Visual scene discrimination: A perceptual advantage in autistic adults

Nazia Jassim (nj304@cam.ac.uk)
University of Cambridge
Adrian M. Owen
University of Western Ontario
Paula Smith
University of Cambridge
John Suckling
University of Cambridge
Rebecca P. Lawson
University of Cambridge
Simon Baron-Cohen
University of Cambridge
Owen Parsons
University of Cambridge

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Abstract

Discriminating between similar scenes proves to be a remarkably demanding task due to the limited capacity of our visual cognitive processes. Here we examine how visual scene discrimination is modulated by perceptual differences arising from neurodiversity. A large sample of autistic (n = 140) and typical (n = 147) participants completed two visual scene discrimination experiments online. Each experiment consisted of "match" (identical scenes) and "mismatch" (subtle differences between scenes) conditions. In both experiments, we found strong evidence for an interaction between group and task condition. Specifically, when compared to typical controls, autistic individuals were on average more accurate at identifying subtle differences between scenes. Taken together, these results suggest differential processing of contextual expectations in autism. These findings are consistent with both classic cognitive theories and more recent Bayesian explanations of autistic perception. In addition, this work highlights the strengths of neurodiversity in specific areas of cognition.

Introduction

What makes "spot the difference" puzzles so challenging? And why are some people better at these puzzles than others? The deceptively simple task of identifying the differences between two similar visual scenes highlights the complexity of human visual cognition. Both major and minor differences between seemingly identical scenes can go undetected despite viewers actively engaging in visual search; this is due to the limited capacity of our visual and cognitive processes (Wolfe, 2021).

Actively discriminating between two similar images engages a cascade of steps from low-level processing of stimulus features to high-level object recognition. At the perceptual level, exposure to an object may generate expectations of similar, contextually-related objects (Bar, 2004). For example, consider a scenario in which a person is asked to visually inspect two seemingly identical images, image A and image B, and decide whether they differ or not. After the initial visual processing, image A may prime the visual system to expect something similar in image B's place. These so-called contextual expectations are both rapid and short-lived, only lasting for the duration of the task (Series & Seitz, 2013). Expectation and attention may then interact to facilitate image recognition (Summerfield & Egner, 2009). However, what if image B differs only very slightly from image A? In this scenario, contextual expectations may serve as a double-edged sword and may contribute to one overlooking the difference. While performance on such tasks may boil down to inter-individual differences across various factors such as motivation, working memory, fluid intelligence, and visual attention (Bergmann et al., 2019; Luria & Vogel, 2011; Wolfe & Horowitz, 2017), it may also be modulated by perceptual differences due to neurodiversity such as those seen in autism (Baron-Cohen, 2020; O'Riordan et al., 2001; Robertson et al., 2013; Robertson & Baron-Cohen, 2017).

Autism spectrum conditions (henceforth autism) are a set of neurodevelopmental conditions characterized by difficulties in communication and relationships, alongside unusually narrow interests, repetitive, restricted patterns of behaviour, and sensory-perceptual differences (American Psychiatric

Association, 2013). In this article, we use the preferred identity-first language to describe people on the autism spectrum (Kenny et al., 2016). Autistic people have been described as not “seeing the wood for the trees” due to their more “veridical” perception – findings well-validated in decades of experimental studies (Baron-Cohen et al., 2009; Happé & Frith, 2006; Mottron et al., 2006; Shah & Frith, 1983). Atypical perception in autism may be due to differences in low-level visual processing mechanisms (Robertson & Baron-Cohen, 2017; Simmons et al., 2009), or discrepancies in Bayesian inference thus making autistic individuals less influenced by prior experiences (Pellicano & Burr, 2012).

By capitalising on advancements in online behavioural research, we aimed to a) replicate the finding of detail-oriented autistic perception in a large sample of participants and b) investigate how autistic and typical participants discriminate between two seemingly similar visual scenes. Finally, we evaluate our findings in light of classic and recent theories of autistic perception.

