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Binocular rivalry dynamics associated with high levels of self-reported autistic traits suggest an imbalance of cortical excitation and inhibition

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Abstract

An imbalance in cortical excitation and inhibition (E/I) may underlie both social and non-social symptoms of autism spectrum conditions (ASC). Recent work suggests that an E/I imbalance may underlie some of the sensory differences that are characteristic of ASCs such as anomalous perception. Binocular rivalry dynamics are thought to reflect the balance of E/I in the brain and could serve as a behavioural biomarker for ASC. Previous studies of clinical ASC populations have found a slower rate of binocular rivalry transitions; increased duration of the mixed percept and reduced perceptual suppression. There are some mixed reports of altered rivalry dynamics in the neurotypical population with high self-reported levels of autistic traits. Therefore, we used simple grating stimuli to measure binocular rivalry dynamics in a sample of seventy-nine adults aged 18 - 55 years. We additionally measured the level of autistic traits with the AQ-10 and used CAPS as a measure of anomalous perception. Bayesian correlations showed that those with higher AQ scores had a slower rate of perceptual switching and a longer mixed percept duration. Significant regression models with CAPS and AQ score revealed that AQ score was a significant predictor of switch rate and mixed percept duration, whereas CAPS was not. We also report that CAPS significantly predicted perceptual suppression, whereas AQ score did not. Overall, our findings suggest that in a non-clinical population, autistic traits are a predictor of binocular rivalry dynamics and the cortical E/I imbalance thought to underlie symptoms of ASC may extend to the broader phenotype.

Keywords: Autism spectrum; Autistic traits; Binocular rivalry; Cortical inhibition; Cortical excitation; Behavioural biomarker

1. Introduction

Sensory processing differences are prevalent in autism spectrum conditions (ASC) (Robertson & Baron-Cohen, 2017) and these sensory differences found in ASC often extend to neurotypical samples with high levels of self-reported autistic traits (Jackson et al., 2013). The unique variance of atypical sensory processing in ASC results in some degree of anomalous perception in those on the spectrum (Horder, Wilson, Mendez & Murphy, 2015). Multiple lines of evidence suggest that neurobiological differences in the balance of cortical excitation and inhibition (E/I) may be a mechanism underlying sensory differences and anomalous perception in ASC (Gao & Penzes, 2015). Such atypical neural microcircuitry could lead to the primary behavioural symptoms of ASC (Yizhar et al., 2011; Dakin & Frith, 2005).

In neurotypical populations, an imbalance of cortical excitability has been associated with greater levels of anomalous perception, measured by the Cardiff Anomalous Perception scale (CAPS) (Braithwaite, Mevorach & Takashi, 2015). The CAPS is a 32-item self-report questionnaire, which asks participants whether they have experienced a range of anomalous perceptions; example questions are "do you ever see shapes, lights colours, even though there is nothing really there?" and "do you ever find that sensations happen all at once and flood you with information?". Scores on the CAPS have been found to be significantly correlated with autistic traits in the general population (Horder, Wilson, Mendez & Murphy, 2015) and the use of CAPS has revealed that adults with ASC experience significantly higher levels of anomalous perception (Milne, Dickinson & Smith, 2017) compared to controls. This heightened anomalous perception is thought to be associated with the sensory differences typically shown by those on the autism spectrum (Milne, Dickinson & Smith, 2017) and is likely to arise from a common neural mechanism, which is increasingly thought to be an E/I imbalance (Gao & Penzes, 2015).

An E/I imbalance can occur, either due to potentiation of glutamatergic excitation or weakened GABAergic inhibition (Treiman, 2001; Rubenstein & Merzenich, 2003). An E/I imbalance can cause neurons to fire inappropriately and this is a known causal factor in clinical conditions such as epilepsy where the incidence of anomalous perception is significantly higher than in the neurotypical population (Treiman, 2001; Gloor, 1990). Indeed, there is a high level of co-morbidity between ASC and epilepsy (Lukmanji et al., 2019). Although it is possible to measure GABA concentration in humans with magnetic resonance spectroscopy (MRS), findings are often equivocal and dependent on the scan sequence used (Edden, Muthukumaraswamy, Freeman & Singh, 2009; Cousijn et al., 2014). As such, psychophysical task performance is often used as an alternative way to infer cortical E/I balance. A further advantage is that psychophysical task performance allows demonstrations of E/I balance changes that have functional relevance. For instance, binocular rivalry, a psychophysical task with a clear link to cortical E/I balance, has previously been used to provide an indirect inference of the level of excitation and inhibition in the brain (Leonard et al. 2001; Miller et al. 2003; Pettigrew & Miller, 1998, Robertson et al., 2013, 2016; Said et al., 2013; Freyberg et al., 2015; Mentch, Spiegel, Ricciardi & Robertson, 2019).

