Adults with autism spectrum condition (ASC) have atypical perception of ambiguous figures when bottom-up and top-down interactions are incongruous

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Abstract

We examined the perception of an ambiguous squares stimulus evoking bistable perception in a sample of 31 individuals with autistic spectrum condition (ASC) and 22 matched typical adults (TA). The perception of the ambiguous figure was manipulated by adaptation to unambiguous figures and/or by placing the ambiguous figure into a context of unambiguous figures. This resulted in four conditions testing the independent and combined (congruent and incongruent) manipulations of adaptation (bottom-up) and spatial context (top-down) effects. The strength of perception, as measured by perception of the first reported orientation of the ambiguous stimulus was affected comparably between groups. Nevertheless, the strength of perception, as measured by perceptual durations was affected differently between groups: The perceptual effect was strongest for the ASC group when combined bottom-up and top-down conditions were congruent. In contrast, the strength of the perceptual effect in response to the same condition in the TA group was comparable to the adaptation, but stronger than both the context and the incongruent combined bottom-up and top-down conditions. Furthermore, the context condition was stronger than the incongruent combined bottom-up and top-down condition for the TA group. Thus, our findings support the view of stimulus-specific top-down modulation in ASC.

Keywords: Autistic Spectrum Condition; Ambiguous figures; Adaptation; Context

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Autistic spectrum condition (ASC) is a neurodevelopmental condition characterized by disturbances in social interaction and communication, as well as stereotyped, repetitive behaviors and interests (WHO, 1992). The condition additionally exhibits abnormalities in visual perception and attention (Happé & Frith, 2006; Hill, 2004).

Anecdotal evidence suggests that ASC individuals are very accurate and fast at perceiving visual details of a display (bottom-up perception). A growing body of research confirms that ASC participants are better in tasks, which require predominantly “local” or detail-focused processing, e.g., embedded figures (Shah & Frith, 1983), block design (Shah & Frith, 1993), conjunctive visual search (Plaisted, O’Riordan, & Baron-Cohen, 1998), for a recent meta-analysis on the former two tasks refer to Muth, Hönekopp, and Falter (2014). Although evidence for an enhanced local processing is consistent, reports on deficits in global processing are inconclusive (Dakin & Frith, 2005).

On a neural level, a decreased top-down neural control might manifest itself in a local processing style at the expense of processing the global ‘gist’ (Frith, 2003). Frith (2003) suggests lack of pruning of neuronal feedback projections during brain development in ASC individuals, which results in malfunctioning of neural feedback control systems. Functional neuroimaging studies have supported the view of atypical top-down modulation of early sensory processing in ASC individuals: task-dependent early sensory processing areas activate or even hyper-activate, while later processing areas hypo-activate in response to various perceptual and attentional manipulations (Freitag et al., 2008). Loth, Gómez, & Happé (2010) and Cook, Barbalat, & Blakemore (2012) show that top-down influence of prior knowledge and top-down dominance on task performance is reduced in ASC. However, Bird, Catmur, Silani, Frith, & Frith (2006) and Greenaway & Plaisted (2005) imply that top-down influence on task performance can be stimulus-specific. Mitchell, Mottron, Soulières, and Ropar (2010) discuss whether top-down processing in ASC might be attenuated in the sense of a general deficit, or top-down processing might be merely stimulus or task-dependent.

We tested this particular question for the first time and explored spontaneous influences of bottom-up and top-down information on perception and their interaction in ASC using an ambiguous figures paradigm. Ambiguous figures are such stimuli that make our perception constantly oscillate between two (or more) alternative interpretations. When participants merely observe the ambiguous figures, ASC participants and typical adults experience similar perceptual changes (Ropar, Mitchell, & Ackroyd, 2003; Sobel, Capps, & Gopnik, 2005). Our ambiguous figures paradigm, however, allows the implementation of bottom-up and top-down processing on their own, as well as under combined congruent and incongruent conditions (Intaitė et al., 2013). This is achieved by including adaptation (bottom-up) and context (top-down) effects into the task. An adaptation effect is obtained in studies where participants are presented with an unambiguous stimulus before the actual ambiguous stimulus is shown. The unambiguous stimulus represents one of the possible interpretations of the ambiguous figure, hence biasing the subsequent perception of the ambiguous figure, i.e. participants tend to first recognize the alternative interpretation of the subsequently presented ambiguous figure (Long & Moran, 2007). In this study, all participants were adapted to an unambiguous squares stimulus in either 'upwards' or 'downwards' orientation that was followed by the ambiguous squares stimulus. Contrary to the adaptation effect, the context effect is achieved by presenting an ambiguous test figure within the spatial context of unambiguous figures representing one of the possible perceptual interpretations. In this case, the ambiguous test figure is more likely to be perceived in the same orientation as the context figures (Intaitė et al., 2013; Sundareswara & Schrater, 2008). In the current study, the ambiguous squares stimulus was presented in the spatial context of unambiguous squares stimuli. Adaptation and context conditions were presented either in separate trials or within the same trials. In the latter case, the orientation of the context stimuli either matched the formerly presented adapting stimulus or not. This resulted in four conditions: an adaptation only condition, a context only condition, an adaptation different from context condition (combined congruent), and an adaptation identical to context condition (combined incongruent) (see Fig. 1). Previously Happé (1996) and Happé & Frith (2006) suggested that perception in ASC individuals might be less influenced by context in a top-down manner. Yet, Greenaway & Plaisted (2005) and Mitchell et al. (2010) indicate that top-down attentional modulation might be stimulus-specific or task-dependent rather than generally attenuated. Hence, we sought to investigate these two hypotheses of either a general deficit of top-down modulation (i.e., the ASC group would show weaker responses to context effect alongside to weaker responses to both combined bottom-up and top-down manipulations) or a stimulus-specific top-down modulation by testing ambiguous figure perception under these four conditions.