Methods

Participants:

All participants were recruited online via an email notification sent to individuals registered to two University of Cambridge databases: 1) the Autism Research Centre database (accessible at www.autismresearchcentre.com) was used to recruit autistic adults and 2) a second database (accessible at www.cambridgepsychology.com) was used to recruit the non-autistic adult controls. Participants were entered into a prize draw for the chance to win £50. After excluding participants with missing/incomplete data, the dataset contained 140 autistic (82 females) and 147 non-autistic (118 females) adults aged 18-60 years. There were no significance group differences in age (t(283)= -0.55, p= 0.579) for autism (*Mean*= 35.1, *SD*= 9.85) and controls (*Mean*= 35.8, *SD*= 9.85).

Procedure:

This study was approved by the Psychology Research Ethics Committee in Cambridge (PREC. 2015.018). Participants completed behavioural tasks probing working memory and visual perception via *Cambridge Brain Sciences* (www.cambridgebrainsciences.com), a web-based platform for cognitive assessments. Verbal and visuospatial working memory were assessed using the standardised Digit Span test, which measures the ability to recall a sequence of digits, and the Monkey Ladder test, which measures the ability to recall the location of digits (Inoue & Matsuzawa, 2007; Wechsler, 1981). All tasks were adapted for online computerized testing and validated in large samples (Hampshire et al., 2012).

For each visual perception experiment, participants were given 90 seconds to complete as many trials as possible, with a timer and the score displayed on one side of the screen. The difficulty level of each trial increased or decreased based on the participant’s performance on the previous trial. The following visual scene discrimination experiments were conducted:

Experiment 1: Interlocking polygons

The Interlocking Polygons task is based on pen-and-paper tasks used in clinical neuropsychological tests (Folstein et al., 1975). In this task, a pair of interlocked polygons is displayed on one side of the screen. Participants were instructed to indicate whether a polygon displayed on the other side of the screen is identical (“match”) or not identical (“mismatch”) to one of the interlocking polygons (Fig 1A). Difficulty on each trial corresponded to more subtle differences in the polygons.

Experiment 2: Feature match

The Feature Match task is a visual search task based on the feature integration theory of visual attention (Treisman & Gelade, 1980). Arrays of abstract shapes were displayed on either side of the screen. Participants were instructed to indicate whether the arrays’ contents were identical (“match”) or differed by a single shape (“mismatch”) (Fig 1B). Difficulty on each trial corresponded to an increase in the number of shapes in the array.

Data analysis:

Data were analysed in *R version 4.0.3* (R Core Team, 2020) and *RStudio* (RStudio Team, 2020) with the help of the “*tidyverse”* package (Wickham et al., 2019). For Bayesian statistics, we used the “*Bayes Factor”* R package and report Bayes factors (BF) which quantify the strength of evidence for the alternative hypothesis (BF_{10}) over the null (BF_{01}) (Morey et al., 2021; Rouder et al., 2012). The magnitude of this strength increases with deviation from 1, with $BF_{10} > 3$ considered as moderate evidence and $BF_{10} > 10$ as strong evidence for the alternative hypothesis, while $BF_{10} < 3$ is insufficient evidence for or against the alternative hypothesis (Keysers et al., 2020; Lee & Wagenmakers, 2014; Ly et al., 2016). For t-tests, we report t-statistics, p-values, 95% confidence interval (CI) values, and effect sizes in addition to the Bayes factors.

To help address the heterogeneity within our online sample, we first excluded participants whose working memory scores were less than 2 standard deviations from the overall mean. We then conducted exploratory t-tests to measure the extent to which the Autism and Control groups differed in working memory abilities.

For both visual perception experiments, overall and condition-specific accuracy rates were computed for each group. To investigate differences in task performance due to task condition and group, a Bayesian 2x2 factorial Analysis of Variance (ANOVA) was computed on accuracy rates with group (Autism vs Control) and task condition (Match vs Mismatch) as factors. Each individual participant was included as a random factor. As a sanity check, we also conducted independent two-sample t-tests on the total number of trials attempted by each group to ensure that accuracy rate group differences could not be attributed to differences in this measure.