During binocular rivalry tasks, discrepant monocular images are presented to the right and left eyes. Prism glasses or an array of mirrors overlay the images in retinotopic space such that the two images compete for perceptual dominance, leading to a percept which switches between the right and left image as one image is suppressed while another is in awareness; or a mixed percept can be perceived which combines both images (e.g. Levelt, 1965). The rate of switching between the left and right image varies between viewers, with some people experiencing rapid transition from one image to the other, and others experiencing slower transition and a longer time perceiving the mixed percept. Such rivalry dynamics are considered to reflect relative levels of cortical excitation and inhibition (Laing and Chow, 2002; Wilson, 2003) in area V1 in the primary visual cortex, where rivalry is thought to occur (Wilson, 2007). Cortical inhibition via the inhibitory neurotransmitter GABA, mediates the activity-dependent development of ocular dominance columns in the primary visual striate cortex (Toyoizumi & Miller, 2009; Turrigiano et al., 1998). Ocular dominance columns, once developed, respond preferentially to input from one eye or the other (Hubel et al., 1977) via interocular suppression. That is, when one eye receives dominant visual input, reciprocal inhibitory interactions suppress activity in the corresponding retinal location of the other eye (Blake, 1989; Wolfe, 1986). Specifically, studies have shown that binocular rivalry dynamics appear to be influenced by increased excitatory or inhibitory neuronal connections between the ocular dominance columns (Dayan, 1998; Klink et al., 2010; Said et al., 2013). Said et al., (2013) conclude from a simulation model that either low levels of cortical inhibition or low cortical excitation would cause an increase in mixed perception.

An underlying difference in the balance of cortical excitation and inhibition may lead to the higher rates of anomalous perception in ASC (Gao & Penzes, 2015) and several studies have investigated binocular rivalry in ASC. Said et al., (2013) did not find that binocular rivalry dynamics were any different in those with an ASC, compared to neurotypical controls. However, the vast amount of this literature reveals consistent differences of binocular rivalry dynamics in ASC, using multiple stimulus types, across different sample cohorts.

Robertson et al., (2013) and Robertson et al., (2016) both utilised object stimuli to compare binocular rivalry dynamics in adults with and without ASC. In both studies, the ASC groups showed slower switch rates, associated with higher rates of reversions and increased time spent perceiving the mixed percept. In addition, Robertson et al., (2016) reported a reduced period of perceptual suppression in those with ASC, which indicates reduced GABAergic signalling in this group (Mentch, Spiegel, Ricciardi & Roberston (2019). Spiegel, Mentch, Haskins and Robertson (2019) and Freyberg et al., (2015) replicated slower switch rates in participants with ASC, using grating stimuli.

With the recognition of ASC as a spectrum condition, with 3 levels of symptom severity (American Psychiatric Association, 2013), it has become standard to investigate cognitive and behavioural correlates of ASC using a continuous measure of autistic traits. This method has a further advantage of avoiding the complexities surrounding ASC diagnosis. Therefore, work has sought to extend knowledge of binocular rivalry dynamics to those with no diagnosis of an ASC, who exist on the broader ASC phenotype and report high levels of autistic traits. Autistic traits are measured using a questionnaire developed for use in the clinical and neurotypical population (Baron-Cohen et al., 2001). Wykes, Hugrass and Crewther, (2018) measured the association of rivalry dynamics and AQ scores in a neurotypical sample and found a weak negative correlation between autistic traits and switch rates, when grating stimuli were presented centrally. However, there was no relationship between autistic traits and switch rates when stimuli were peripheral (Wykes, Hugrass & Crewther, 2018). Furthermore, the authors reported no relationship between autistic traits and reversion rates in either central or peripheral stimuli (Wykes, Hugrass & Crewther, 2018). Wykes, Hugrass and Crewther (2018) suggest that overall; their results do not provide evidence that autistic traits account for a substantial percentage of variation in altered binocular rivalry dynamics. In addition to this work, Robertson et al., (2013), reported a slower switch rate in those with an ASC, however, switch rate did not correlate with autistic traits in either the clinical or the neurotypical population.

Results of studies investigating binocular rivalry and autistic traits are so far equivocal; this study will investigate further whilst also collecting data on rates of anomalous perception. Using simple grating stimuli, we designed a binocular rivalry paradigm to investigate whether autistic traits in a neurotypical population account for a significant percentage of individual variation in binocular rivalry dynamics. Based on the literature suggesting that anomalous perception arises from an imbalance of cortical E/I, we aimed to investigate whether anomalous perception, as measured by CAPS, accounts for individual variation in binocular rivalry dynamics.

