

615

Declarations

616

617

Ethics approval and consent to participate

619 Written informed consent was obtained from all individual participants included in the study.

620 All procedures performed in this study involving human participants were in accordance with

621 the Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved

622 by the local ethics committee (CER-Grenoble Alps, COMUE University Grenoble Alpes,

623 IRB00010290).

Availability of data and materials

625 The datasets generated and/or analyzed during the current study are available in the Open

626 Science Framework repository, <https://osf.io/maqvy/>. Any other materials are available from

627 the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by the French Ministry of Higher Education, Research and Innovation (France) to Adeline Lacroix and by the Pole Grenoble Cognition.

Author's contribution

AL collected, analyzed, interpreted the data, and wrote the manuscript. MG and MM were major contributors to data interpretation and writing of the manuscript. MF largely contributed to data collection. MP and MM conceived the experiment. GP, CP, NV, MP and FD contributed in data interpretation and substantively revised the manuscript. All authors provided approval for publication of the content.

Acknowledgments

We thank all participants and their families for their help in this study. We also thank the Epxertise Center for Asperger of Grenoble, the Savoyard Center for Autism Evaluation, Nelly Coroir and Jérôme Ecochard for their help with volunteer recruitment. Finally, we thank Eric Guinet for his invaluable assistance with screen tests and calibration.

References

- [1] Tanaka JW. The entry point of face recognition: Evidence for face expertise. *Journal of Experimental Psychology: General* 2001;130:534–43. <https://doi.org/10.1037/0096-3445.130.3.534>.
- [2] Uljarevic M, Hamilton A. Recognition of Emotions in Autism: A Formal Meta-Analysis. *J Autism Dev Disord* 2013;43:1517–26. <https://doi.org/10.1007/s10803-012-1695-5>.
- [3] American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition: DSM-5*. 5 edition. American Psychiatric Publishing; 2013.
- [4] Park G, Van Bavel JJ, Vasey MW, Egan EJJ, Thayer JF. From the heart to the mind's eye: Cardiac vagal tone is related to visual perception of fearful faces at high spatial frequency. *Biological Psychology* 2012;90:171–8. <https://doi.org/10.1016/j.biopsycho.2012.02.012>.
- [5] Bar M, Kassam KS, Ghuman AS, Boshyan J, Schmid AM, Dale AM, et al. Top-down facilitation of visual recognition. *PNAS* 2006;103:449–54. <https://doi.org/10.1073/pnas.0507062103>.
- [6] Peyrin C, Michel CM, Schwartz S, Thut G, Seghier M, Landis T, et al. The Neural Substrates and Timing of Top–Down Processes during Coarse-to-Fine Categorization of Visual Scenes: A Combined fMRI and ERP Study. *Journal of Cognitive Neuroscience* 2010;22:2768–80. <https://doi.org/10.1162/jocn.2010.21424>.
- [7] Goffaux V, Peters J, Haubrechts J, Schiltz C, Jansma B, Goebel R. From Coarse to Fine? Spatial and Temporal Dynamics of Cortical Face Processing. *Cereb Cortex* 2011;21:467–76. <https://doi.org/10.1093/cercor/bhq112>.
- [8] Panichello MF, Cheung OS, Bar M. Predictive Feedback and Conscious Visual Experience. *Front Psychol* 2013;3. <https://doi.org/10.3389/fpsyg.2012.00620>.