Results

Working memory:

After excluding participants whose working memory performance was below the cut-off, 276 participants remained: 129 Autism (75 female, 54 male) and 147 Control (118 female, 29 male). The exploratory t-test on verbal working memory as assessed by the Digit Span test showed evidence in favour of group differences (BF_{10}=27, *t*(273) = 3.40, *p*<0.001, *d*= 0.40, 95% *CI* [0.14, 0.56]) between the Autism (*Mean*= 5.44, *SD*=0.82) and Control (*Mean*= 5.84, *SD*=0.91) groups. Meanwhile, between-group results for the visuospatial working memory test yielded a BF_{10} smaller than 1 (BF_{10}=0.69), with evidence leaning towards a lack of group differences (*t*(273)=1.87, *p*=0.06, *d*=0.22, 95% *CI* [-0.006, 0.27]) between the Autism (*Mean*= 5.07, *SD*= 0.57) and Control (*Mean*= 5.21, *SD*= 0.62) groups. The distribution of working memory scores can be seen in Supplementary Figures 1 & 2.

Experiment 1: Interlocking Polygons

The Bayesian ANOVA on accuracy rates with group and task condition as factors yielded strong positive evidence in favour of an interaction effect of group and task condition (BF_{10} =28) (Fig 2). We found no clear evidence for or against the main effect of group (BF_{10} = 0.10) or task condition (BF_{10} = 0.22). The mean number of trials completed by both groups in each condition are reported in *Table 1*. The independent samples t-test on the total number of trials attempted by each group yielded BF_{10}=1.44, suggesting no evidence in favour of group differences (*t*(540)=2.36, *p*=0.018, *d*=0.20, 95% *CI* [0.19, 2.1]) between the Autism (*Mean*= 26.65, *SD*= 3.63) and Control (*Mean*= 25.51, *SD*= 3.60) groups.

Experiment 2: Feature Match

Mean accuracy rates were high across the Autism (*Mean*=91.6, *SD*=6.35) and Control (*Mean*=93, *SD*=5.56) groups, both overall and when split according to condition (Table 1, Fig 3A, Fig 3C). The Bayesian ANOVA on accuracy rates with group and task condition as factors showed strong evidence in favour of an interaction effect of group and task condition (BF_{10}=42) (Fig 3B). There was no clear evidence for or against the main effect of group (BF_{10}=0.31) or task condition (BF_{10}=0.16). The average number of trials completed by each group in each condition are reported in Table 1.The independent samples t-test on the total number of trials attempted by each group yielded BF_{10} <1 (BF_{10}=0.09) suggesting no evidence of group differences (*t*(539)=0.22, *p*=0.82, *d*=0.02, 95% *CI* [-0.53, 0.67]) between the Autism (*Mean*= 25.5, *SD*= 3.63) and Control (*Mean*= 25.4, *SD*= 3.60) groups.

Table 1: Summary statistics from Experiment 1: Interlocking Polygons and Experiment 2: Feature Match

Task	Group	Task Condition	Number of Trials Attempted *Mean (SD)*	Accuracy Rate *Mean (SD)*
1. Interlocking Polygons	Autism	Match	12.7 (2.9)	71.1 (20.2)
		Mismatch	12.7 (2.4)	79.7 (20.5)
	Control	Match	13.2 (3.2)	76.2 (21.6)
		Mismatch	12.4 (2.1)	73.1 (20)
2. Feature Match	Autism	Match	12.8 (2.1)	89.8 (10.3)
		Mismatch	12.7 (2.4)	93.4 (9.8)
	Control	Match	13 (2.4)	93.4 (9.1)
		Mismatch	12.5 (2.1)	92.6 (9.4)

