CORTEX 117 (2019) 247–256

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Research Report

No evidence for altered up- and downregulation of brain activity in visual cortex during illusory shape perception in autism

Christian Utzerath [a,b,*], Iris C. Schmits [b], Peter Kok [c], Jan Buitelaar [a,b] and Floris P. de Lange [b]

[a] Radboudumc, Donders Institute for Brain, Cognition, and Behaviour, Department of Cognitive Neuroscience, Nijmegen, the Netherlands

[b] Radboud University, Donders Institute for Brain, Cognition and Behaviour, Nijmegen, the Netherlands

[c] Wellcome Centre for Human Neuroimaging, University College London, London, United Kingdom

ARTICLE INFO

Article history:
Received 17 September 2018
Reviewed 26 October 2018
Revised 24 January 2019
Accepted 12 March 2019
Action editor Sarah Weigelt
Published online 26 March 2019

Keywords:
Autism spectrum disorder
fMRI
Illusions
Hypoprior
Perception

ABSTRACT

Autism spectrum disorder (ASD) may be marked by an altered balance between sensory input and prior expectations. Because many illusions rely on integrating sensory input with prior information such as spatial context, individuals with ASD may therefore be less susceptible to visual illusions than typically developing (TD) individuals. Yet empirical evidence on the matter is rather divergent, varying depending on the type of illusion, study procedure, and population.

Visual illusions lead to neural activity alterations in the visual system. In the so-called Kanizsa illusion, these are likely caused by top-down feedback to V1. Here we tested the hypothesis that a reduced susceptibility to illusions in ASD would manifest as diminished modulation of V1 activity by illusions, using functional magnetic resonance imaging (fMRI). We presented 22 adolescents with ASD and 22 age-, gender-, and intelligence-matched TD controls with displays that consisted of three circular inducers. These either formed an illusory triangle (Kanizsa illusion) or not. We identified regions in primary visual cortex (V1) that corresponded to (the visual field locations of) the illusory triangle and its inducers, and recorded their visual response.

Previous research in healthy volunteers has shown a specific pattern of up- and downregulation in regions of V1 that process the shape and inducers, respectively. Here, we replicated this pattern of up- and downregulation in V1, in both the TD and ASD groups, with no differences between groups. This suggests that illusory shape processing in primary visual cortex is equally present in ASD, suggesting unimpaired processing of spatial context.

* *Corresponding author*. Radboudumc, Radboud University, Donders Institute for Brain, Cognition and Behaviour, 6525 EN, Nijmegen, the Netherlands.
E-mail address: c.utzerath@donders.ru.nl (C. Utzerath).

https://doi.org/10.1016/j.cortex.2019.03.011
0010-9452/

1. Introduction

Perceiving and understanding our world requires us to interpret the evidence provided by the senses in the light of our prior knowledge and expectations of the world (Friston, 2005; Rao & Ballard, 1999; Yuille & Kersten, 2006). Recent theoretical accounts hypothesize that this balancing process between prior expectations and sensory evidence may be altered in autism spectrum disorder (ASD) (Pellicano, 2013; Pellicano & Burr, 2012). Some advocates of this hypothesis posit that in ASD, prior expectations are weakened or imprecise (Lawson, Rees, & Friston, 2014; Pellicano, 2013; Pellicano & Burr, 2012). Others put forward that on the contrary, individuals with ASD experience perceptual prediction errors marked by an inflexible and inflated precision (Van de Cruys et al., 2014, 2016). Either way, the net result of such an imbalance is a sensory world that is capricious, chaotic, and confusing.

One sensory prior governing our visual perception is spatial context. In the Kanizsa illusion (Kanizsa, 1976), an illusory shape emerges from an arrangement of circular inducers with collinear openings (Fig. 1A, left). Work in the 1990s suggested that individuals with ASD might not be swayed as much by such illusions as typically developing individuals. Happé and colleagues presented children with and without ASD with several types of visual illusions and found that the group with ASD was less susceptible to especially Kanizsa illusions (Happé, 1996). However, later experiments suggested that these results might have been influenced by ambiguities in task instructions that could lead children with ASD to give different reports than children without ASD (Ropar & Mitchell, 1999).

Whether or not ASD generally affects the susceptibility to illusions became contentious: a range of experiments across different illusions and including non-verbal response modes demonstrated that individuals with and without ASD seemed equally susceptible to many illusions (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; Hoy, Hatton, & Hare, 2004; Milne & Scope, 2008; Ropar and Mitchell, 1999, 2001).

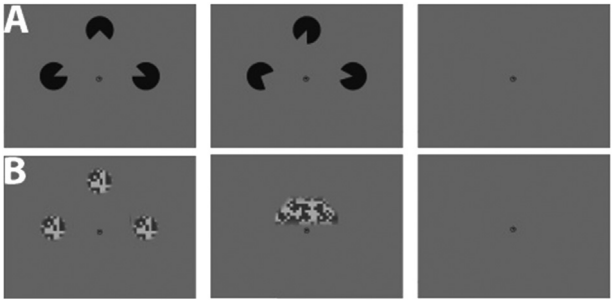

Fig. 1 – Stimuli and task. A. During the main task, the stimulus conditions presented were Illusory Triangles (IT, left), No Illusory Triangles (NoIT, middle), and null events (right). B. During the localizer, inducers (left), triangles (middle), or null events (right) were displayed as random checkerboards instead of IT and NoIT configurations. Triangles were cut to trapezoids to remove overlap with the inducers. Edges of the checkerboards were smoothed to avoid hard borders. During both localizer and main task, participants were doing a detection task at fixation.

Some studies found altered susceptibility to the Müller-Lyer, Shepard's table, and square-diamond illusions (Chouinard et al., 2013, 2016). Another observed a relationship between illusion susceptibility and specific personality traits (Walter, Dassonville, & Bochsler, 2009). Finally, using a delayed match-to-sample paradigm, it has been found that the processing of Kanizsa illusion changes over development. Younger children looked at and touched illusions at the inducers rather than the illusory figure more often than older children and adults. This is interpreted as a gradual shift in processing strategy, from one prefers local stimulus features to one that favors global meaning of the stimulus. Importantly, this development occurred similar in children with and without ASD (Nayar, Franchak, Adolph, & Kiorpes, 2015; Voyles, Nayar, Castellanos, Di Martino, & Kiorpes, 2013). Thus behaviorally, to which degree illusory perception might be altered in ASD, remains uncertain.