Methods

Participants

Thirty-six individuals with Autism Spectrum Condition (ASC; twenty-three males) and twenty-eight typical adults (TA; fourteen males) took part in the experiment. All ASC participants met international criteria for autism (F84.0) or Asperger's Syndrome (F84.5) confirmed by clinical interviews according to ICD-10 (WHO, 1992), as judged by two clinicians specializing in the assessment and diagnosis of the condition. Participants of this study were recruited from the database at the Outpatient Clinic for Adults with Autism Spectrum Disorder at the University Hospital Cologne. Eleven participants (five from the ASC group and six from the TA group) were excluded from analyses because of an inability to report reversals in one or more experimental conditions in spite of reporting to see both interpretations of the ambiguous squares stimulus during the practice period. Thus, the data of thirty-one ASC (twenty males; age = 43:6 years:months, *SD* = 8.6) and twenty-two TA participants (twelve males; age = 39:3 years:months, *SD* = 8.7) were entered into the analyses. Each participant had reported normal or corrected-to-normal vision. Written informed consent was obtained from all participants and the ethics board of the University Hospital Cologne formally approved the study.

Psychometric testing

Participants completed this study as part of a larger battery of three perceptual experiments. They also completed a neuropsychological test battery including the Beck Depression Inventory (BDI, Hautzinger, Keller, & Kühner, 2006), Wechsler Intelligence Scale (WIE, Aster, Neubauer, & Horn, 2006), the Autism-Spectrum Quotient (AQ, Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001), the Empathy Quotient (EQ, Baron-

Cohen, Wheelwright, 2004), the Systemizing Quotient (SQ, Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003), Toronto Alexithymia Scale (TAS-20, Bagby, Parker, & Taylor, 1994), the Intuitive Physics Test (IPT, Baron-Cohen, S, Wheelwright, Scahill, Lawson, & Spong, 2001) and Theory of Mind - Reading the Mind in the Eyes Test (Baron-Cohen, S, Wheelwright, Hill, Raste, & Plumb, 2001). ASC and TA groups were matched with respect to age, verbal, and performance IQ (Table 1; *largest* t = 1.82). TA participants were screened for not having a prior history of neurological or psychiatric conditions. Eleven ASC participants were taking antidepressants at the time of the study. Taking into account the altered excitation/inhibition balance in the autistic brain (Nelson & Valakh, 2015), we have rerun our statistics excluding these ASC participants and the results were comparable to the results obtained with a complete sample. Results excluding ASC participants taking antidepressants are available online (https://osf.io/nhrxk/).

<<<Table 1 about here>>>

Design and Procedure

An ambiguous squares figure was used as the main experimental stimulus. Each trial started with a 120 s adaptation period followed by a blank screen presented for 1 s. Afterwards, participants were presented with an ambiguous squares stimulus (in the four different conditions described below) for 30 s and had to report the perceived changes of the square's orientation by pressing one of the two keys (upwards or downwards) on the response keyboard. An inter-trial interval of 120 s was presented after each trial. A central fixation point was always present in the middle of the screen/figure except during the intertrial intervals. The participants were asked to keep their eyes focused on this point throughout the experiment. The four conditions had the following characteristics:

1) The adaptation condition (hereafter AC): During the adaptation period, an unambiguous ‘upwards’ or ‘downwards’ oriented squares stimulus was presented. During the test period an ambiguous squares stimulus (i.e., no context) was presented (Fig. 1A).

2) The context condition (hereafter CC): During the adaptation period, only the fixation point was used as a stimulus (i.e., no adaptation). During the test period an ambiguous squares stimulus was presented in the context of surrounding unambiguous squares stimuli in either ‘upwards’ or ‘downwards’ orientation (Fig. 1B).

3) The adaptation different from context (hereafter ADC) condition: During the adaptation period, an unambiguous squares stimulus oriented either ‘upwards’ or ‘downwards’ was presented. During the test period an ambiguous squares stimulus was presented in the context of surrounding unambiguous squares stimuli in either a ‘downwards’ or ‘upwards’ orientation, respectively (Fig. 1C).

4) The adaptation identical to context (hereafter AIC) condition: During the adaptation period, the unambiguous squares stimulus oriented either ‘upwards’ or ‘downwards’. During the test period an ambiguous squares stimulus was presented in the context of surrounding unambiguous squares stimuli in either ‘upwards’ or ‘downwards’ orientation, respectively (Fig. 1D).

All stimuli were drawn in black (~ 12.78 cd/m^2), presented on a white background (~ 14.98 cd/m^2), and viewed binocularly. A single figure subtended a visual angle of 1.51° × 1.51°, the fixation point was 0.02° large, and line thickness in degrees of visual angle was around 0.07°. The entire display consisting of ambiguous squares in the context of unambiguous squares subtended 5.82° × 5.82° of visual angle. Stimuli were presented on a 24 inch computer screen (frame rate: 59 Hz, mean luminance of the monitor: ~ 13.88 cd/m^2, Michelson contrast: 0.15, LED monitor) at a viewing distance of ~ 60 cm. The position of the fixation point on each version of unambiguous squares was adjusted to match the center of the screen and the center of the subsequently presented ambiguous squares stimulus.