Discussion

Using a large sample of autistic and typical participants, we conducted two visual perception experiments to test scene discrimination ability. In Experiment 1: Interlocking Polygons, participants indicated whether a target polygon was present in the comparison scene of interlocking polygons. In Experiment 2: Feature Match, participants indicated whether two arrays of shapes differed by a single item. In both experiments, we found strong evidence for an interaction between group (Autism vs Control) and task condition (Match vs Mismatch). Specifically, when compared to typical controls, autistic individuals were on average more accurate at identifying a “mismatch” between two similar scenes in both - Interlocking Polygons and Feature Match - experiments. In addition, in the Interlocking Polygons experiment, autistic individuals were on average comparatively impaired in the “match” condition.

A growing body of research examines autistic perception in the framework of Bayesian inference. According to Bayesian theories of perception in autism, autistic individuals may rely less on their prior expectations relative to sensory evidence, (Brock, 2012; Lawson et al., 2014, 2014; Pellicano & Burr, 2012; Van de Cruys et al., 2017). For example, autistic individuals show less susceptibility to certain visual illusions, which can be attributed to reduced top-down influences on perception (Chouinard et al., 2018; Happé, 1996; Manning et al., 2017). In our experiments, contextual expectations would benefit typical participants in the “match” trials but would conflict with sensory evidence in the “mismatch” conditions. Less reliance on contextual priors may explain why autistic participants showed superior performance in the “mismatch” trials in both experiments, but at the same time fared worse in the “match” trials of the Interlocking Polygons experiment.

A prominent cognitive theory of autism attributes the detail-oriented perceptual-processing style to "weak central coherence" or a weakened tendency to aggregate information into global percepts (Happé & Frith, 2006). This may explain why autistic people tend to show superior performance in gestalt segmentation during the block design test (Shah & Frith, 1993). In addition, autistic individuals have been found to consistently outperform typical participants in identifying hidden figures in complex scenes and in classic visual search paradigms (Jolliffe & Baron-Cohen, 1997; Plaisted, O'Riordan, & Baron-Cohen, 1998). A second prominent theory posits that due to their "enhanced perceptual function", autistic people are by default locally-oriented and hence tend to outperform typical participants in static, low-level visual discrimination tasks (Mottron et al., 2006). In line with this, autistic people have been found to show enhanced discrimination of novel, highly similar stimuli (Plaisted, O'Riordan, & Baron-Cohen, 1998), and greater perceptual load capacity during processing of distractors (Remington et al., 2009). Our findings of an autism advantage in scene discrimination during "mismatch" trials are broadly consistent with these theories.

Notably, our results suggest that the superior task performance by autistic participants in the "mismatch" conditions is independent of working memory differences. Autistic participants outperformed typical participants on our visual scene discrimination tasks *despite* scoring comparatively lower on verbal working memory abilities (*Supplementary Fig. 1*) and showing no significant group differences on visuospatial working memory (*Supplementary Fig. 2*). As reward plays a role in visuospatial experiments by rapidly enhancing visual perception, there may also be a motivational component associated with task performance (Cheng et al., 2021). Autistic individuals are hypothesised to have a heightened drive to "systemise" or to identify *if-and-then* patterns or rules (Baron-Cohen et al., 2003, 2009). An increased drive to "systemise" - coupled with the comfort of completing the experiments online while in a familiar environment - may have also contributed to the superior performance of our autistic participants.

While a strength of this online study is the sufficiently large sample size, our study also has its limitations: the less-controlled nature of our online experiments, the sampling bias of participants with access to computers and internet, and the unbalanced sex ratio within our study sample. A greater percentage of female participants reflects what is the norm with online research (Smith, 2009). However, due to possible sex differences in autism and visual cognition, we acknowledge this as an important caveat. To account for the unbalanced sex ratio, we computed exploratory summary statistics for a female-only subset of participants and found the direction of results to be unchanged to those of our main results (*Supplementary Figs. 3 & 4*). These results suggest that our findings are independent of sex.