2. Material and methods

2.1 Participants

Participants were student and staff volunteers from The University of Sheffield in the UK. Seventy-nine participants aged between 18 and 55 years were initially recruited to the study. Participants were excluded if they reported being a recreational drug user (N = 6), were diagnosed with epilepsy (N = 0), experienced migraines (N = 7) or made only one response per trial and therefore appeared to misunderstand the task-instructions (N = 5), leaving a sample of 61 participants. Twelve of the final participants reported the use of antidepressant or antianxiety medication. These participants were not excluded from the main analysis, however, the data are shown with these participants included and then excluded (see section 3.2.5). The mean age of the retained participants was 23 years (S.D. = 7.0). Forty-nine participants were female and twelve were male. All participants had either normal vision, or were able to wear contact lenses if correction to their vision was required. Participants received course-credit, or £5, as a gesture of thanks for their time. Ethical approval was obtained from the University of Sheffield, Department of Psychology ethics committee. Participants provided informed written consent, in accordance with the declaration of Helsinki.

2.2 Materials

All of the questionnaires were presented on the online survey tool Qualtrics (Qualtrics, 2005). The participants completed demographic questions, which included questions on age, gender, current medication and recreational drug use and the following inventories.

2.2.1 CAPS

The Cardiff Anomalous Perceptions Scale (CAPS) (Bell, Halligan & Ellis, 2006) measures anomalous perception and was designed for use in a non-clinical population. It includes 32 items which describe anomalous perceptual experiences across the sense-modalities and participants are asked to indicate via a “yes” or “no” response whether they have experienced each item. Potential scores on the item therefore range from 0 to 32. The CAPS also includes questions that ask participants to rate how frequent, distressing or and intrusive experience is, although as we were primarily interested in the extent to which each participants experienced anomalous perceptions we did not administer this part of the scale.

2.2.2 AQ-10

The Autism Quotient - 10 (AQ-10, also known as AQ-S) is a 10-item questionnaire which measures the degree to which adults report traits associated with the core autistic phenotype (Allison, Auyeung & Baron-Cohen, 2012). This scale is a shortened version of the 50-item Autism Quotient, which has been found to be as successful as the full AQ at discriminating between those with and without a clinical diagnosis of ASC (Booth et al., 2013). Booth et al., (2013) suggest that a score above 6 on the AQ-10 would be indicative of the need to undertake a full clinical diagnostic assessment. Lundin, Kosidou and Dalman (2019) report a normal distribution of AQ-10 scores in a general population sample of 44,722; the AQ-10 also correlated positively with ADHD traits, psychological distress and education in sciences, further adding to the validity of the scale. Each of the 10 items scores 0 or 1, which 1 being indicative of a response associated with an autistic-like trait. Thus, the maximum score - indicative of a high level of autistic traits - is 10.

2.2.3 Binocular rivalry

The binocular rivalry paradigm was based on two studies, one in which binocular rivalry was used to measure cortical hyper-excitability in migraine (Wilkinson, Karanovic and Wilson, 2008), and another which used binocular rivalry in association with autism (Freyberg, Robertson & Baron-Cohen, 2015). Freyberg, Robertson and Baron-Cohen (2015) reported that grating stimuli showed the most significant difference between those with ASC and controls, therefore we used the same grating stimuli for our study. Stimuli were presented on a 15-inch LCD screen at a distance of 50cm, and consisted of two black and white sinewave gratings with a spatial frequency of 3 cpd. Each grating had a diameter of 4.5 cm, the grating presented on the left of the screen was rotated 135° from horizontal and the grating on the right was rotated 45° from horizontal. The background was isoluminant (grey). To provide stable vergence cues, a black fixation dot was set in the centre of each stimulus and the stimuli were enclosed by a black rectangle. Stimuli were presented using PsychoPy (Python) (Peirce, 2007), and data were processed using custom scripts written in Python.

Head position was maintained using a chin rest. To further ensure that the image on the left side of the computer screen was presented to the left eye, and the image on the right side of the screen was presented to the right eye, a thin board was placed in the midline between the participant's nose and the computer screen. Prism glasses were worn to overlay the two images in retinotopic space.

Participants used the computer keyboard to indicate which percept they were experiencing (see procedure below). The timings of key presses throughout each trial were used to calculate a sequence of perceptual transitions. Perceptual transitions during binocular rivalry can be either be 'switches' which are when the percept changes from one dominant percept to the other, with or without an intermediate mixed percept; or 'reversions' which is when the percept changes from a dominant percept to a mixed percept, but then returns again to the original percept (Freyburg et al., 2015). The total number of transitions and reversions were calculated and averaged across all included trials; the final transition and reversion values are expressed as number of transitions per 40 seconds. The mean time spent on the dominant percept and the mean time spent on the mixed percept were calculated and the proportion of perceptual suppression, expressed as the amount of time spent viewing a dominant percept was calculated as (dominant percept/(dominant + mixed percept).