Each participant took part in a 90 min individual testing session. Ambient lighting was kept constant throughout each testing session. Before testing commenced, the ambiguous squares stimulus was shown to each participant, and they were instructed to watch it until reversals were perceived. In the beginning of the session, each participant performed two practice trials (the CC and the ADC conditions) in order to get acquainted with the task requirements.

<<<Figure 1 about here>>>

Each of the four conditions consisted of four trials, resulting in a total of 16 experimental trials. For each of the three experimental conditions with an adaptation period (the AC, the ADC and the AIC), the four trials consisted in the ambiguous squares stimulus being presented twice after the ‘downwards’ and twice after the ‘upwards’ unambiguous squares stimulus. The 16 trials were organized in two experimental blocks, separated by a 5 min break. Each block contained eight randomly presented trials, with two trials from every experimental condition and one of each of the two unambiguous orientations: ‘upwards’ and ‘downwards’. The participants were asked to let the perceptual reversals occur naturally and were instructed not to intentionally manipulate their percepts. No feedback on performance was given.

Statistical analyses

There were two dependent measures used in the analyses: (1) the first responses regarding the percept of the orientation of the ambiguous squares stimulus (hereafter

Orientation First Percept) and (2) the average durations during the 30 sec test period, calculated separately for the ‘upwards’ and ‘downwards’ percepts (hereafter Perceptual Durations). The Orientation First Percept is a direct measure of the influence of the experimental manipulations on perception and the Perceptual Durations are metrics of the fluctuations of the perception. Concerning the analysis of Orientation First Percept, the initial interpretations were coded in terms of whether the ambiguous squares stimulus was perceived in the predicted (score = 1) or unpredicted (score = 0) orientation with respect to the expected effects from the experimental stimulus conditions (for further information about calculating the predicted scores see Intaitė et al.), and an average score was used for statistical analyses (for further information on statistical analyses see Intaitė et al., 2013).

A mixed ANOVA with one between-participant factor of GROUP (ASC and TA) and one within-participant factor of CONDITION (AC, CC, ADC, AIC) were conducted for the dependent variable Orientation First Percept. One-way ANOVAs (Bonferroni-Holm corrected, hereafter B-H) (Holm, 1979) were used as post-hoc tests to compare different conditions in case of a significant effect of CONDITION.

For the statistical analyses of the Perceptual Durations, successive presses of the same key during ambiguous squares stimulus observation (e.g. several subsequent indications of ‘upwards’ => ‘upwards’ or ‘downwards’ => ‘downwards’ percepts) were treated as errors and removed from the analyses. This happened on average ~1.97 times (SD = 3.04) for the ASC and ~ 1.41 times (SD = 1.12) for TA participants. Due to the limit in the ambiguous squares stimulus presentation duration (i.e., 30 s), a number of percepts were truncated as a result of the end of stimulus display and thus they were not included in the analyses. Kolmogorov-Smirnov tests revealed that Perceptual Durations values did not meet the condition of normality. The distribution of the raw scores were leptokurtic and positively skewed, thus lognormal transformations were applied to these data (Howell, 2009).

A mixed ANOVA with one between-participant factor of GROUP (ASC and TA) and three within-participant factors of CONDITION (AC, CC, ADC, AIC), ADAPTING (or CONTEXT) STIMULUS (upwards and downwards) and PERCEPTUAL RESPONSE (upwards and downwards) were conducted on the data of Perceptual Durations (LOG transformed). After obtaining a significant effect of CONDITION and significant interactions with GROUP, and in order to correct for individual differences, we calculated the difference scores for each Perceptual Duration by subtracting the unpredicted Perceptual Durations from the predicted Perceptual Durations. After this, the predicted difference scores obtained for 'upwards' and 'downwards' perceptual orientations were averaged together creating 'effect of manipulation' variables for each condition. Subsequent one-way ANOVAs (B-H) were used as post-hoc tests to compare different 'effect of manipulation' variables for each GROUP separately. In all cases of significant violations of sphericity, Huynh-Feldt corrections were applied.

Control experiment: Eye-movement recording and analysis

In order to determine whether the participants were able to maintain central fixation during the experimental task we have performed a short control experiment. The stimuli and procedure were identical to the main experiment with the following exceptions: each of the conditions was presented only twice in order to reduce the total time of the experiment from 90 min to 45 min.

During this control experiment, eye-tracking data (sample frequency 250 Hz) were recorded with an Eyelink 1000 (SR Research, Ottawa, Ontario, Canada). The device was individually calibrated with a 9-point calibration routine at the beginning of the experiment. Sixteen ASC (eleven male, mean age = 45.44 years, SD = 8.41) and thirteen TA participants (five male, mean age = 41.08 years, SD = 7.29) took part in the control experiment. ASC and TA groups were matched on age, verbal, and performance IQ (*largest* $t = 1.47$). Eleven ASC participants (seven male) and seven TA participants (four male) took part in both the main and the control experiments, the latter of which was performed on another day and therefore would have not influenced behavioral performance during the main experiment. The data were prescreened for co-morbidity and medication in the same manner as the data of the main experiment.