Problems caused by task instruction and giving overt behavioral reports can be partially circumvented by recording the neural response in visual cortex to illusions. An EEG study observed that the effect of illusory contours on the N1 component of the event-related potential (ERP) was inverted compared to controls in a sample of children with ASD (Stroganova et al., 2007). Similarly, in a later study oscillatory activity in the beta- and gamma-band range shortly after stimulus onset (120–170 msec) was increased for illusory figures in typically developing (TD) children, but absent in the ASD group (Stroganova et al., 2012). This raises the possibility that the processing of illusions is altered at the cortical level.

To understand the cortical processing of illusions, it is useful to be able to record the responses to their constituent elements. The Kanizsa illusion is well suited to this, as its illusory shape and the inducers occupy different parts of the visual field. In view of the retinotopic organization of the primary visual cortex (V1), where different regions of V1 process different parts of the visual field (Benson et al., 2012; Wandell, Dumoulin, & Brewer, 2007), it is possible to separate activity elicited by the inducers and illusory shapes using functional magnetic resonance imaging (fMRI).

In this manner, Kok and colleagues (Kok & de Lange, 2014) were able to map out the response of V1 to the Kanizsa illusion and its inducers. They observed that the Kanizsa illusion simultaneously up-regulates those areas of V1 whose receptive fields fall onto the illusion, and down-regulates areas processing the inducers. These modulations may be the result of a feedback signal from higher-order visual areas, e.g., lateral occipital cortex (LOC; Fang, Kersten, & Murray, 2008; Murray, Kersten, Olshausen, Schrater, & Woods, 2002), consistent with the timing of ERP components during illusory contour perception (Murray & Herrmann, 2013; Shpaner, Molholm, Forde, & Foxe, 2013). In V1, such feedback signals might select the triangle region as an object and reduce the activity of the inducers that form the background of the object (Bartels, 2014). Alternatively, feedback might convey the perceptual expectation of a triangle. That expectation is confirmed when the bottom-up stimulus of an inducer matches an occluded circle, resulting in less prediction error being fed forward (Kok, Bains, Mourik, Norris, & Lange, 2016). In both cases, spatial context constitutes a sensory prior modulating the response of V1.

The aim of this study is to elucidate whether these activity modulations by the presence of a visual illusion in V1 differs between TD individuals and individuals with ASD. We reasoned that if the balance between sensory priors and evidence is indeed altered in ASD, the modulations of V1 activity during the perception of an illusion should be diminished. We presented adolescents with and without ASD with configurations of Kanizsa inducers that either formed an illusory triangle or not, while their brain activity was recorded using fMRI. We used a separate localizer to identify regions of V1 that processed the illusory figure and the inducers, respectively.

This approach allowed us to measure whether the interaction between sensory evidence and priors is altered in ASD. However, the data recorded here do not allow us to distinguish between scenarios in which the precision of the prior is weakened (Lawson et al., 2014; Pellicano, 2013; Pellicano & Burr, 2012) or increased (Van de Cruys et al., 2014, 2016). To preview our findings, we replicated earlier findings of modulatory effects of a visual illusion on brain activity in V1, but this effect was similarly and robustly present in individuals both with and without ASD.

2. Method

We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study. All behavioral and functional neuroimaging data of this study as well as software for analysis can be downloaded at the Donders Data Repository (http://hdl.handle.net/11633/aabxbkd7).

2.1. Participants

The sample consisted of 44 participants (22 with ASD, 22 TD). In both groups, there was an equal amount of females (three). The same sample took part in an earlier experiment (Utzerath, Schmits, Buitelaar, & de Lange, 2018).

Participants with ASD were recruited from referrals from Karakter Child and Adolescent Psychiatry University Centre, Nijmegen, The Netherlands. TD participants were recruited from local schools. All participants and their parents provided written, informed consent. They understood that they could withdraw from the study at any time. We compensated participants with gift vouchers. The experiment was conducted and analyzed according to a protocol approved by and registered at the local ethics committee (CCMO protocol NL45835.091.13, accessible at www.toetsingonline.nl).

We matched the two groups on age, gender, and intellectual ability. Participants had to be between 12 and 18 years old, native Dutch speakers, have normal or corrected-to-normal vision, and an IQ above 85. Exclusion criteria were (comorbid) psychiatric or neurological disorders, history of brain surgery or trauma, current or recent alcohol or drug addiction, use of antipsychotic medication, irremovable metal objects in the body (with the exception of dental wires), claustrophobia, and pregnancy.

The age range was set from 12 to 18 for practical and theoretical reasons. A number of autism-related behaviors are expressed more strongly at younger ages (Ben-Sasson et al., 2009). This makes it desirably to have younger participants. For this reason, confirming diagnoses would also occur more reliably in younger compared to older participants. On the other hand, we expected very young children to experience more discomfort in the MRI scanner, and to have more trouble complying with task instructions. We reasoned that during the ages of 12–18, participants would comfortably partake in the experiment while still expressing autism-related traits comparatively strong.

All participants in the ASD group were required to conform to a clinical diagnosis of Autism Spectrum Disorder according to criteria specified in the DSM-5 (APA, 2013), which was confirmed by a structured interview (Autism Diagnostic Interview-Revised, ADI-R Lord, Rutter, & Le Couteur, 1994). In four cases, ASD diagnosis could not be confirmed. Moreover, in one additional participant from the ASD group, a significant brain anomaly was discovered. These participants of the ASD group were therefore replaced. Members of the TD group were additionally required to not have any history of neurological or psychiatric disorders, which was controlled by scores on the screening questionnaires (see below). One participant from the TD group withdrew from the study due to claustrophobia within the scanner. Two TD participants were excluded when the presence of neurodevelopmental disorders was subsequently revealed. These participants were replaced.

2.2. General procedure

All participants underwent the same general procedure. After providing written informed consent, we verified study eligibility by administering participants and their caregivers several tests and questionnaires. Participants were then familiarized with the task and MRI scanner in a replica MRI environment. Finally, participants performed the task in the MRI scanner.