- 673 [9] De Gardelle V, Kouider S. How Spatial Frequencies and Visual Awareness Interact
 674 During Face Processing. *Psychological Science* 2010;21:58–66.
 675 <https://doi.org/10.1177/0956797609354064>.
- 676 [10] Schyns PG. Diagnostic recognition: task constraints, object information, and their
 677 interactions. *Cognition* 1998;67:147–79. [https://doi.org/10.1016/S0010-0277\(98\)00016-X](https://doi.org/10.1016/S0010-0277(98)00016-X).
- 678 [11] Schyns PG, Oliva A. Dr. Angry and Mr. Smile: when categorization flexibly modifies
 679 the perception of faces in rapid visual presentations. *Cognition* 1999;69:243–65.
 680 [https://doi.org/10.1016/S0010-0277\(98\)00069-9](https://doi.org/10.1016/S0010-0277(98)00069-9).
- 681 [12] Ashwin E, Ashwin C, Rhydderch D, Howells J, Baron-Cohen S. Eagle-Eyed Visual
 682 Acuity: An Experimental Investigation of Enhanced Perception in Autism. *Biological*
 683 *Psychiatry* 2009;65:17–21. <https://doi.org/10.1016/j.biopsych.2008.06.012>.
- 684 [13] Kéïta L, Guy J, Berthiaume C, Mottron L, Bertone A. An early origin for detailed
 685 perception in Autism Spectrum Disorder: biased sensitivity for high-spatial frequency
 686 information. *Scientific Reports* 2014;4:5475. <https://doi.org/10.1038/srep05475>.
- 687 [14] Mottron L, Dawson M, Soulières I, Hubert B, Burack J. Enhanced Perceptual
 688 Functioning in Autism: An Update, and Eight Principles of Autistic Perception. *J Autism Dev*
 689 *Disord* 2006;36:27–43. <https://doi.org/10.1007/s10803-005-0040-7>.
- 690 [15] Jemel B, Mottron L, Dawson M. Impaired Face Processing in Autism: Fact or Artifact?
 691 *J Autism Dev Disord* 2006;36:91–106. <https://doi.org/10.1007/s10803-005-0050-5>.
- 692 [16] Caplette L, Wicker B, Gosselin F. Atypical Time Course of Object Recognition in
 693 Autism Spectrum Disorder. *Scientific Reports* 2016;6:35494.
 694 <https://doi.org/10.1038/srep35494>.
- 695 [17] Deruelle C, Rondan C, Gepner B, Tardif C. Spatial Frequency and Face Processing in

- 696 Children with Autism and Asperger Syndrome. *J Autism Dev Disord* 2004;34:199–210.
 697 <https://doi.org/10.1023/B:JADD.0000022610.09668.4c>.
- 698 [18] Deruelle C, Rondan C, Salle-Collemiche X, Bastard-Rosset D, Da Fonséca D. Attention
 699 to low- and high-spatial frequencies in categorizing facial identities, emotions and gender in
 700 children with autism. *Brain and Cognition* 2008;66:115–23.
 701 <https://doi.org/10.1016/j.bandc.2007.06.001>.
- 702 [19] Shapiro KL, Raymond JE, Arnell KM. The attentional blink. *Trends in Cognitive*
 703 *Sciences* 1997;1:291–6. [https://doi.org/10.1016/S1364-6613\(97\)01094-2](https://doi.org/10.1016/S1364-6613(97)01094-2).
- 704 [20] Olivers CNL, Meeter M. A boost and bounce theory of temporal attention.
 705 *Psychological Review* 2008;115:836–63. <https://doi.org/10.1037/a0013395>.
- 706 [21] Müsch K, Engel AK, Schneider TR. On the Blink: The Importance of Target-Distractor
 707 Similarity in Eliciting an Attentional Blink with Faces. *PLOS ONE* 2012;7:e41257.
 708 <https://doi.org/10.1371/journal.pone.0041257>.
- 709 [22] De Jong PJ, Koster EHW, van Wees R, Martens S. Emotional facial expressions and the
 710 attentional blink: Attenuated blink for angry and happy faces irrespective of social anxiety.
 711 *Cognition and Emotion* 2009;23:1640–52. <https://doi.org/10.1080/02699930802490227>.
- 712 [23] Maratos FA, Mogg K, Bradley BP. Identification of angry faces in the attentional blink.
 713 *Cognition & Emotion* 2008;22:1340–52. <https://doi.org/10.1080/02699930701774218>.
- 714 [24] Georgiou-Karistianis N, Tang J, Vardy Y, Sheppard D, Evans N, Wilson M, et al.
 715 Progressive age-related changes in the attentional blink paradigm. *Neuropsychol Dev Cogn B*
 716 *Aging Neuropsychol Cogn* 2007;14:213–26. <https://doi.org/10.1080/13825580500320681>.
- 717 [25] Colzato LS, Spapé MMA, Pannebakker MM, Hommel B. Working memory and the
 718 attentional blink: Blink size is predicted by individual differences in operation span.