Fixations were calculated based on the recorded gaze behavior. A fixation duration threshold of 150 ms was used. Fixations that had the same position and were separated by a blink were concatenated. To calculate dwell time (i.e., the percent of time spent fixating on the interest area), consecutive fixations were concatenated. For pupil data analysis, the pupil area values at 1 sec before each perceptual reversal were averaged together. Two rectangular areas of interest (AOI), one comprising the size of the ambiguous squares stimulus (1.51° × 1.51°) (hereafter AOI-1) and one comprising the size of the context stimuli (5.82° × 5.82°) (hereafter AOI-2) were defined. As the responses to the provided test stimuli depended on the participants' performance during the adaptation period, for the AOI-1 we analyzed the fixations' data both for the adaptation period (120 s before presenting the ambiguous squares stimulus) and for the test period (30 s of the ambiguous squares stimulus presentation time). For the AOI-2 analyses, only fixations data obtained during the test period were analyzed (Table 2). Kruskal-Wallis tests were performed to compare study groups regarding the average count of fixations, the dwell times both for AOI-1 and for AOI-2, and pupil area values at 1 sec before the presses indicating perceptual reversals between all conditions and groups.

<<< Table 2 about here >>>

Results

Eye tracking

Results revealed no statistically significant group differences between the average count of fixations (largest $\chi^2 = .52$), the dwell times neither for AOI-1 (largest $\chi^2 = 1.61$) nor for AOI-2 (largest $\chi^2 = .52$), and pupil area values at 1 sec before the presses indicating perceptual reversals (largest $\chi^2 = 2.02$) across all conditions and across groups (see Table 2).

Orientation First Percept

We performed a mixed ANOVA with one between-subjects factor of GROUP (ASC, TA), one within-subjects factor of CONDITION (AC, CC, AIC, ADC) and Orientation First Percept as dependent variable. The first reported percepts of the ambiguous squares were differentially influenced by experimental manipulations as indicated by a significant effect of CONDITION ($F(3,153) = 15.71$, $p < .001$, $\eta p^2 = .24$). Effects of these experimental manipulations were comparable across GROUPS (GROUP effect, CONDITION × GROUP interaction: largest $F < 1$). First, we wanted to check whether adaptation or context had a stronger influence on the first ambiguous squares figure percept. Thus, we compared the adaptation and context conditions independently and this revealed that irrespective of GROUP ($F < 1$) the manipulation of context was stronger than that of adaptation ($F(1, 51) = 25.15$, $p < .001$, $\eta p^2 = .33$) (Fig. 2A). Further, we solely compared those conditions that had the same predicted orientations of responses (Intaitė et al., 2013): AC with the ADC (adaptation-matching first interpretation of ambiguous squares stimulus) and the CC with the AIC (context-matching first interpretation of the ambiguous squares stimulus). Subsequent comparisons revealed that the predicted effect was stronger in response to the ADC than in response to the AC ($F(1,51) = 38.56$, $p < .001$, $\eta p^2 = .43$), and the predicted effect was stronger in response to the CC than in response to the AIC, ($F(1,51) = 6.47$, $p < .05$, $\eta p^2 = .11$), for both GROUPS (all F-values < 1), confirming our previous findings (Intaitė et al., 2013). This suggests that context may strengthen (the ADC) or weaken (the AIC) effect of adaptation depending on whether the top-down and bottom-up manipulations are congruent or incongruent.

However, the independent adaptation effect obtained in our study was weaker than the effects obtained in response to other experimental conditions. It is known that adaptation effects are heavily influenced by adaptation duration, stimulus size, location, and temporal proximity between adapting and ambiguous stimuli (Long & Moran, 2007; Long et al., 1992; von Grünau et al., 1984). Given that we were exploring the effects of spatial context on adaptation (and vice versa), we have used a lower number of adaptation trials in comparison to earlier studies (Long & Moran, 2007; Long et al., 1992; von Grünau et al., 1984). Furthermore, studies testing adaptation effects have relatively large amounts of participants (i.e., > 60) (Intaitė et al., 2013; Long & Moran 2007; Long, Toppino & Mondin, 1992). In order to verify that this effect was indeed weaker due to the smaller sample, we have added the data available from our supplementary experiment to our original adaptation condition and conducted a one-sample t-test. The mean values of the AC were significantly larger than random responding (i.e., 0.5): AC $t(63) = 1.83$, $p < .04$, one-tailed, $d = .23$. The statistical data are summarized in Table 3.

<<<Figure 2 about here>>>

Perceptual Durations

In order to investigate whether Perceptual Durations were influenced by experimental manipulations, as well as by the ‘downwards’ and the ‘upwards’ interpretations of the ambiguous stimulus, we have conducted a mixed ANOVA with CONDITION (AC, CC, AIC, ADC), ADAPTING (or CONTEXT) STIMULUS, PERCEPTUAL RESPONSE (downwards, upwards) as within-subjects factors and GROUP (ASC, TA) as between-subjects factor and Perceptual Durations as dependent variable. The mixed ANOVA showed significant effects of CONDITION ($F(3,153) = 7.69$, $p < .001$, $\eta p^2 = .13$) and PERCEPTUAL RESPONSE ($F(1,51) = 14.01$, $p < .001$, $\eta p^2 = .22$) revealing that perceptual ‘downwards’ responses were longer than ‘upwards’ responses, a finding termed the *perceptual orientation bias*, i.e. the perception of the ambiguous cube-like figure (e.g., Necker cube) is typically biased towards a ‘front-side-down’ interpretation. Significant PERCEPTUAL RESPONSE × GROUP ($F(1,51) = 5.21$, $p < .05$, $\eta p^2 = .09$), CONDITION × PERCEPTUAL RESPONSE ($F(3,153) = 3.33$, $p < .05$, $\eta p^2 = .06$), CONDITION × PERCEPTUAL RESPONSE × GROUP ($F(3,153) = 2.90$, $p < .05$, $\eta p^2 = .05$) and CONDITION × ADAPTING STIMULUS × PERCEPTUAL RESPONSE ($F(3,153) = 49.07$, $p < .001$, $\eta p^2 = .49$) interactions were obtained, whereas the effect of GROUP was not significant ($F < 1$). In order to simplify our data, we have calculated difference scores between the predicted and unpredicted Perceptual Durations (the selection of predicted and unpredicted Perceptual Durations were based on the predicted and unpredicted Orientation First Percept scores). The difference scores were calculated separately for ‘upwards’ and ‘downwards’ orientations and then averaged together to obtain a single ‘effect of manipulation’ variable per condition. In order to further explore the significant GROUP interactions obtained in the mixed ANOVA, subsequent one-way ANOVAs were performed for each GROUP separately.