The tests and questionnaires included, for all participants, four subtests of the Wechsler Intelligence Scale for Children/Adults (WISC-III/WAIS-III Kort et al., 2002; Wechsler, 1991; Wechsler, 2000, based on their age at inclusion). The subtests included were picture completion, vocabulary, block design, and similarities. Participants furthermore completed the self-report Edinburgh Handedness Inventory (Oldfield, 1971) and the Adult-Adolescent Sensory Profile (AASP Brown & Dunne, 2002). All parents completed the Child Social Behavior Questionnaire (CSBQ Hartmann, Luteijn, Serra, & Minderaa, 2006) about their child as a continuous measure of ASD symptoms. Parents of TD participants also completed the Child Behavior Checklist (CBCL Achenbach, 1991) to control for the presence of psychopathology. Parents of participants with ASD completed the Social Communication Questionnaire (Rutter & Bailey, 2003) and the ADI-R (Lord et al., 1994).

Subsequently, all participants familiarized themselves with the MRI environment and the experimental task through means of a replica MRI system. The intent of this was to set participants at ease. Here, participants, parents, and experimenters documented the (apparent) anxiety of the participant using the MR short anxiety screening tool (Durston et al., 2009). Aided by visual cues, the tool prompts respondents to

rate the participant's anxiety on a scale from 1 to 10. If either party indicated anxiety levels of 8 or higher the experiment would be stopped. At levels between 6 and 8, the participant would be consulted to see if they wanted to continue.

2.3. Stimuli and task

The stimuli and tasks were programmed using MATLAB R2012b (The MathWorks, Natick, MA, USA) in combination with PsychToolbox (Brainard, 1997). During fMRI, all participants underwent a main task and a localizer experiment.

During the main task, two different stimulus configurations were used (Fig. 1A). In the Illusory Triangle condition (IT), three circular inducers were lined up such that their openings suggested the presence of an illusory triangle. The inducers had a diameter of 3.6° visual angle. The (illusory) triangle was 12° wide, and had a height of 6°. In the No Illusory Triangle (NoIT) condition, the inducers were rotated such that they would not generate an illusory triangle while keeping the overall configuration similar to the IT condition. The triangle was centered horizontally on the screen, and its base was displaced vertically by 1° above a fixation circle (.7° diameter) at the center of the screen. There were also null events, during which only the fixation circle was displayed on the screen. These null events established a baseline response in the brain, against which the other conditions could be contrasted. In the main task, trials of IT and NoIT configurations and null events were presented in randomized order. Each trial lasted 13.6 sec, and the stimuli were flashed on the screen at a rate of 2 Hz. Participants were instructed to attend and fixate the fixation circle, wherein combinations of letters and symbols were displayed. Their task instruction was to report with a button press whenever the circle contained the targets ':)' or '8)'. The purpose of this task was to ensure that participants attended to and fixated on the fixation circle. In total, participants completed 90 trials, of which 36 trials were IT, 36 were NoIT, and 18 were null events. The task was split into two runs of equal length, which lasted approximately 10 min each.

During the localizer, random checkerboard textures were presented instead of the illusory triangle or inducers (Fig. 1B). These checkerboard textures flashed and changed at a rate of 2 Hz during trials that again lasted 13.6 sec. There were also null events again, during which only the fixation circle was displayed. The goal of the localizer was to identify voxels that responded to visual stimulation at the location of the illusory triangle, or the inducers (Fig. 1B). Inducer, triangle, and null event trials were presented in randomized order. Participants performed the same target detection task at fixation. There were 18 triangle trials, 18 inducer trials, and 8 null trials, lasting approximately 10 min.

2.4. Image acquisition and pre-processing

Images were captured on a 3-T Siemens Prisma MRI system (Siemens, Erlangen, Germany). A structural image was created using a T1-weighted sequence (TR = 2.3 sec, TE = 3.03 msec, 1 mm isometric in-plane resolution). Functional images were recorded using a 2D Multiband sequence (acceleration factor 8, TR = .68 sec, TE = 39 msec, 2.4 mm isometric resolution, 64 sagittal slices). We used SPM12 (Wellcome Trust Centre for Neuroimaging, London, UK) for preprocessing and statistical analysis.

For every run, the first ten volumes were discarded in order to allow for T1 equilibrium. We spatially realigned functional images to the mean functional image. While no participant was excluded for excessive head motion, head motion parameters obtained during the realignment procedure were kept to add as nuisance regressors during first-level analysis. Next, the mean functional image was co-registered with the T1 and normalization parameters for the structural image were obtained. Owing to the slow task rate of the experiment and the fast acquisition rate of the multiband sequence, we could apply a low-pass filter on the functional images (Savitzky–Golay filter with a window size of 15 samples and an order of 3). This removed frequencies from the data that were substantially higher than the expected BOLD modulation by task and more likely related to breathing and heartbeat artifacts. Finally, all functional images were normalized into MNI space and spatially smoothed (6 mm FWHM).

2.5. Identification of triangle- and inducer-coding voxels

We combined functional and anatomical information to identify voxels that responded to (illusory) triangles at the center of the screen and the surrounding inducers.

We first created a cortical surface reconstruction of every participant on the basis of their anatomical (T1-weighted) scan using Freesurfer (surfer.nmr.mgh.harvard.edu/) (Benson et al., 2012). We then applied an automated method to identify primary visual cortex based on cortical folds (Fig. 2A), which is an accurate predictor of the anatomical location of striate cortex (Benson et al., 2012; Hinds et al., 2008). After bringing the reconstructed brain surface in register with the functional volumes, labels corresponding to primary visual cortex were converted into volume space. Using SPM12, these volumes were finally transformed into MNI space.

Subsequently, we used contrast maps obtained from the localizer experiment to select voxels that were responsive to the illusory triangle and the inducers (i.e., showed a positive response to these compared to baseline; Fig. 2B). We only considered voxels that were more active for stimuli than baseline during the localizer.