- Psychonomic Bulletin & Review 2007;14:1051–7. <https://doi.org/10.3758/BF03193090>.
- [26] Amirault M, Etchegoyhen K, Delord S, Mendizabal S, Kraushaar C, Hesling I, et al. Alteration of Attentional Blink in High Functioning Autism: A Pilot Study. *J Autism Dev Disord* 2009;39:1522–8. <https://doi.org/10.1007/s10803-009-0821-5>.
- [27] Rinehart N, Tonge B, Brereton A, Bradshaw J. Attentional blink in young people with high-functioning autism and Asperger's disorder. *Autism* 2010;14:47–66. <https://doi.org/10.1177/1362361309335718>.
- [28] Gaigg SB, Bowler DM. Brief Report: Attenuated Emotional Suppression of the Attentional Blink in Autism Spectrum Disorder: Another Non-Social Abnormality? *J Autism Dev Disord* 2009;39:1211–7. <https://doi.org/10.1007/s10803-009-0719-2>.
- [29] Yerys BE, Ruiz E, Strang J, Sokoloff J, Kenworthy L, Vaidya CJ. Modulation of attentional blink with emotional faces in typical development and in autism spectrum disorders. *Journal of Child Psychology and Psychiatry* 2013;54:636–43. <https://doi.org/10.1111/jcpp.12013>.
- [30] Visser TAW, Bischof WF, Di Lollo V. Rapid serial visual distraction: Task-irrelevant items can produce an attentional blink. *Perception & Psychophysics* 2004;66:1418–32. <https://doi.org/10.3758/BF03195008>.
- [31] Wechsler D. Wechsler intelligence scale for children-WISC-IV. Psychological Corporation; 2003.
- [32] Wechsler D. WAIS-III, Wechsler adult intelligence scale: Administration and scoring manual. Psychological Corporation; 1997.
- [33] Wechsler D. Wechsler Adult Intelligence Scale—Fourth Edition (WAIS-IV) 2008. <https://scholar.googleusercontent.com/scholar?q=cache:VlcK12BcQ6kJ:scholar.google.com/>

742 &hl=fr&as_sdt=0,5 (accessed December 11, 2018).

743 [34] Lord C, Rutter M, DiLavore P, Risi S, Gotham K, Bishop S. Autism diagnostic
744 observation schedule–2nd edition (ADOS-2). Los Angeles, CA: Western Psychological
745 Corporation 2012.

746 [35] Lord C, Rutter M, Couteur AL. Autism Diagnostic Interview-Revised: A revised
747 version of a diagnostic interview for caregivers of individuals with possible pervasive
748 developmental disorders. *J Autism Dev Disord* 1994;24:659–85.
749 <https://doi.org/10.1007/BF02172145>.

750 [36] Grégoire J, Wierzbicki C. Comparaison de quatre formes abrégées de l'échelle
751 d'intelligence de Wechsler pour adultes – troisième édition (WAIS-III). *Revue Européenne de*
752 *Psychologie Appliquée/European Review of Applied Psychology* 2009;59:17–24.
753 <https://doi.org/10.1016/j.erap.2007.08.003>.

754 [37] American Psychiatric Association. DSM-IV-TR Manuel diagnostique et statistique des
755 troubles mentaux : Texte révisé. 2e ed. Issy-les-Moulineaux: Editions Masson; 2003.

756 [38] American Psychiatric Association, Crocq M-A, Guelfi J-D, Boyer P, Pull C-B, Pull M-
757 C. DSM-5 - Manuel diagnostique et statistique des troubles mentaux. 5e édition. Issy-les-
758 Moulineaux: Elsevier Masson; 2015.

759 [39] OMS, Collectif. CIM-10/ICD-10 : Descriptions cliniques et directives pour le
760 diagnostic. Editions Masson; 1992.

761 [40] Ma DS, Correll J, Wittenbrink B. The Chicago face database: A free stimulus set of
762 faces and norming data. *Behav Res* 2015;47:1122–35. [https://doi.org/10.3758/s13428-014-](https://doi.org/10.3758/s13428-014-0532-5)
763 [0532-5](https://doi.org/10.3758/s13428-014-0532-5).