For both ASC and TA groups, there was no difference between the adaptation (the AC) and the context (the CC) conditions (both F-values < 1), meaning that both conditions were influencing the perception of both groups at a comparable strength.

<<<Figure 3 about here>>>

ASC. The 'effect of manipulation' variables were different between experimental conditions (as shown by significant effect of CONDITION ($F(3,90) = 16.29$, $p < .001$, $\eta p^2 = .35$)). Subsequent one-way ANOVAs, comparing pairwise all the experimental conditions (B-H corrected), revealed that the 'effect of manipulation' was larger in response to the ADC condition compared to all other conditions ($F(1,30) \geq 11.92$, $p < .003$, $\eta p^2 \geq .28$). That is, the experimental manipulation was strongest in the ASC group, when bottom-up and top-down manipulations were congruent (Fig. 3).

TA. The effect of manipulations was different between experimental conditions as shown by a significant effect of CONDITION ($F(3,63) = 6.34$, $p < .003$, $\eta p^2 = .23$). Subsequent one-way ANOVAs, comparing pairwise all experimental conditions (B-H corrected), revealed that the 'effect of manipulation' was stronger in response to the condition where bottom-up and top-down manipulations were congruent (the ADC) compared to the values obtained in response to the context condition (the CC), or the condition where bottom-up and top-down manipulations were incongruent (the AIC) ($F(1,21) \geq 10.61$, $p < .005$, $\eta p^2 \geq .34$). Furthermore, the effect of context alone (the CC) was stronger than that of AIC ($F(1,21) = 7.98$, $p < .02$, $\eta p^2 = .28$).

More results (https://osf.io/nhrxk/), as well as the spreadsheet of the summary data (https://mfr.osf.io/render?url=https://osf.io/4bcqz/?action=download%26mode=render), and our experimental code (https://osf.io/y73mn/), are available online.

<<<Table 3 about here>>>

Results containing dependent measures 'Response to the First Reversal' (standard measurement of effects of adaptation on ambiguous figure perception) and 'Reversal Rate' (standard measurement of ambiguous figure perception) are included in the supplement results section online. Furthermore, Spearman correlation coefficients were used to examine the relationship between task performance and symptom severity indexed in AQ scores as well as systemizing tendency indexed in IPT scores (https://osf.io/nhrxk/).

Discussion

We aimed to examine perceptual processing in ASC and a matched TA group using a previously validated paradigm, which, for the first time allows the investigation of both the independent and the combined influence of bottom-up and top-down influences on perception of ambiguous figures in ASC. We replicated previous findings of adaptation (Intaitė et al., 2013; Long & Moran, 2007; Long et al., 2002) and context (Intaitė et al., 2013; Sundareswara & Schrater, 2008) effects on the perception of ambiguous figures in TA and found no differences between the ASC and the TA groups. The current results confirmed both an adaptation effect in the adaptation condition (the AC) and a context effect in the context condition (the CC), the latter of which surpassed the adaptation effect for both groups. Furthermore, we obtained the perceptual orientation bias, which is a typical finding showing that the cube-like ambiguous figures are perceived in 'front-side-down' orientation for longer durations (Dobbins & Grossmann, 2010; Kersten & Yuille, 2003; Murata et al., 2003; Sundareswara & Schrater, 2008; Toppino & Long, 2015; Troje & McAdam, 2010; Washburn et al., 1931). With respect to group differences, we found that the effect of manipulation on Perceptual Durations for the ASC group was strongest when bottom-up manipulation was further strengthened by the top-down manipulation (the ADC) compared to all other conditions. The results of the TA group revealed that the same manipulation (the ADC) was comparable to independent adaptation (the AC) condition, but stronger than independent context (the CC) or incongruous bottom-up and top-down manipulation (the AIC). To sum up, our results add to converging evidence of additivity of bottom-up and top-down processes operating in the human visual system (Intaitė et al., 2013; Long & Toppino, 2004; Toppino,

2003) and show that general characteristics of basic visuo-perceptual functioning appear intact in ASC (for an extended discussion please see: (https://osf.io/nhrxk/).

A Bayesian account (Pellicano & Burr, 2012) proposes that the interpretation of sensory information is less biased by prior experiences in ASC. Adaptation is a form of experience-dependent plasticity in which the current sensory experience is modified by the stimuli presented only up to several seconds before. Certain forms of this adaptation are reduced in ASC (Turi et al., 2015; Turi, Karaminis, Pellicano, & Burr, 2016). However, the type of adaptation tested in this study is not reduced in ASC, as in this paradigm the presentation time of at least one and a half minutes is necessary to attain the effect (Long et al., 1992). A shorter stimulus presentation exhibits a priming effect, that is the subsequent ambiguous figure is typically perceived in the same interpretation as the preceding unambiguous figure (Bugelski & Alampay, 1961; Long et al., 1992).