These voxels were then divided further into voxels that were more active for the triangles rather than the surrounding circles during the localizer (hence representing the location where the illusory triangle would be generated), and voxels that showed the opposite pattern (representing the location where the inducers would be displayed). Of note, we did not include any voxels that showed positive activity for the opposing stimulus. That is to say, voxels were not considered to represent the locations of the triangles if they also showed a positive response to inducers, and vice versa. These voxels were then considered as processing the illusory triangle and inducers during the main experiment.

Identifying inducer- and triangle-coding voxels is possible, as the resolution of our functional images allows voxels to have receptive field sizes of 1–1.5° (Dumoulin & Wandell, 2008). Please note that unlike some earlier work that used layered imaging (Kok et al., 2016), our approach does not separate feedback- and feedforward processing.

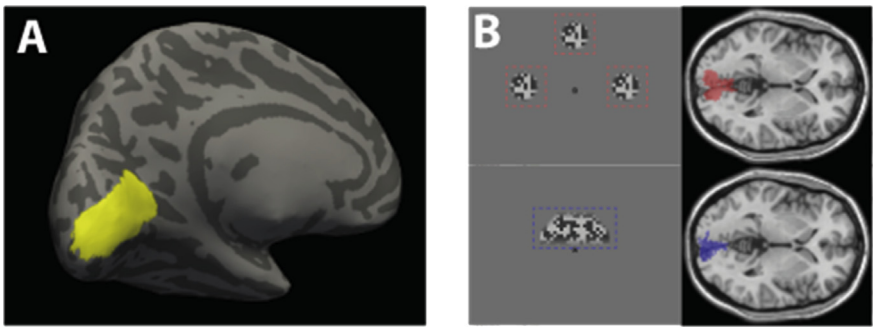

Fig. 2 – Voxel selection. Voxels sensitive to triangles and inducers were identified per participant by cross-referencing maps of V1 and brain responses during the localizer. A. Inflated surface of a representative participant's brain (V1 highlighted in yellow). Based on these maps, volume masks for V1 were generated. B. Utilizing these masks, V1 voxels were identified that processed locations belonging to the inducers or triangle, respectively, by contrasting the corresponding conditions from the localizer experiment. Regions highlighted in red (or blue) represent the collected voxels across all participants that were more sensitive for inducers than triangles (or triangles than inducers), at z = 0.

2.6. *Statistical analysis*

Sample characteristics and task performance during the main experiment were compared between groups using an independent-samples *t*-test.

The fMRI analysis was based on a General Linear Model (GLM) that was performed in SPM12. We used a 128 sec high-pass filter to remove scanner drifts. For the main experiment, we modeled separate regressors for null events, presentations of illusory triangles, and presentations of scrambled illusions. For the localizer, we modeled null events, and presentation of triangles and circles. These regressors were then convolved with SPM12's canonical hemodynamic response function. We furthermore included the motion parameters obtained during realignment, as well as their first and squared first derivatives as nuisance regressors. The parameters for null events were subtracted from the conditions of interest. We then collected the resulting mean beta parameter estimates for triangle- and inducer-coding voxels.

These data were subjected to a within-subjects repeated measures analysis of variance (ANOVA) with the within-subject factors Location (triangle, inducer), Illusion (illusory shape, no illusory shape), and Group (TD, ASD). This model allowed us to probe what the effect of an illusory shape was in the voxels corresponding to different retinotopic areas, and whether ASD modulated such effects. A main effect of illusion (illusory shape > no illusory shape) would mean that voxel activity increased when the Kanizsa illusion was present as opposed to absent. A main effect of location (e.g., inducer > triangle) would mean that voxel activity was generally higher in one part of the visual field than the other. An interaction between the two factors would imply that there was up- or downregulation of activity, but its direction would depend on the visual field that the voxel population was responsive to.

Statistical testing for sample characteristics, behavioral performance, and modulations of early visual cortex activity was performed in JASP (Love et al., 2017). We analyzed our data both within a frequentist framework, and in a Bayesian framework by calculating the relative likelihood of the alternative compared to the null hypothesis, i.e., the Bayes Factors (BF_{10}) for each test. $p < .05$ was considered significant for frequentist analyses, while Bayes Factors larger than 3 (10) were considered as substantial (strong) evidence for the alternative hypothesis. Correspondingly, a BF_{10} smaller than 1/3 (1/10) was considered as substantial (strong) evidence for the null hypothesis (Rouder, Speckman, Sun & Morey, 2009; Wetzels, Wetzels, Raaijmakers, Jakab & Wagenmakers, 2009; Jeffreys, 1961). Statistical testing of whole-brain activations was done in SPM12.

3. Results

3.1. *Sample characteristics*

Sample characteristics are detailed in supplementary Table ST1. On average, our participants were 15 years and 0 months of age. There was no significant difference between groups in age ($p = .41$, $BF_{10} = .394$), gender, or intellectual ability (Table ST1; all $p > .2$, all $BF_{10} < .6$).

Across all scales of the CSBQ, ASD participants scored significantly higher than TD participants (all $p < .001$; all $BF_{10} > 200$; Table ST1). On the AASP, ASD participants reported elevated scores with regards to Low Registration and Sensory Avoiding (both $p < .01$; both $BF_{10} > 6$; Table ST1). On the CBCL, the TD participants scored within normal range (Table ST1). The ASD group scored within the lower clinical range on the SCQ (Table ST1) and their diagnoses were confirmed by the ADI-R (Table ST2).

The groups did not differ in terms of head motion (translation, rotation) during the scans, as indicated by independent samples *t*-tests on the motion parameters (all $p > .25$, all $BF_{10} < .51$).

3.2. *Behavioral performance*

The TD group had a mean hit rate of 77.6% (SD: 13.2%). The ASD group had a mean hit rate of 77.2% (SD: 9.9%). On average, participants detected 77.43% (SD = 11.56%) of all targets. There was no difference between groups [$t(42) = -.12$, $p = .90$, $BF_{10} = .30$]. The difference between groups was not significant [$t(42) = .13$, $p = .9$, $BF_{10} = .3$].

3.3. Modulation of early visual cortex activity by illusory shapes

The response of triangle- and inducer-coding voxels during the presentation of illusory triangles and scrambled illusions is shown in Fig. 3. The distribution of all conditions is shown in Supplementary Fig. S1.