2.3 Procedure

The binocular rivalry paradigm comprised of two runs, the first set of trials comprising one practice and seven experimental trials and the second set comprising seven experimental trials. After consenting and completing the demographics questionnaire, participants completed the first set of binocular rivalry trials. Participants were given time to become accustomed to wearing the prism glasses and experience fusion prior to beginning the experimental trials, fusion was achieved once the participant reported seeing one circular grating. Following the report of fusion, participants were given instruction and practice with the task where there was not a minimum number of trials but participants could complete up to 10 practice trials. All participants used their right hand and were instructed to indicate their percept by pressing the left arrow key when they saw the left image, the right arrow key when they saw the right image and the up arrow key when they saw the mixed percept - a plaid (see Figure 1). Each trial lasted for a total of 1 min 15 s and consisted of 5s preparation period; 10s of fixation points; 40s of gratings; and a 20-second break before the start of the next trial. The second set of trials were administered after a delay of approximately 15 min, during which time participants completed the AQ-10 and the CAPS.

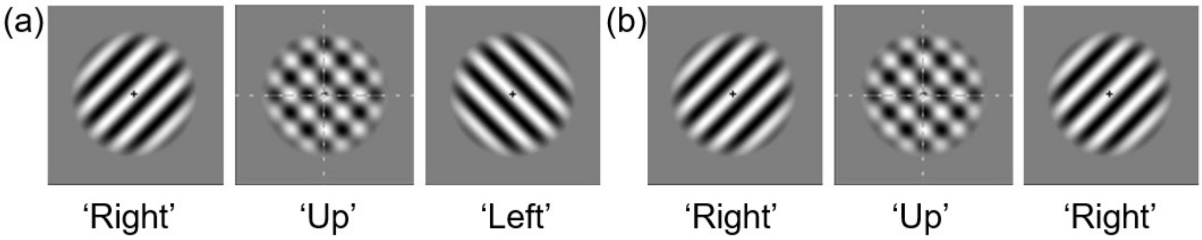


Figure 1. Sample sequence of binocular rivalry transitions showing the required keyboard arrow response. (a) Sample sequence of switches and (b) sample sequence of reversions.

The associations between the inventories and binocular rivalry dynamics were examined.

3. Results

3.1 AQ-10 & CAPS

The mean AQ-10 score was 2, (SD = 2), (range = 0-7), which is similar to the mean AQ-10 score of 2.5 reported by Lundin, Kosidou and Dalman (2019) in a neurotypical sample. The mean CAPS score was 7, (SD = 5), (range = 0-25) which is similar to the mean CAPS score of 7.3 reported by Bell, Halligan & Ellis, (2006) in a neurotypical sample. In line with Horder et al., (2015), there was a positive correlation between AQ and CAPS scores (r (61) = .36, $p < .05$, $BF_{10} = 7.2$).

3.2 Binocular rivalry

Five participants were excluded from final analyses because their percept duration data was identified as lying more than 2 SDs from the mean. Two participants had an outlying mixed duration, and three participants had an outlying dominant duration. This resulted in a final analysed sample of 56. Individual trials were excluded if there was no button press or if there was a single button press for the duration of the trial as these indicate that the trial was not completed properly, trials were excluded for thirteen participants. The mean number of trials excluded was 1.7; the minimum and maximum number of trials excluded were 1 and 4 respectively. The variables were averages calculated from a maximum of 14, 40-second trials.

The mean number of switches was 11.9 per 40 seconds, (SD = 4.6), (range = 2.6 - 23.9). The mean number of reversions was 1.1 per 40 seconds, (SD = 0.8), (range = 0 – 5). The mean time spent on a dominant percept was 2.8 seconds, (SD = 1.3), (range = 1.2 – 7.0) and the mean time spent on the mixed percept was 2.9 seconds, (SD = 1.5), (range = 0.1 – 6.9). The switch rate in this study is similar to the mean switch rate reported by Freyberg, Robertson & Baron-Cohen (2015) who reported a switch rate of 11.1 per 40 seconds in a neurotypical sample, using similar grating stimuli to the present study.

3.2.1 Binocular rivalry correlations

Mean number of switches did not correlate with the mean number of reversions (*r* (56) = .25, p = .06, BF_{10} = 0.9). Mean number of switches was negatively correlated with the mean time spent perceiving the dominant percept (*r* (56) = -.74, p = <.001, BF_{10} = 6.9) and mixed percept (*r* (56) = -.70, p = <.001, BF_{10} = 6.9), where those who made more switches, spent less time perceiving the dominant percept. Mean reversions were negatively correlated with time spent on the dominant percept (*r* (56) = -.35, p = <.05, BF_{10} = 5.6), where those who spent less time on the dominant percept made fewer reversions.