Our results also add to the view of perception in ASC being characterized by relative autonomy from top-down or contextual information resulting in more veridical perception as lined out by the Enhanced Perceptual Functioning account (Mottron et al., 2006). However, our results indicate that altered top-down modulation is stimulus- and task-specific (Greenaway & Plaisted, 2005). Mitchell and colleagues (2010) suggest that some of the induced top-down effects are atypically engaged in autistic perception. Top-down effects might be attenuated in autistic cognition, especially when they are not task-relevant; TA individuals are compelled to engage top-down processing to a much greater degree. Perceptual ambiguity and its manipulations reveal that we actively interpret the available visual information, rather than passively view it. Our data suggest that top-down processing exhibited by the ASC participants might as well depend on the respective bottom-up processing, hence in such cases where top-down manipulation was supported by bottom-up manipulation (i.e., the ADC), we observe intact top-down processing. However, if the top-down manipulation is not supported by bottom-up manipulation (i.e., the AIC), the ASC participants show reduced interpretation of the available visual information, thus their top-down processing might be merely stimulus or task-dependent.

In summary, this study examines whether top-down processing in ASC is a general or a task-specific deficit. Our findings indicate that both bottom-up and top-down processes can influence perception concurrently and independently for the TA participants. We have observed a perturbation in the dynamics of perceptual ambiguity in ASC individuals when the presented top-down manipulation was not supporting the bottom-up manipulation. Thus ASC participants show the atypical task-specific bottom-up and top-down interactions that imply minor abnormalities in their visual perception and attention, thus supporting the view of stimulus-specific top-down modulation in ASC.

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FIGURES

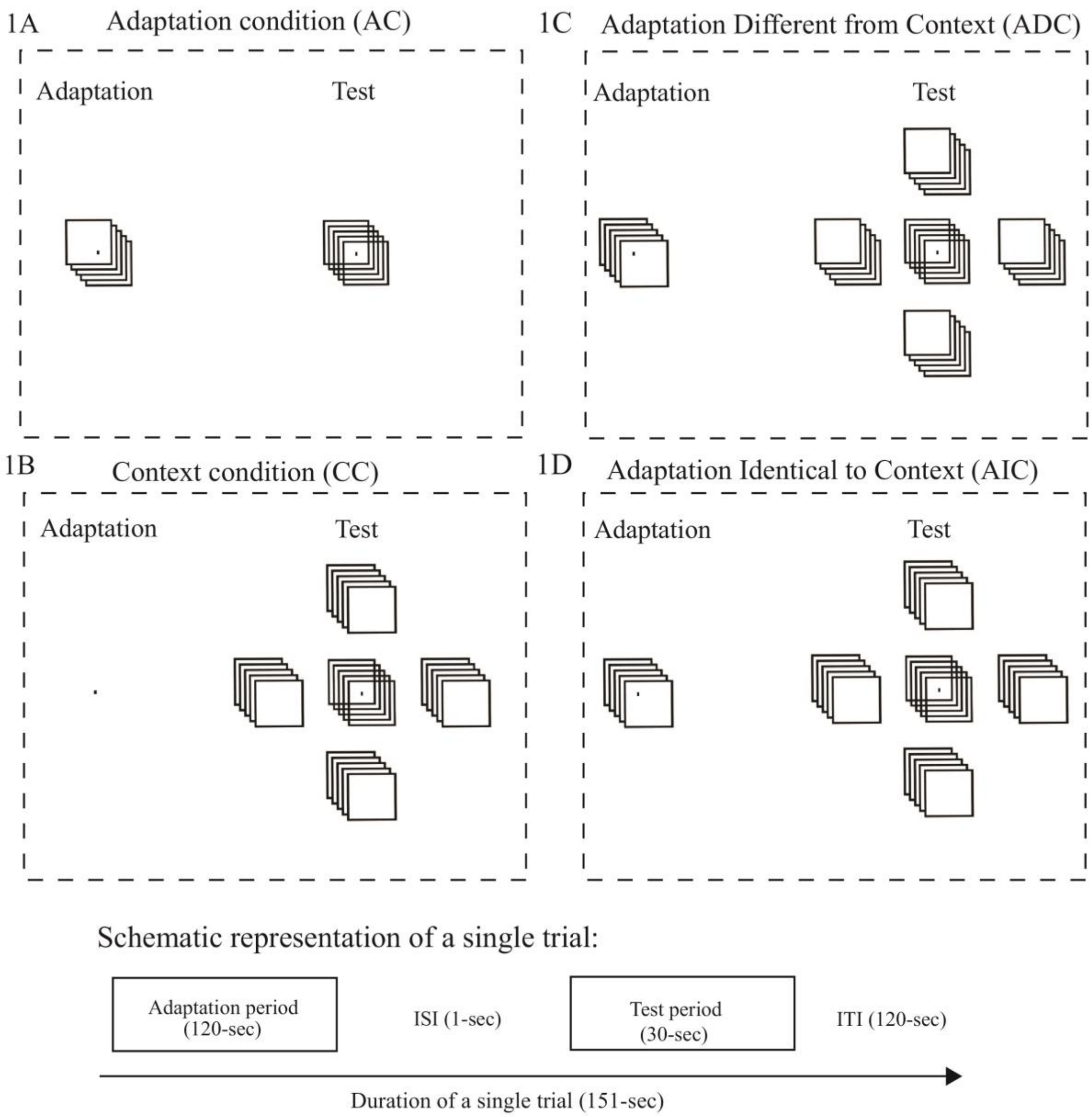

Figure 1. Schematic representation of all experimental conditions: (a) the adaptation condition (AC), (b) the context condition (CC), (c) the adaptation different from context condition (ADC), and (d) the adaptation identical to context condition (AIC). A schematic representation of a single experimental trial is depicted in the lower part of the figure.