In the TD group, inducer-coding voxels were more active than triangle-coding voxels [$F(1,21) = 128.69$, $p < .001$, $BF_{10} = 4.85e7$]. This is expected, given that only the inducer-coding voxels received stimulus input during the experiment. The presence of an illusory shape (as opposed to a configuration of inducers that produced no illusory shape) did not lead to a general increase in V1 activity ($p = .18$, $BF_{10} = .53$). However, there was an interaction between the factors Location and Illusion, indicating that the response of a voxel to an illusion depended on which region that voxel processed [$F(1,21) = 19.8$, $p < .001$, $BF_{10} = 134.9$]. Specifically, post-hoc t-tests confirmed inducer-coding voxels were significantly suppressed during the presence of an illusion [$t(21) = -2.88$, $p = .009$, $BF_{10} = 5.46$]. By contrast, triangle-coding voxels did not significantly increase their activity in response to an illusion [$t(21) = .54$, $p = .6$, $BF_{10} = .25$].

Similarly, in the ASD group, inducer-coding voxels generally were more active than triangle-coding voxels [$F(1,21) = 70$, $p < .001$, $BF_{10} = 3.52e5$]. Voxels did not significantly increase their activity when presented an illusory shape [$F(1,21) = .55$, $p = .47$, $BF_{10} = .29$]. As in the TD group, the response of a voxel to an illusion depended on whether it coded triangles or the inducers, as indicated by a significant Location*Illusion interaction [$F(1,21) = 29.18$, $p < .001$, $BF_{10} = 1016.55$]. Post-hoc t-tests showed that triangle-coding voxels significantly increased their activity in response to an illusion [$t(21) = 2.2$, $p = .04$, $BF_{10} = 1.62$]. By contrast, inducer-coding voxels were not significantly suppressed during the presence of an illusion [$t(21) = -1.0$, $p = .33$, $BF_{10} = .35$].

Across both groups, the response of inducer-coding voxels was generally stronger than that of triangle-coding voxels [recall that only the inducer-coding voxels received stimulus input; $F(1,42) = 190.13$, $p < .001$, $BF_{10} = 2.0*10e14$]. When presented an inducer configuration that resulted in an illusory shape as compared to no illusory shape, inducer-coding voxels significantly decreased their activity [post-hoc $t(43) = -2.815$, $p = .007$, $BF_{10} = 5.14$]. By contrast, triangle-coding voxels showed a trend towards increasing their activity [post-hoc $t(43) = 1.952$, $p = .057$, $BF_{10} = .92$]. This interplay culminated in a significant Location*Illusion interaction [$F(1,42) = 45.45$, $p < .001$, $BF_{10} = 2.013e14$].

Average activity did not differ between groups ($p = .16$, $BF_{10} = .68$). There were also no group differences in the effects of Location ($p = .21$, $BF_{10} = .57$), Illusion ($p = .14$, $BF_{10} = .75$), or the interaction between the two ($p = .58$, $BF_{10} = .34$). The up- and downregulation by illusory figures in triangle- and inducer-coding voxels respectively did not differ between groups ($p = .23$, $BF_{10} = .55$; $p = .12$, $BF_{10} = .84$, respectively).

To examine the possible influence of development on these results, we included the participants' age as covariate. This did not explain a significant amount of variance in any of our analyses (all $p > .13$, $BF < .39$).

3.4. Whole-brain modulation by illusory shapes

We explored the effect of illusory shapes outside of our regions of interest with a whole-brain analysis using SPM12. The results of this analysis are detailed in Table 1. Two occipital regions responded to the presence of illusory triangles (relative to scrambled illusions) with an increase in brain activity. By contrast, regions in right superior occipital gyrus and right middle occipital gyrus showed increased activity when the inducers did not form an illusory triangle compared to when they did. These activity differences were not modulated by group.

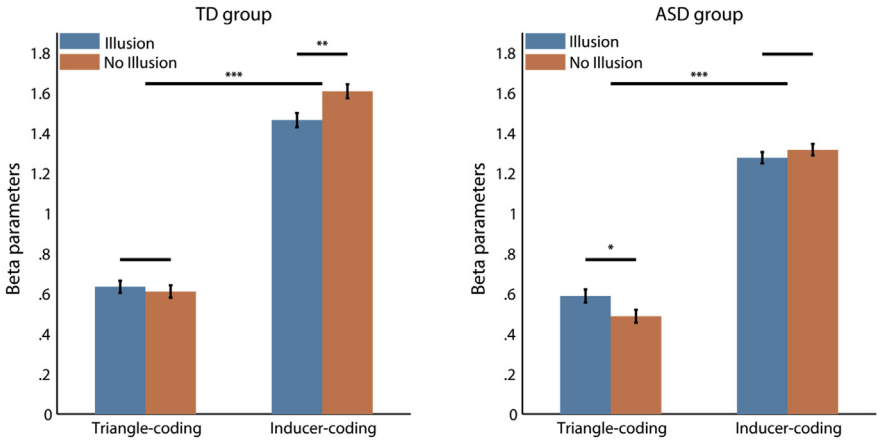

Fig. 3 – Illusory shapes modulate activity in early visual cortex. Panels depict each group's brain response during the main task. The effect of an illusory shape depended on what location the corresponding voxels were processing, with an increased activity in triangle-coding voxels and decreased activity in inducer-coding voxels. These effects were equally present in both groups. Error bars reflect within-subject standard error of the mean. Supplementary Fig. S1 depicts the distribution of each of these conditions. *$p < .05$, **$p < .01$, ***p .001.

Table 1 – Modulation of whole-brain activity by illusory contours across groups.

Contrast *Anatomical region*	X_{MNI}	Y_{MNI}	Z_{MNI}	t	k	p_{FWE}
Illusory contour > no illusory contour						
L. mid. occ. gyrus	−4	−82	−6	5.49	115	.03
L. lingual gyrus	−30	−92	28	5.27	376	<.001
No illusory contour > illusory contour						
R. sup. occ. gyrus	22	−92	18	7.05	665	<.001
R. mid. occ. gyrus	48	−72	8	4.99	140	<.001

Note. *p*-values were estimated using an auxiliary threshold of $p < .001$ uncorrected. *p*-values reflect cluster statistics corrected for family-wise error (FWE). Coordinates refer to the peak of each cluster.