In conclusion, when compared to typical people, autistic individuals are, on average, more accurate at identifying subtle differences between two similar scenes. On the other hand, autistic individuals may be worse at making perceptual judgements about two identical images. Taken together, our findings are consistent with classic and current theories of autistic perception.

Declarations

Data availability:

The raw datasets generated and/or analysed during the current study are not publicly available as volunteers in the Cambridge Autism Research Database (CARD) did not consent for their data to be deposited in an Open Access archive. However, the CARD Management Committee considers requests by researchers for specific parts of the database (in anonymised form) to test specific hypotheses (please contact: research@autismresearchcentre.com).

Code availability:

All the analyses scripts are publicly shared and can be accessed here: https://github.com/naziajassim/visual_scene

Author contributions:

N.J: Conceptualization, Investigation, Formal analysis, Writing- Original Draft, Writing- Review & Editing; A.M.O: Conceptualization, Resources, Funding acquisition, Writing – Review & Editing; P.S: Resources, Project administration, Data curation; J.S: Supervision, Writing- Review & Editing; R.P.L: Supervision, Writing - Review & Editing, S.B.C: Conceptualization, Supervision, Funding acquisition, Writing – Review & Editing; O.E.P: Conceptualization, Data curation, Investigation, Supervision, Writing – Review & Editing

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Conflicts of Interest

The cognitive tests used in this study are marketed by Cambridge Brain Sciences Inc., of which AMO is the unpaid Chief Scientific Officer. Under the terms of the existing licensing agreement, AMO and his collaborators are free to use the platform at no cost for their scientific studies and such research projects neither contribute to, nor are influenced by, the activities of the company. As such, there is no overlap between the current study and the activities of Cambridge Brain Sciences Inc., nor was there any cost to the authors, funding bodies or participants who were involved in the study.