764 [41] Kauffmann L, Chauvin A, Pichat C, Peyrin C. Effective connectivity in the neural

- 765 network underlying coarse-to-fine categorization of visual scenes. A dynamic causal modeling
 766 study. *Brain and Cognition* 2015;99:46–56. <https://doi.org/10.1016/j.bandc.2015.07.004>.
- 767 [42] R Core Team. R: A language and environment for statistical computing. 2013 2019.
- 768 [43] Navajas J, Ahmadi M, Quiroga RQ. Uncovering the Mechanisms of Conscious Face
 769 Perception: A Single-Trial Study of the N170 Responses. *J Neurosci* 2013;33:1337–43.
 770 <https://doi.org/10.1523/JNEUROSCI.1226-12.2013>.
- 771 [44] Quiroga RQ, Mukamel R, Isham EA, Malach R, Fried I. Human single-neuron
 772 responses at the threshold of conscious recognition. *PNAS* 2008;105:3599–604.
 773 <https://doi.org/10.1073/pnas.0707043105>.
- 774 [45] Sergent C, Baillet S, Dehaene S. Timing of the brain events underlying access to
 775 consciousness during the attentional blink. *Nature Neuroscience* 2005;8:1391.
 776 <https://doi.org/10.1038/nn1549>.
- 777 [46] Happé F, Frith U. The Weak Coherence Account: Detail-focused Cognitive Style in
 778 Autism Spectrum Disorders. *J Autism Dev Disord* 2006;36:5–25.
 779 <https://doi.org/10.1007/s10803-005-0039-0>.
- 780 [47] Iarocci G, Burack JA, Shore DI, Mottron L, Enns JT. Global–Local Visual Processing
 781 in High Functioning Children with Autism: Structural vs. Implicit Task Biases. *J Autism Dev*
 782 *Disord* 2006;36:117–29. <https://doi.org/10.1007/s10803-005-0045-2>.
- 783 [48] Rondan C, Deruelle C. Face processing in high functioning autistic adults: A look into
 784 spatial frequencies and the inversion effect. *Journal of Cognitive and Behavioral*
 785 *Psychotherapies* 2004;4:149–63.
- 786 [49] Corradi-Dell’Acqua C, Schwartz S, Meaux E, Hubert B, Vuilleumier P, Deruelle C.
 787 Neural responses to emotional expression information in high- and low-spatial frequency in

- 788 autism: evidence for a cortical dysfunction. *Front Hum Neurosci* 2014;8.
 789 <https://doi.org/10.3389/fnhum.2014.00189>.
- 790 [50] Chita-Tegmark M. Social attention in ASD: A review and meta-analysis of eye-tracking
 791 studies. *Research in Developmental Disabilities* 2016;48:79–93.
 792 <https://doi.org/10.1016/j.ridd.2015.10.011>.
- 793 [51] Frazier TW, Strauss M, Klingemier EW, Zetzer EE, Hardan AY, Eng C, et al. A Meta-
 794 Analysis of Gaze Differences to Social and Nonsocial Information Between Individuals With
 795 and Without Autism. *Journal of the American Academy of Child & Adolescent Psychiatry*
 796 2017;56:546–55. <https://doi.org/10.1016/j.jaac.2017.05.005>.
- 797 [52] Brock J. Alternative Bayesian accounts of autistic perception: comment on Pellicano
 798 and Burr. *Trends in Cognitive Sciences* 2012;16:573–4.
 799 <https://doi.org/10.1016/j.tics.2012.10.005>.
- 800 [53] Friston K. The free-energy principle: a unified brain theory? *Nat Rev Neurosci*
 801 2010;11:127–38. <https://doi.org/10.1038/nrn2787>.
- 802 [54] Sinha P, Kjelgaard MM, Gandhi TK, Tsourides K, Cardinaux AL, Pantazis D, et al.
 803 Autism as a disorder of prediction. *PNAS* 2014;111:15220–5.
 804 <https://doi.org/10.1073/pnas.1416797111>.
- 805 [55] Van de Cruys S, Evers K, Van der Hallen R, Van Eylen L, Boets B, De-Wit L, et al.
 806 Precise minds in uncertain worlds: predictive coding in autism. *Psychological Review*
 807 2014;649–75.
- 808 [56] Stefanics G, Kremláček J, Czigler I. Visual mismatch negativity: a predictive coding
 809 view. *Front Hum Neurosci* 2014;8. <https://doi.org/10.3389/fnhum.2014.00666>.
- 810 [57] Gomot M, Wicker B. A challenging, unpredictable world for people with Autism