4. Discussion

In this study, we investigated whether the modulation of V1 activity by illusory shapes differs between individuals with and without ASD. It has previously been hypothesized that individuals with ASD have a reduced susceptibility to visual illusions, possibly due to reduced perceptual grouping and integration. Contrary to this notion, we found a reliable modulation of activity by the Kanizsa illusion in V1 that was equally present in participants with and without ASD.

4.1. *Unaltered V1 processing of illusions in ASD*

Previous studies have suggested that the perception of illusory shapes is altered by ASD (Chouinard et al., 2013, 2016; Happé, 1996; Voyles et al., 2013; Walter et al., 2009). Yet these studies used behavioral measures, where the differentiation between perception, perceptual decision-making, and perceptual report is difficult. By using fMRI, we were able to measure separate V1 signals for the illusory shape as well as the inducers that created the shape. Previous research has shown that the perceptual grouping process that occurs during the viewing of the Kanizsa illusion generates both increased activity in V1 neurons that process the location of the illusory shape, and a reduction of activity in V1 neurons that process the inducers (Kok & de Lange, 2014; Kok et al., 2016). In the current study we replicated this pattern of results. However, neither the effect of illusions nor its dependency on the visual field location differed between individuals with and without ASD.

It may appear that our results contradict earlier work that observed differences in neural activity elicited by illusory figures in ASD using EEG (Stroganova et al., 2007, 2012). There may be several reasons for this apparent discrepancy. First, the participants in both studies by Stroganova and colleagues were young children (Chernyshev, Pronko, & Stroganova, 2017; Stroganova et al., 2012), whereas our participants were adolescents. Since developmental factors may mediate susceptibility to illusions (Voyles et al., 2013) and individuals with ASD exert considerable compensation (Livingston & Happé, 2017), it is possible that neural differences might be found in younger children. Second, while fMRI offered us very high spatial resolution, the temporal resolution is poor compared to EEG. Similarly, the correspondence between components of the EEG and the BOLD signal is non-trivial. Therefore, it is possible that some effects might be visible in EEG recordings but not the fMRI signal.

A third possibility is that illusion processing is altered in ASD and that this alteration is in principle measurable with fMRI – but the alteration might arise downstream from V1. Indeed, using EEG observed that children with ASD showed an inverted effect of illusory contours on the N1 component of the ERP, compared to controls (Stroganova et al., 2007). This N1 component is thought to originate in lateral occipital cortex (LOC) (Shpaner et al., 2013), a higher order visual cortical region downstream of V1 – that might be the top-down source of the modulations in V1 (Murray and Herrmann, 2013). Of note, in a later study, Stroganova and colleagues also recorded brain oscillations during the viewing of illusory contours. Here, they report that viewing illusory contours has both relatively early and late effects on gamma oscillations; however, differences between children with and without ASD were visible only during the later effect, which was absent in children with ASD (Stroganova et al., 2012). This was seen as consistent with a difference in processing that arises in higher order visual cortex rather than during early processing in V1.

Taken together, our findings as well as earlier research provide little evidence that processing of visual illusions within V1 differs between individuals with and without ASD. Future efforts may therefore elucidate whether differences emerge downstream of V1, with a focus on object-selective cortical area LOC.

4.2. *Unaltered structural priors*

The priors that affect visual processing can differ in a number of ways. As Seriès and Seitz explain, perceptual priors can be classified into two categories: structural priors, that generalize across environmental circumstances, and contextual priors, whose effect changes between environments (Seriès & Seitz, 2013). The Kanizsa illusion is an example of a structural prior: its inducers affect perception of the enclosed space in a manner that remains consistent across circumstances. Thus, our finding suggests that structural priors may not be different between individuals with and without ASD. Another study recently also found no group difference in a different structured prior: the 'light-from-above' prior refers to the human tendency to perceive ambiguous shapes as being convex and illuminated from above, rather than concave and illuminated from below. Croydon and colleagues found that children with ASD utilized this prior to the same degree as TD individuals (Croydon, Karaminis, Neil, Burr, & Pellicano, 2017).

However, our study did not manipulate contextual priors. Indeed, in earlier work (Utzerath et al., 2018), we recorded the response of visual cortex to stimuli that would alternate and repeat according to implicitly learned statistical regularities. In that study, we found the effects of stimulus expectation to vary across groups, while the effects of stimulus repetition were comparable. Thus, while the present study did not find different processing of structural priors, an earlier experiment did show some support for altered use of contextual priors. This is also in agreement with the notion that children with

ASD overestimate the volatility of their sensory environment (Lawson, Mathys, & Rees, 2017). Taken together, it is possible that hypopriors affect primarily the contextual priors that vary between situations, rather than structural ones.

4.3. *Implications for Bayesian and predictive processing accounts of ASD*

Bayesian and predictive processing accounts of ASD posit an imbalance between sensory evidence and priors. These accounts differ in which place of the perceptual system is the locus of the altered balance: some argue that the sensory prediction should be weakened or characterized by lower precision (Lawson et al., 2014; Pellicano & Burr, 2012). Alternatively, the prediction error might have an inflexibly inflated precision estimate (Van de Cruys et al., 2014, 2016). Since we did not find any group differences in the processing of illusions, the present study is not able to support either account.

However, this does not mean that the balance between sensory evidence and priors is proven to be identical in TD individuals and those with ASD. As we outlined, there is a plausible distinction between structural and contextual priors. While our and other research (Croydon et al., 2017) could not find evidence for an alteration of structural priors, work by our group did find some evidence for a group difference in the use of contextual priors (Utzerath et al., 2018). In terms of daily life and experienced symptoms, this might imply that learned regularities and world knowledge (i.e., contextual priors) are affected by ASD to a greater degree than the spatial and geometric relations that compose structural priors.