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Figures

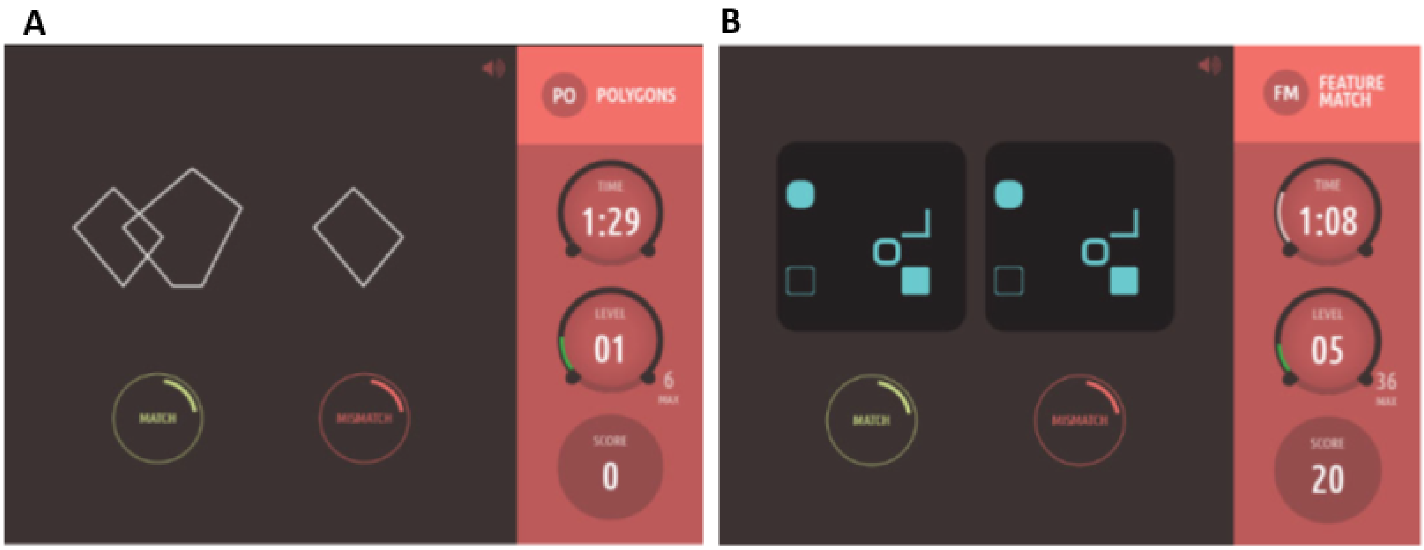

Figure 1

Overview of Cambridge Brain Sciences visual perception experiments. A) Experiment 1 : Interlocking Polygons. B) Experiment 2: Feature Match. Participants were instructed to indicate whether a scene displayed on the other side of the screen is identical (“match”) or not identical (“mismatch”) to the other scene. Participants were given 90 seconds to complete as many trials as possible, with a timer and the score displayed on one side of the screen.

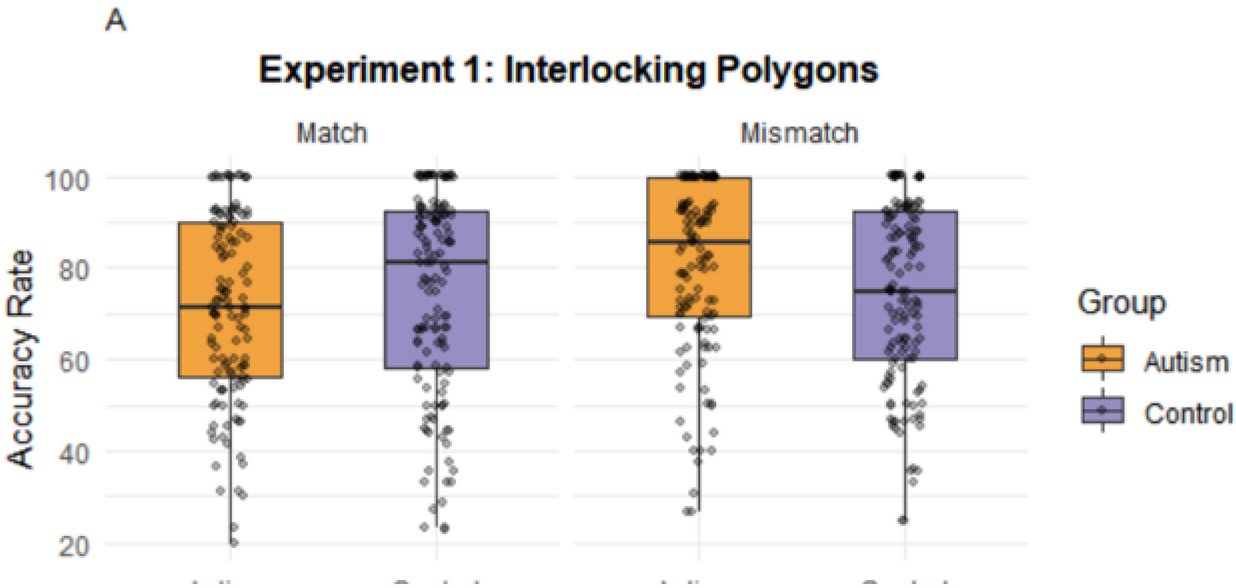

Figure 2

Results from Experiment 1: Interlocking Polygons. 2A. Mean accuracy rates for autism (in orange) and control (purple), split by condition. Dots indicate individual participant means. Error bars show the standard error of the mean. 2B. Interaction effect between group (Autism- orange, Control- purple) and condition (x axis) on accuracy rates (y axis). Error bars show the standard error of the mean.