- 811 Spectrum Disorder. *International Journal of Psychophysiology* 2012;83:240–7.
 812 <https://doi.org/10.1016/j.ijpsycho.2011.09.017>.
- 813 [58] Van de Cruys S, de-Wit L, Evers K, Boets B, Wagemans J. Weak Priors versus
 814 Overfitting of Predictions in Autism: Reply to Pellicano and Burr (TICS, 2012). *i-Perception*
 815 2013;4:95–7. <https://doi.org/10.1068/i0580ic>.
- 816 [59] Raymond JE, Shapiro KL, Arnell KM. Similarity determines the attentional blink. *J Exp*
 817 *Psychol Hum Percept Perform* 1995;21:653–62.
- 818 [60] Elliott JC, Giesbrecht B. Perceptual load modulates the processing of distractors
 819 presented at task-irrelevant locations during the attentional blink. *Attention, Perception, &*
 820 *Psychophysics* 2010;72:2106–14. <https://doi.org/10.3758/BF03196687>.
- 821 [61] Shore DI, McLaughlin EN, Klein RM. Modulation of the attentional blink by
 822 differential resource allocation. *Canadian Journal of Experimental Psychology/Revue*
 823 *Canadienne de Psychologie Expérimentale* 2001;55:318–24.
 824 <https://doi.org/10.1037/h0087379>.
- 825 [62] Jones CRG, Pickles A, Falcaro M, Marsden AJS, Happé F, Scott SK, et al. A multimodal
 826 approach to emotion recognition ability in autism spectrum disorders. *Journal of Child*
 827 *Psychology and Psychiatry* 2011;52:275–85. [https://doi.org/10.1111/j.1469-](https://doi.org/10.1111/j.1469-7610.2010.02328.x)
 828 [7610.2010.02328.x](https://doi.org/10.1111/j.1469-7610.2010.02328.x).
- 829 [63] Wright B, Clarke N, Jordan J, Young AW, Clarke P, Miles J, et al. Emotion recognition
 830 in faces and the use of visual context in young people with high-functioning autism spectrum
 831 disorders. *Autism* 2008;12:607–26. <https://doi.org/10.1177/1362361308097118>.
- 832 [64] Steffener J, Stern Y. Exploring the neural basis of cognitive reserve in aging. *Biochimica*
 833 *et Biophysica Acta (BBA) - Molecular Basis of Disease* 2012;1822:467–73.

834 <https://doi.org/10.1016/j.bbadis.2011.09.012>.

835 [65] Lever A, Geurts H. Age-related differences in cognition across the adult lifespan in
836 autism spectrum disorder. *Autism Research : Official Journal of the International Society for*
837 *Autism Research* 2015;9. <https://doi.org/10.1002/aur.1545>.

838 [66] Montgomery CB, Allison C, Lai M-C, Cassidy S, Langdon PE, Baron-Cohen S. Do
839 Adults with High Functioning Autism or Asperger Syndrome Differ in Empathy and Emotion
840 Recognition? *J Autism Dev Disord* 2016;46:1931–40. [https://doi.org/10.1007/s10803-016-](https://doi.org/10.1007/s10803-016-2698-4)
841 [2698-4](https://doi.org/10.1007/s10803-016-2698-4).

842 [67] Latinus M, Mofid Y, Kovarski K, Charpentier J, Batty M, Bonnet-Brilhault F. Atypical
843 Sound Perception in ASD Explained by Inter-Trial (In)consistency in EEG. *Front Psychol*
844 2019;10. <https://doi.org/10.3389/fpsyg.2019.01177>.

845