Mean number of switches was significantly associated with AQ-10 score (*r* (56) = -.34, p = <.05, BF_{10} = 3.7), where those with a higher AQ score made significantly fewer switches (see Figure 3). However, the mean number of switches was not associated with CAPS score (*r* (56) = -.12, p = .36, BF_{10} = 0.3). Mean time (seconds) spent on the mixed percept was significantly positively correlated with AQ-10 (*r* (56) = .41, p = <.05, BF_{10} = 18.5) where those with higher scores spent significantly more time perceiving the mixed percept (see Figure 3). Time spent on the mixed percept was significantly associated with CAPS score (*r* (56) = .28, p = .04, BF_{10} = 1.4), though the *r* value and Bayes factor suggest that this correlation was weak. Mean time spent on the dominant percept did not correlate with AQ-10 (*r* (56) = .26, p = .05, BF_{10} = 1.1) or CAPS score (*r* (56) = -.05, p = .71, BF_{10} = 0.2). The mean number of reversions was not associated with AQ-10, (*r* (56) = -.01, p = .94, $BF_{10} = 0.2$) or CAPS score (*r* (54) = -.02, p = .88, $BF_{10} = 0.2$).

3.2.2 Perceptual switching

A multiple regression was run to predict perceptual switching rates from AQ and CAPS scores. The multiple regression model statistically significantly predicted switching rates, $F(2, 55) = 3.4$, $p = .04$, adj. $R^2 = .08$. AQ score added statistically significantly to the prediction, $p = .02$. However, CAPS score did not significantly predict transitions, $p = .92$. Regression coefficients and standard errors can be found in Table 1. Figure 2 shows a scatterplot of switch rates and AQ score.

Table 1. *Summary of multiple regression analysis for switching rates*

	B	*SE B*	*β*
Intercept	14.0	1.2	
AQ	-1.0	0.41	-0.33*
CAPS	-0.00	0.13	0.00

Note. * $p < .05$

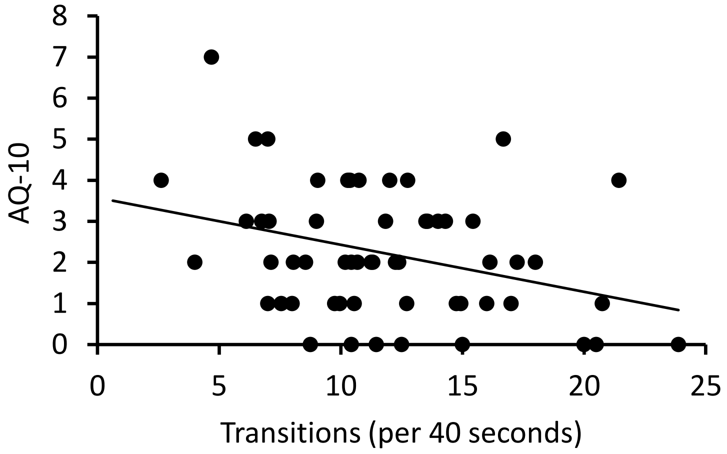


Figure 2. Scatterplot of perceptual switching rate (transitions) vs AQ score

3.2.3 Reversions

A multiple regression was run to predict reversions from AQ and CAPS scores. The multiple regression model did not predict reversion rates, $F(2, 55) = .003$, $p = .99$, adj. $R^2 = .00$. Regression coefficients and standard errors can be found in Table 2.

Table 2. *Summary of multiple regression analysis for reversions*

	B	*SE B*	*β*
Intercept	1.1	0.22	
AQ	-0.02	0.08	-0.02
CAPS	0.01	0.02	-0.03

3.2.4 Time spent on dominant and mixed percept

A multiple regression was run to predict mean time spent perceiving the dominant percept from AQ and CAPS scores. The multiple regression model did not predict mean time spent on the dominant percept, $F(2, 55) = 2.0$, $p = .14$, adj. $R^2 = .04$. Regression coefficients and standard errors can be found in Table 3.

Table 3. *Summary of multiple regression analysis for dominant percept*

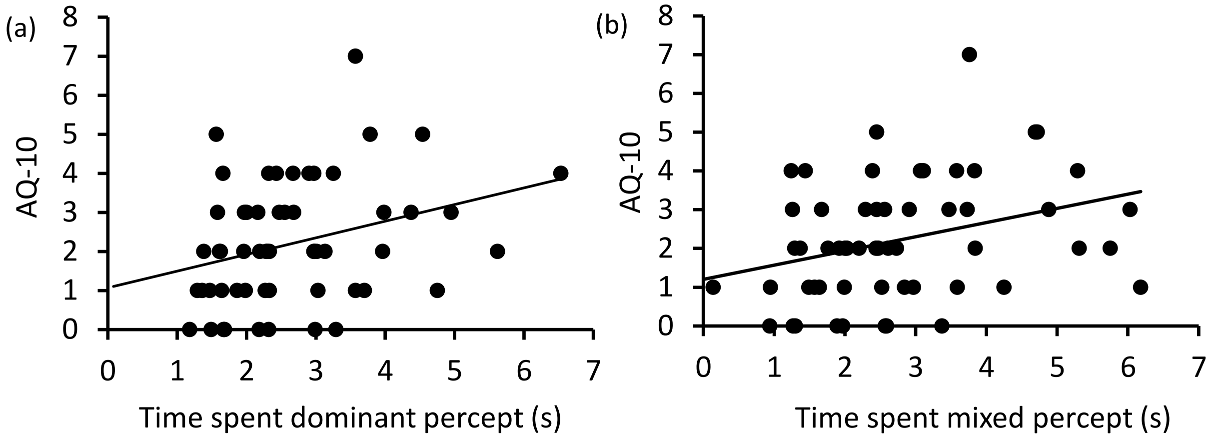
	B	*SE B*	*β*
Intercept	2.4	0.33	
AQ	0.23	0.12	0.26
CAPS	-0.01	0.04	-0.52