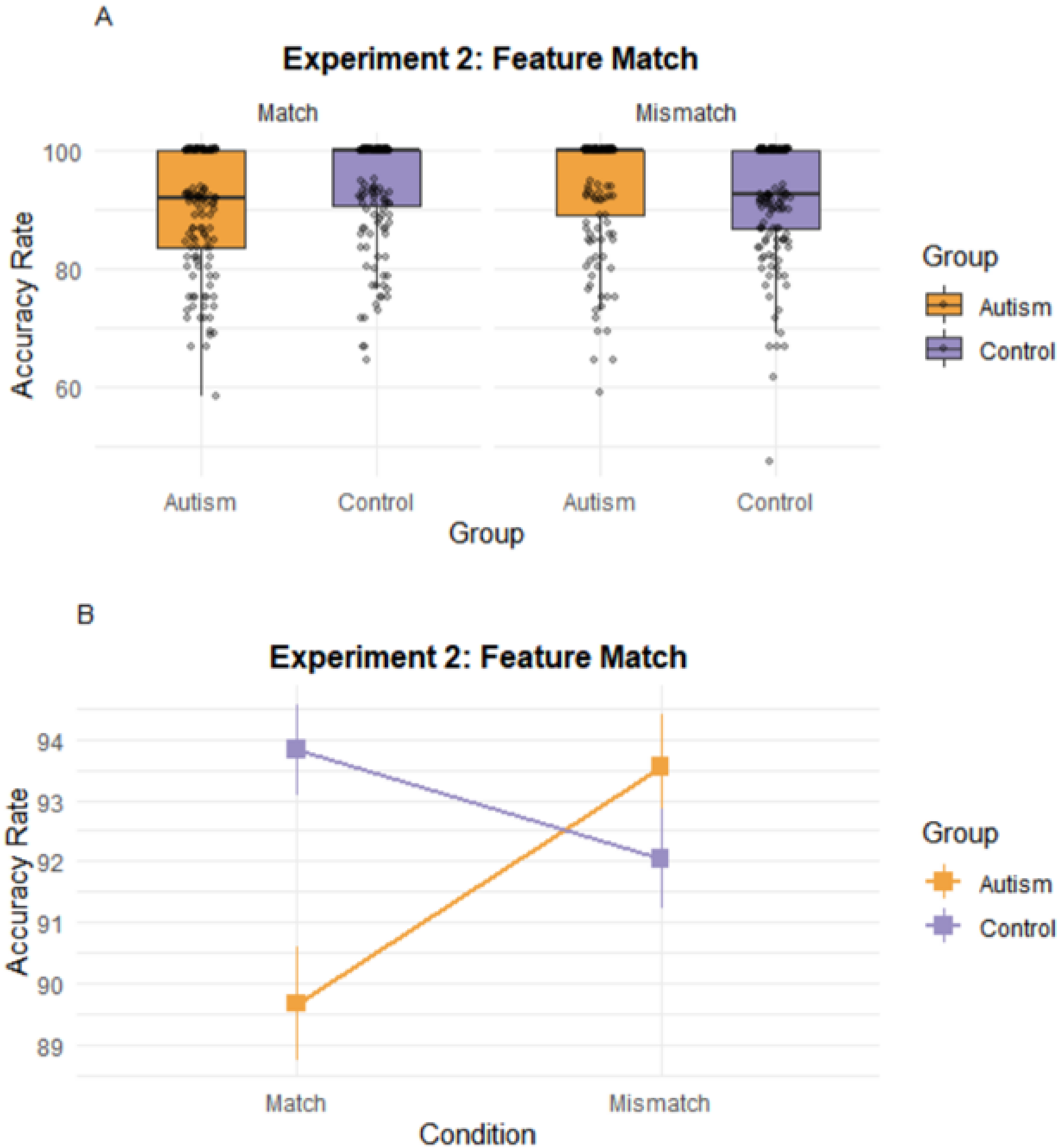

Figure 3

Results from Experiment 2: Feature Match. 3A. Mean accuracy rates for autism (in orange) and control (purple), split by condition. Dots indicate individual participant means. Error bars show the standard error of the mean. 3B. Interaction effect between group (Autism- orange, Control- purple) and condition (x axis) on accuracy rates (y axis). Error bars show the standard error of the mean.

Supplementary Files

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