4.4. *Visual illusions in ASD*

A question one might ask is how our results relate to earlier studies on visual illusions in ASD. For a large number of visual illusions, TD individuals and those with ASD are behaviourally indistinguishable (Chouinard et al., 2016; Ropar & Mitchell, 1999). While an early investigation had suggested that children with ASD were less susceptible to Kanizsa illusions (Happé, 1996), it was later demonstrated that this group difference depended critically on how the task was explained to children. Once responses could be given non-verbally, children with and without ASD were similarly susceptible to the Kanizsa and other illusions (Milne & Scope, 2008). Others have found the behaviour of individuals towards Kanizsa illusions to be dependent on age, not diagnosis (Nayar et al., 2015; Voyles et al., 2013). Thus, in this sense our study is not inconsistent with previous work.

4.5. *Limitations of the study*

The present study is limited primarily by two factors. First, the sample size is relatively modest. This may have impeded the power of this study to detect subtle differences between groups. A larger sample size would have furthermore been desirable in order to measure cortical processing of visual illusions across several age groups. This would have been potentially illuminating, given the developmental aspect to the perception of Kanizsa illusions (Nayar et al., 2015; Voyles et al., 2013). Future studies should therefore aim to recruit larger samples.

5. Conclusion

We conclude that the modulation of V1 activity by illusory shapes is robustly present in individuals with and without ASD, suggesting similar cortical feedback to V1 by object grouping processes. These results put constraints on neurocognitive accounts proposing an alteration in the balancing process of sensory evidence and prior expectations in ASD.

Funding

This work was funded by a Donders Institute internal grant to C.U. F.d.L is supported by the Netherlands Organisation for Scientific Research (NWO Vidi grant) and the EC Horizon 2020 Program (ERC starting grant 678286).

CRediT authorship contribution statement

Christian Utzerath: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration, Funding acquisition. **Iris C. Schmits:** Investigation, Data curation, Project administration. **Peter Kok:** Conceptualization, Validation, Writing - review & editing. **Jan Buitelaar:** Conceptualization, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Floris P. de Lange:** Conceptualization, Methodology, Formal analysis, Resources, Writing - review & editing, Visualization, Project administration, Funding acquisition.

Open practices

The study in this article earned Open Materials and Open Data badges for transparent practices. Materials and data for the study are available at http://hdl.handle.net/11633/aabxbkd7.

Acknowledgements

We would like to thank Alexandra Vlassova and Patricia Romero Verdugo for their helpful suggestions on an earlier draft of this manuscript.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2019.03.011.

REFERENCES

Achenbach, T. M. (1991). *Manual for the child behavior checklist*. University of Vermont.

American Psychiatric Publishing. (2013). *Diagnostic and statistical manual of mental disorders*.

Bartels, A. (2014). Visual perception: Early visual cortex fills in the gaps. *Current Biology, 24*, R600–R601.

Ben-Sasson, A., Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 39*(1), 1–11.

Benson, N. C., Butt, O. H., Datta, R., Radoeva, P. D., Brainard, D. H., & Aguirre, G. K. (2012). The retinotopic organization of striate cortex is well predicted by surface topology. *Current Biology, 22*(21), 2081–2085.

Bölte, S., Holtmann, M., Poustka, F., Scheurich, A., & Schmidt, L. (2007). Gestalt perception and local-global processing in high-functioning autism. *Journal of Autism and Developmental Disorders, 37*, 1493–1504.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436.

Brown, C., & Dunne, W. (2002). *The adolescent/adult sensory profile: User's manual*.

Chernyshev, B. V., Pronko, P. K., & Stroganova, T. A. (2017). Early suppression effect in human primary visual cortex during Kanizsa illusion processing: A magnetoencephalographic evidence. *Visual Neuroscience, 33*.

Chouinard, P. A., Katy Unwin, B. L., Oriane Landry, B., & Irene Sperandio, B. (2016). Susceptibility to optical illusions varies as a function of the autism-spectrum quotient but not in ways predicted by local–global biases. *Journal of Autism and Developmental Disorders, 46*, 2224–2239.

Chouinard, P. A., Noulty, W. A., Sperandio, I., & Landry, O. (2013). Global processing during the Müller-Lyer illusion is distinctively affected by the degree of autistic traits in the typical population. *Experimental Brain Research, 230*, 219–231.

Croydon, A., Karaminis, T., Neil, L., Burr, D., & Pellicano, E. (2017). The light-from-above prior is intact in autistic children. *Journal of Experimental Child Psychology, 161*, 113–125.

Dumoulin, S. O., & Wandell, B. A. (2008). Population receptive field estimates in human visual cortex. *Neuroimage, 39*, 647–660.

Durston, S., Nederveen, H., van Dijk, S., van Belle, J., de Zeeuw, P., Langen, et al. (2009). Magnetic resonance simulation is effective in reducing anxiety related to magnetic resonance scanning in children. *Journal of the American Academy of Child and Adolescent Psychiatry, 48*(2), 206–207.

Fang, F., Kersten, D., & Murray, S. O. (2008). Perceptual grouping and inverse fMRI activity patterns in human visual cortex. *Journal of Vision, 8*, 2.

Friston, K. (2005). A theory of cortical responses. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*, 815–836.

Happé, F. G. (1996). Studying weak central coherence at low levels: Children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology and Psychiatry, 37*, 873–877.

Hartmann, C. A., Luteijn, E., Serra, M., & Minderaa, R. (2006). Refinement of the children's social behavior questionnaire (CSBQ): An instrument that describes the diverse problems seen in milder forms of PDD. *Journal of Autism and Developmental Disorders, 36*, 325–342.

Hinds, O. P., Rajendran, N., Polimeni, J. R., Augustinack, J. C., Wiggins, G., Wald, et al. (2008). Accurate prediction of V1 location from cortical folds in a surface coordinate system. *Neuroimage, 39*(4), 1585–1599.

Hoy, J. A., Hatton, C., & Hare, D. (2004). Weak central coherence: A cross-domain phenomenon specific to autism? *Autism: the International Journal of Research and Practice, 8*, 276–281.

Jeffreys, H. (1961). *Theory of probability*. Oxford University Press.

Kanizsa, G. (1976). Subjective Contours. *Scientific American, 234*, 48–52.

Kok, P., Bains, L. J., Van Mourik, T., Norris, D. G., & De Lange, F. P. (2016). Selective activation of the deep layers of the human primary visual cortex by top-down feedback report selective activation of the deep layers of the human primary visual cortex by top-down feedback. *Current Biology, 26*, 371–376.