A multiple regression was run to predict mean time spent perceiving the mixed percept, from AQ and CAPS scores. The multiple regression model significantly predicted mean time spent on the mixed percept, $F(2, 55) = 7.3$, $p = .004$, adj. $R^2 = .15$. AQ score added significantly to the prediction, $p = .011$. However, CAPS score did not significantly predict transitions, $p = .26$. Regression coefficients and standard errors can be found in Table 4. Figure 3 shows a scatterplot of time spent on each percept and AQ score.

Table 4. *Summary of multiple regression analysis for mixed percept*

	B	*SE B*	*β*
Intercept	1.85	0.37	
AQ	0.34	0.13	0.35*
CAPS	0.48	0.04	0.15

Note. * $p < .05$



Note. * $p < .05$

Figure 3. Scatterplot of time spent on the dominant (a) and mixed (b) percept vs AQ score.

3.2.5 Proportion of perceptual suppression

A multiple regression was run to predict the proportion of perceptual suppression, from AQ and CAPS scores. The multiple regression model significantly predicted the perceptual suppression score, $F(2, 55) = 3.5$, $p = .04$, adj. $R^2 = .08$. CAPS score significantly predicted proportion of perceptual suppression, $p = .04$, however, AQ score did not add significantly to the model, $p = .46$. (Table 5 shows the regression coefficients and standard errors). (Figure 4 shows scatterplots of perceptual suppression, AQ and CAPS score).

Table 5. *Summary of multiple regression analysis for perceptual suppression*

	B	*SE B*	*β*
Intercept	0.60	0.30	
AQ	-.010	0.10	-0.10
CAPS	-.010	0.00	-0.29*

Note. * $p < .05$

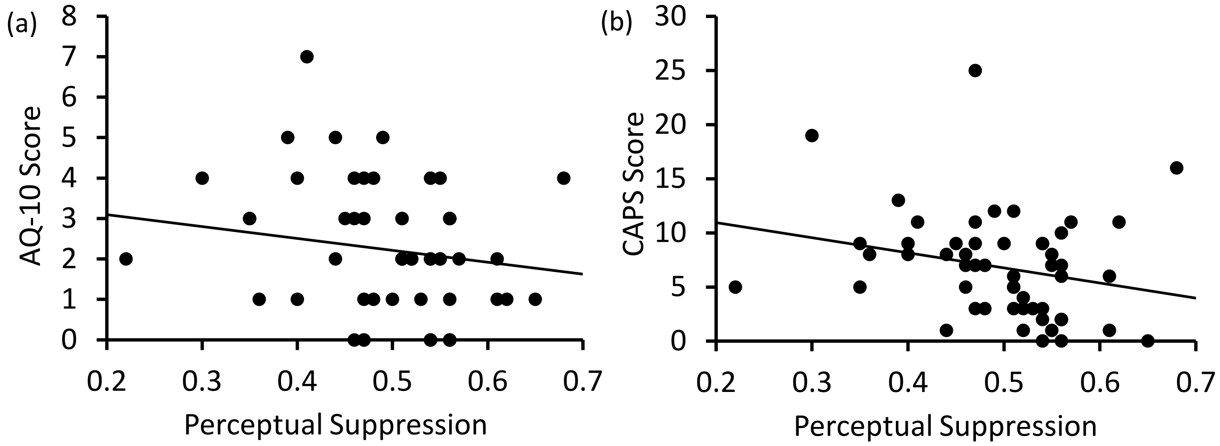


Figure 4. Scatterplot of the proportion of perceptual suppression vs (a) AQ-10 score and (b) CAPS score

3.2.6 Age and binocular rivalry

Age was included as a predictor for the models that were significant in the main analyses as age has been shown to affect switching rate (Ukai, Ando & Kuze, 2003). The results did not differ considerably when age was included.

3.2.6.1 Perceptual switching

A multiple regression was run to predict perceptual switching rates from AQ and CAPS scores and age. The multiple regression model was not significant, *F*(2, 55) = 2.2, *p* = .10, adj. R^2 = .06. AQ score added statistically significantly to the prediction, *p* = .02. However, CAPS score *p* = .99 and age, *p* = .94 did not significantly predict transitions.