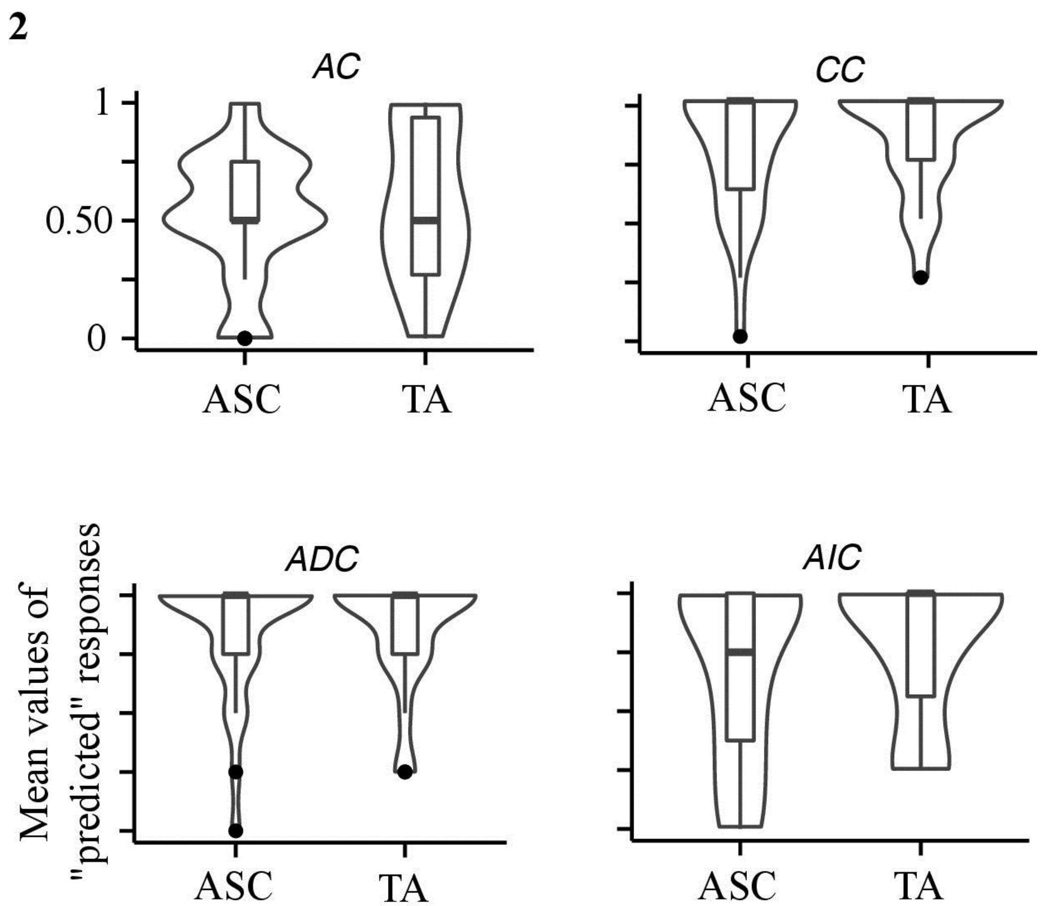

Figure 2. Median number of times that autistic spectrum condition (ASC) and typical adults (TA) first reported the "predicted" orientation of the ambiguous squares stimulus, in accordance with the orientation elicited by the respective experimental condition. Violin plots depict the shape of the distribution and region inside the violin contains all of the observed data. Values obtained in the wider parts of the violin are more probable than those in narrower parts. The median and interquartile ranges are displayed by overlaying a box plot. Error bars represent the lowest and the highest data points still within 1.5 interquartile ranges (IQR).