Kok, P., & de Lange, F. P. (2014). Shape perception simultaneously up- and downregulates neural activity in the primary visual cortex. *Current Biology, 24*, 1531–1535.

Kort, W., Compaan, E. L., Bleichrodt, N., Resing, W. C. M., Schittekatte, M., & Bosman, M. (2002). *WISC-III [Dutch translation of the Wechsler intelligence scales for children]*. NDC/NIP.

Lawson, R. P., Mathys, C., & Rees, G. (2017). Adults with autism overestimate the volatility of the sensory environment. *Nature Neuroscience, 20*, 1293–1299.

Lawson, R. P., Rees, G., & Friston, K. J. (2014). An aberrant precision accout of autism. *Frontiers in Human Neuroscience, 8*, 1–16.

Livingston, L. A., & Happé, F. (2017). Conceptualising compensation in neurodevelopmental disorders: Reflections from autism spectrum disorder. *Neuroscience and Biobehavioral Reviews, 80*, 729–742.

Lord, C., Rutter, M., & Le Couteur, a. (1994). Autism diagnostic interview-revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 24*, 659–685.

Love, J., Selker, R., Marsman, M., Jamil, T., Dropmann, D., & Verhagen. (2017). *JASP (version 0.8.1.1)*. Retrieved from https://jasp-stats.org/.

Milne, E., & Scope, A. (2008). Are children with autistic spectrum disorders susceptible to contour illusions? *The British Journal of Developmental Psychology, 26*, 91–102.

Murray, M. M., & Herrmann, C. S. (2013). Illusory contours: A window onto the neurophysiology of constructing perception. *Trends Cognitive Sciences, 17*, 471–481.

Murray, S. O., Kersten, D., Olshausen, B. A., Schrater, P., & Woods, D. L. (2002). Shape perception reduces activity in human primary visual cortex. *Proceedings of the National Academy of Sciences, 99*, 15164–15169.

Nayar, K., Franchak, J., Adolph, K., & Kiorpes, L. (2015). From local to global processing: The development of illusory contour perception. *Journal of Experimental Child Psychology, 131*, 38–55.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 97–113.

Pellicano, E. (2013). Sensory symptoms in autism: A blooming, buzzing confusion? *Child Development Perspectives, 7*, 143–148.

Pellicano, E., & Burr, D. (2012). When the world becomes 'too real': A Bayesian explanation of autistic perception. *Trends Cognitive Sciences, 16*, 504–510.

Rao, R. P. N., & Ballard, D. H. (1999). Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience, 2*, 79–87.

Ropar, D., & Mitchell, P. (1999). Are individuals with autism and Asperger's syndrome susceptible to visual illusions? *Journal of Child Psychology and Psychiatry, 40*, 1283–1293.

Ropar, D., & Mitchell, P. (2001). Susceptibility to illusions and performance on visuospatial tasks in individuals with autism. *Journal of Child Psychology and Psychiatry, 42*, 539–549.

Rouder, J. N., Speckman, P. L., Sun, D., & Morey, R. D. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review, 16*, 225–237.
Rutter, M., & Bailey, A. (2003). *Social communication questionnaire*.
Seriès, P., & Seitz, A. R. (2013). Learning what to expect (in visual perception). *Frontiers in Human Neuroscience, 7*.
Shpaner, M., Molholm, S., Forde, E.-J., & Foxe, J. J. (2013). Disambiguating the roles of area V1 and the lateral occipital complex (LOC) in contour integration. *Neuroimage, 6911*.
Stroganova, T. A., Orekhova, E. V., Prokofyev, A. O., Posikera, I. N., Morozov, A. A., Obukhov, Y. V., et al. (2007). Inverted event-related potentials response to illusory contour in boys with autism. *Neuroreport, 18*(9), 931–935.
Stroganova, T. A., Orekhova, E. V., Prokofyev, A. O., Tsetlin, M. M., Gratchev, V. V., Morozov, A. A., et al. (2012). High-frequency oscillatory response to illusory contour in typically developing boys and boys with autism spectrum disorders. *Cortex, 48*(6), 701–717.
Utzerath, C., Schmits, I. C., Buitelaar, J., & de Lange, F. P. (2018). Adolescents with autism show typical fMRI repetition suppression, but atypical surprise response. *Cortex, 109*, 25–34.
Van de Cruys, S., Evers, K., Van der Hallen, R., Van Eylen, L., Boets, B., de-Wit, L., et al. (2014). Precise minds in uncertain worlds: Predictive coding in autism. *Psychological Review, 121*(4), 649–675.
Van de Cruys, S., Van der Hallen, R., & Wagemans, J. (2016). Disentangling signal and noise in autism spectrum disorder. *Brain and Cognition*. https://doi.org/10.1016/j.bandc.2016.08.004.
Voyles, A., Nayar, K., Castellanos, F. X., Di Martino, A., & Kiorpes, L. (2013). Development of Kanizsa illusory contour perception in autism spectrum disorder. *Journal of Vision, 13*, 838–838.
Walter, E., Dassonville, P., & Bochsler, T. M. (2009). A specific autistic trait that modulates visuospatial illusion susceptibility. *Journal of Autism and Developmental Disorders, 39*, 339–349.
Wandell, B. A., Dumoulin, S. O., & Brewer, A. A. (2007). Visual field maps in human cortex. *Neuron, 56*, 366–383.
Wechsler, D. (1991). *The Wechsler intelligence scale for children*. The Psychological Corporation.
Wechsler, D. (2000). *WAIS-III Nederlandstalige bewerking*. Technische handleiding, Swets & Zeitlinger.
Wetzels, R., Wetzels, R., Raaijmakers, J. G. W., Jakab, E., & Wagenmakers, E.-J. (2009). How to quantify support for and against the null hypothesis: A flexible WinBUGS implementation of a default Bayesian t test. *Psychonomic Bulletin & Review, 16*, 752–760.
Yuille, A., & Kersten, D. (2006). Vision as Bayesian inference: Analysis by synthesis? *Trends in Cognitive Sciences, 10*, 301–308.