3.2.6.2 Mixed percept duration

A multiple regression was run to predict time spent on the mixed percept from AQ and CAPS scores and age. The multiple regression model was significant, *F*(2, 55) = 4.0, *p* = .01, adj. R^2 = .14. AQ score added statistically significantly to the prediction, *p* = .02. However, CAPS score *p* = .26 and age, *p* = .73 did not significantly predict mixed percept duration.

3.2.6.3 Perceptual suppression

A multiple regression was run to predict perceptual switching rates from AQ and CAPS scores and age. The multiple regression model was not significant, *F*(2, 55) = 2.5, *p* = .07, adj.

R^2 = .8. CAPS score added statistically significantly to the prediction, p = .04. However, AQ score p = .56 and age, p = .43 did not significantly predict transitions,.

3.2.7 Analyses with medicated participants excluded

The results did not considerably differ when those who reported the use of depression or antianxiety medication were excluded from the analysis.

3.2.7.1 Perceptual switching

A multiple regression was carried out to predict perceptual switching rates from AQ and CAPS scores. The multiple regression model was significant, $F(2, 46)$ = 3.9, p = <.05, adj. R^2 = .11. AQ score added statistically significantly to the prediction, p = .01. However, CAPS score did not significantly predict transitions, p = .79.

3.2.7.2 Reversions

A multiple regression was run to predict reversions from AQ and CAPS scores. The multiple regression model did not predict reversion rates, $F(2, 46)$ = 0.3, p = .78, adj. R^2 = -.03.

3.2.7.3 Dominant and mixed percept

A multiple regression was run to predict mean time spent perceiving the dominant percept from AQ and CAPS scores. The multiple regression model did not predict mean time spent on the dominant percept, $F(2, 46)$ = 2.1, p = .13, adj. R^2 = .05.

A multiple regression was run to predict mean time spent perceiving the mixed percept, from AQ and CAPS scores. The multiple regression model significantly predicted mean time spent on the mixed percept, $F(2, 46)$ = 10.7, p = <.001, adj. R^2 = .30. AQ score added statistically significantly to the prediction, p = .001. However, CAPS score did not significantly predict time spent on the mixed percept, p = .34.

4. Discussion

The aim of this study was to gain further insight into the relationship between binocular rivalry dynamics, autistic traits and anomalous perception in the neurotypical population. An imbalance of cortical E/I may be a mechanism underlying atypical sensory processing and anomalous perception in ASC (Gao & Penzes, 2015) and studies using binocular rivalry have supported this suggestion by showing slower binocular rivalry in ASC (Robertson, Ratai & Kanwisher, 2016; Robertson et al., 2013). We utilised binocular rivalry to extend the investigation of a potential E/I imbalance to the neurotypical population by measuring autistic traits. We recruited neurotypical participants and reported CAPS score, AQ-10 score and binocular rivalry dynamics. CAPS and AQ-10 score predicted switching rates, with AQ-10 score significantly adding to the model. Slower switching was associated with higher levels of autistic traits. In line with this finding, higher levels of autistic traits were associated with a longer duration spent on the mixed percept. We did not find that AQ score predicted reversion rates. We also found that CAPS score significantly predicted the proportion of perceptual suppression, whereas AQ score did not.

This data supports the literature showing slower rate of transitions in the autism spectrum (Spiegel et al., 2019; Freyberg et al., 2015; Robertson, Ratai & Kanwisher, 2016; Robertson et al., 2013). We add to the literature on binocular rivalry in the broader autism spectrum by substantiating the results reported by Wykes, Hugrass and Crewther (2018), where there was a weak relationship between autistic traits and transition rate (BF_{10} = 5.90) in a neurotypical sample, with a sample size smaller than the one reported in the present study. The present study has the advantage of a final analysed sample size of fifty-six, however, there is the limitation that unlike Freyburg et al., 2015 we did not include a control 'non – rivalry' experiment so cannot rule out the possibility that differences in decision criteria or motor latencies may account for observed correlations However, given the previous literature this seems unlikely.

Wilson (2007) summarises models of binocular rivalry, which all suggest that there is strong competitive neuronal inhibition between cortical areas corresponding to the left and right monocular images; eventually the suppression reduces and neurons are released from inhibition, either due to a process of neuronal adaptation or fatigue. Therefore, the atypical dynamics of binocular rivalry observed here in those with high levels of autistic traits and in those with ASC (Robertson et al., 2013) may arise from altered connectivity between neural populations. Though, it must be noted that this is likely to be one part of a complex story and not a singular explanation for anomalous perception in ASC. Due to the reciprocal nature of E/I, we are unable infer a direction from our data; however the literature suggests that there is an excitatory dominant synaptic imbalance in ASC (Rubenstein & Merzenich, 2003; Pizzarelli & Cherubini, 2011), which appears to arise from a reduction in GABA signalling (Chao et al., 2010). This is supported by findings of a reduced proportion of perceptual suppression in ASC (Robertson, Ratai & Kanwisher, 2016) which is associated with reduced GABAergic signalling (Mentch, Spiegel, Ricciardi & Robertson, 2019). Perceptual suppression in binocular rivalry is where one image is entirely suppressed from visual awareness. Reduced perceptual suppression in ASC suggests a lack of interocular inhibition and therefore, a lack of GABAergic activity. This study, however, did not find that AQ score predicted perceptual suppression, which is contradictory to the findings from previous measurements of binocular rivalry in ASC (Robertson, Ratai & Kanwisher, 2016).