3

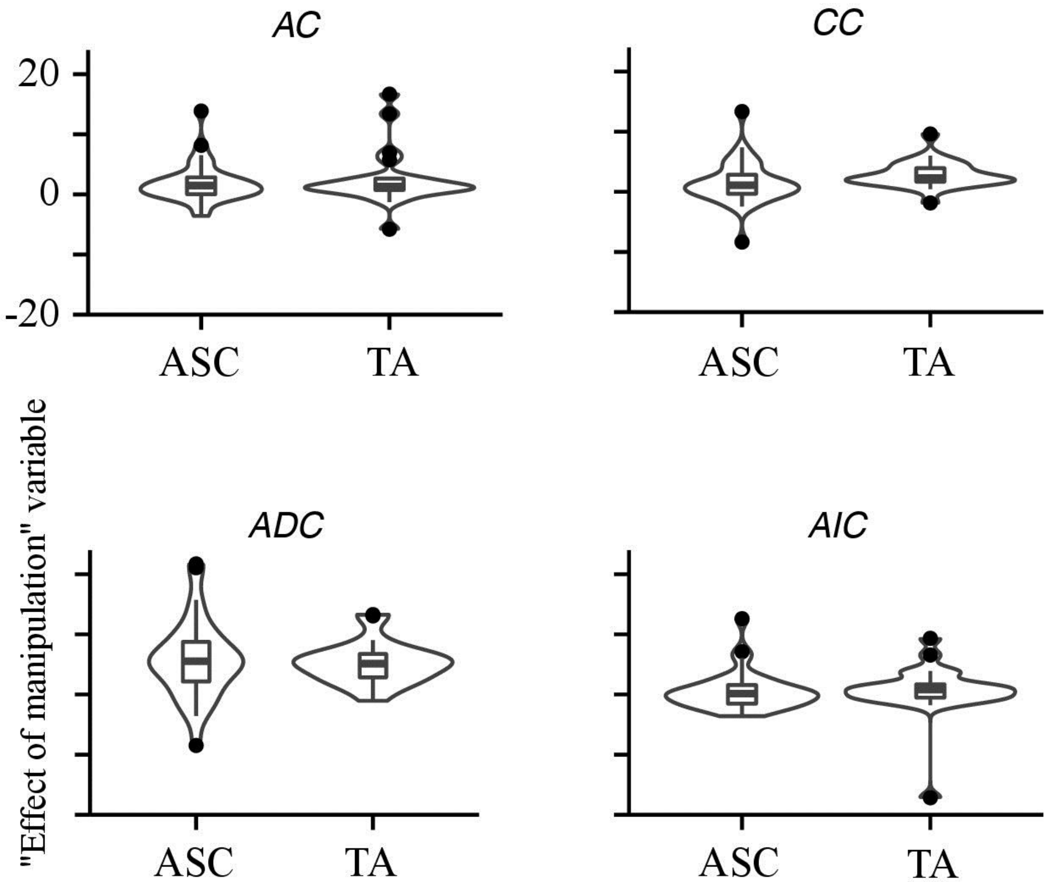

Figure 3. Median "effect of manipulation" variables. Violin plots depict the shape of the distribution and region inside the violin contains all of the observed data. Values obtained in the wider parts of the violin are more probable than those in narrower parts. The median and interquartile ranges are displayed by overlaying a box plot. Error bars represent the lowest and the highest data points still within 1.5 IQR.

TABLES

	ASC (N=31; 20 male)			TA (N=22; 12 male)		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
Age	43:6	8:6	20:2 – 55:9	39:3	8:7	22:2 – 53:0
VIQ	113	17	81 – 135	115	13	94 – 137
PIQ	108	18	67 – 141	107	14	73 – 132
FIQ	113	18	78 – 140	111	13	83 – 139
AQ	41	4	27 – 48	17	6	6 – 29
IPT	8	3	2 – 15	10	2	4 – 14

Table 1: Means, standard deviations, and ranges of age (years:months), verbal IQ (VIQ), performance IQ (PIQ), full IQ (FIQ), Autism-Spectrum Quotient (AQ), number of mistakes made in Intuitive Physics Test (IPT) of participants with autism spectrum condition (ASC) and typical adults (TA).

		ASC (N=12; 10 male)			TA (N=7; 4 male)		
		Fix	DT	PA	Fix	DT	PA
AOI-1	AP (SD)	70.8 (2.8)	83.6 (35.7)	627.2 (134.9)	77.8 (2.4)	94.6 (29.9)	548.6 (95.0)
	TP (SD)	71.2 (3.4)	21.1 (11.3)	629.5 (144.9)	74.5 (3.1)	23.2 (9.7)	558.4 (93.4)
AOI-2	AP (SD)						
	TP (SD)	98.8 (14.4)	28.2 (4.3)	623.2 (146.9)	98.5 (3.7)	28.7 (1.4)	560.1 (88.4)

Table 2: Means (SD) of eye tracking data for fixations (Fix.; %) dwell times (DT; s) and Pupil area (PA; arbitrary units) of participants with an autism spectrum condition (ASC) and typical adults (TA) for the two Areas-of-Interest: AOI-1 (size: 1.51° × 1.51°) and AOI-2 (size: 5.82° × 5.82°) during Adaptation (AP) and Test periods (AP).

Dependent variable	**Findings for experimental Conditions and Groups**	
Orientation First Percept (1stP)	Main ANOVA: CONDITION (F(3,153) = 15.71, p < .001, ηp^2 = .24) **AC < CC**: (F(1, 51) = 25.15, p < .001, ηp^2 = .33) **AC < ADC**: (F(1,51) = 38.56, p < .001, ηp^2 = .43) **AIC < CC**: (F(1,51) = 6.47, p < .05, ηp^2 = .11) Group interactions: all F-values < 1 Group effect: F < 1	
Perceptual Durations	Main ANOVA: CONDITION (F(3,153) = 7.69, p < .001, ηp^2 = .13) PERCEPTUAL RESPONSE (F(1,51) = 14.01, p < .001, ηp^2 = .22) Group interactions: PERCEPTUAL RESPONSE × GROUP (F(1,51) = 5.21, p < .05, ηp^2 = .09), CONDITION × PERCEPTUAL RESPONSE × GROUP (F(3,153) = 2.90, p < .05, ηp^2 = .05). All other GROUP interactions F-values < 1 Group effect: F < 1	
	ASC (N = 31; 20 male)	**TA (N = 22; 12 male)**
'Effect of Manipulation'	**AC ≈ CC** (F < 1) **ADC > AC, CC, AIC**: (F(1,30) ≥ 11.92, p < .003, ηp^2 ≥ .28)	**AC ≈ CC** (F < 1) **ADC > CC and AIC**: (F(1,21) ≥ 10.61, p < .005, ηp^2 ≥ .34) **AIC < CC**: (F(1,21) = 7.98, p < .02, ηp^2 = .28)

Table 3: Overview of results across dependent variables and conditions (AC: Adaptation Condition, CC: Context Condition, ADC: Adaptation different from Context, AIC: Adaptation identical to Context) of participants with an autism spectrum condition (ASC) and typical adults (TA) for all dependent variables of the experiment.