Models of binocular rivalry predict that an imbalance in E/I would also lengthen the time spent perceiving the mixed percept (Said et al., 2013), however, it is also possible that neural noise could disrupt perceptual switches and cause mixed percept duration to lengthen (Robertson et al., 2013). Robertson et al., (2013) and Robertson, Ratai & Kanwisher (2016), found that those with an ASC spent more time on the mixed percept with the use of object stimuli. Additionally, Said et al., (2013) reported longer mixed percept duration in ASC with the use of gratings. However, so far, this finding has not been extended to those with high levels of autistic traits; both Robertson et al., (2013) and Wykes, Hugrass and Crewther (2018) reported that autistic traits did not correlate with mixed percept duration. Here we used grating stimuli and report longer time spent on the mixed percept in those with higher levels of autistic traits; this finding may reflect a subclinical E/I imbalance in the neurotypical population who report high levels of autistic traits.

Robertson et al., (2013) and Robertson, Ratai & Kanwisher (2016) found that the longer time spent on the mixed percept by those with an ASC was associated with a disproportionate return to the previous percept (reversion). Reversions are a less explored characteristic of binocular rivalry and are thought to occur as a result of neural noise (Robertson et al., 2013). However, our finding that AQ score did not predict reversions is in line with Wykes, Hugrass and Crewther, (2018), who reported no relationship between rates of reversion and an AQ score. Therefore, the present study reports that while those with higher levels of autistic traits had fewer perceptual transitions and longer duration of mixed percept, they had no greater tendency to revert from the mixed percept back to the previous percept.

A specific characteristic of ASC that may arise from an E/I imbalance is anomalous perception, e.g. hallucinations (Milne, Dickinson & Smith, 2017). Therefore, we predicted that a measure of anomalous perception, CAPS, would also relate to binocular rivalry dynamics. However, CAPS score did not predict switching or reversion rates or time spent on the mixed or dominant percept. Milne, Dunn, Zhao and Jones (2018) recently reported no difference in the frequency of gamma-band EEG responses in a non-clinical sample of those who report hallucinatory experiences. Differences in the frequency of the visual induced gamma-band response are thought to be indicative of variation in the balance of neural excitation and inhibition (Snijders, Milivojevic & Kemner, 2013). Thus, anomalous perception may not arise from significantly altered balance between cortical E/I. Contrarily; the present study did find that a higher CAPS score was associated with reduced perceptual suppression. This means that those who reported higher CAPS scores showed less tendency to fully suppress one image from visual awareness. This infers reduced GABAergic transmission (Mentch, Spiegel, Ricciardi & Robertson, 2019; Robertson, Ratai & Kanwisher, 2016) in those who reported that they experience higher levels of anomalous perception.

In the present study, higher levels of autistic traits were associated with reduced switching rate and longer time spent on the mixed percept during a binocular rivalry task. AQ score did not predict proportion of perceptual suppression. CAPS score did not predict any binocular rivalry dynamics; however, CAPS score did predict reduced perceptual suppression. This data suggests that anomalous perception per se, may not be the result of a significant imbalance in E/I, whereas manifestations of visual processing disturbances in the autism spectrum may be the result of an E/I imbalance. The literature is not yet able to clearly define the direction of this imbalance and this study does not support the idea that there is reduced GABAergic signalling driving an E/I imbalance in the autism spectrum, specifically in a neurotypical population reporting higher levels of autistic traits. Overall, this study suggests that a cortical E/I imbalance extends to the broader ASC phenotype and future work should aim to be more conclusive regarding the direction of an imbalance. Overall, the differences in binocular rivalry dynamics reported here suggest that there is a common disruption in neural signalling in the autism spectrum. Finally, despite visual problems in ASC being secondary in importance to the social symptoms of ASC, the visual system remains a valuable target for the investigation of neural circuitry in ASC.

4.1 Conclusions

In conclusion, we report slower rate of perceptual switching and a longer time spent on the mixed percept in those with higher levels of autistic traits. These altered binocular rivalry dynamics support the suggestion of an imbalance of cortical excitation and inhibition in the autism spectrum, and we extend this to a non-clinical population of those who report high levels of autistic traits. These results support theories of altered neural circuitry at fundamental visual levels in the autism spectrum. However, we did find that autistic traits did not predict the proportion of perceptual suppression, which is contradictory to the existing literature and our predictions. Overall, these data support the notion that clinical and sub-clinical manifestations of visual disturbances in the autism spectrum may be the result of altered cortical dynamics.

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