Article:

Dickinson, A., Jones, M. and Milne, E. orcid.org/0000-0003-0127-0718 (2014) Oblique Orientation Discrimination Thresholds Are Superior in Those with a High Level of Autistic Traits. Journal of Autism and Developmental Disorders, 44 (11). pp. 2844-2850. ISSN 0162-3257

https://doi.org/10.1007/s10803-014-2147-1

Abstract

Enhanced low-level perception, although present in individuals with autism, is not seen in individuals with high, but non-clinical, levels of autistic traits (Brock et al., 2011). This is surprising, as many of the higher-level visual differences found in autism have been shown to correlate with autistic traits in non-clinical samples. Here we measure vertical-oblique and, more difficult, oblique-oblique orientation discrimination thresholds in a non-clinical sample. As predicted, oblique-oblique thresholds provided a more sensitive test of orientation discrimination, and were negatively related to autistic traits ($N=94$, $r= -.356$, $p <.0001$). We conclude that individual differences in orientation discrimination and autistic traits are related, and suggest that both of these factors could be mediated by increased levels of the inhibitory neurotransmitter GABA.

In addition to impairments in social interaction and communication exhibited by individuals with autism spectrum disorders (ASD), atypical sensory perception has long been observed as a significant part of the disorder and is now recognised in the diagnostic criteria (American Psychiatric Association, 2013; Kanner, 1943; Leekam, Nieto, Libby, Wing & Gould, 2007). Reports from individuals with ASD and their caregivers often describe atypical sensory functioning (Baranek, David, Poe, Stone & Watson, 2006; Jones, Quigney & Huws, 2003) including hypo- or hyper- sensitivities to sensory stimuli, and problems modulating sensory input (Ben-Sasson et al., 2009). This extends to a variety of modalities including vision (see Simmons et al., 2009, for a review), audition (see Haesen, Boets & Wagemans, 2011, for a review) and touch (Cascio et al., 2008).

Recently researchers have questioned the extent to which atypical sensory perception occurs in members of the neurotypical population who have a high level of autistic traits but do not have a clinical diagnosis of ASD. This approach has indicated that atypical sensory experience is reported more frequently in individuals with higher levels of autistic traits than in individuals with lower levels of autistic traits (Robertson and Simmons, 2013). In the auditory domain it has been found that those with higher levels of autistic traits perform better on a pitch identification task, and are more likely to show absolute pitch (Dohn, Garza-Villarreal, Heaton & Vuust, 2012). This suggests that atypical sensory experiences vary with the level of autistic traits an individual possesses, and that both the expression of autistic traits and the occurrence of atypical sensory experience occur on a continuum (c.f. Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001; Constantino & Todd, 2003).

Of the sensory modalities, the association between visual function and autistic traits has been studied most extensively. Individuals with a high level of self-reported autistic traits have been shown to exhibit superior performance compared to those with a low level of autistic traits on a variety of tasks including visual search (Almeida, Dickinson, Mayberry, Badcock & Badcock, 2012; Brock, Xu & Brooks, 2011; Milne, Dunn, Freeth & Rosas-Martinez, 2013, although see Gregory & Plaisted-Grant, 2013 for negative findings), embedded figures (Almeida, Dickinson, Mayberry, Badcock & Badcock, 2010; Almeida et al., 2012; Grinter, Maybery et al., 2009; Grinter, Van Beek, Maybery & Badcock, 2009) and block design tasks (Grinter, Van Beek et al., 2009; Stewart, Watson, Allcock & Yaqoob, 2009). This collection of findings mirrors earlier reports showing enhanced performance on these tasks in individuals with autism compared to neurotypical matched controls (Lockyear & Rutter, 1970; O' Riordan, Plaisted, Driver & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998; Shah & Frith, 1983; Shah & Frith, 1993).

One aspect of visual perception which appears to be unrelated to autistic traits, however, is orientation discrimination. Although Bertone, Mottron, Jelenic and Faubert (2005) found that individuals with ASD showed an enhanced ability to identify the orientation of first-order gratings, Brock, Xu & Brooks (2011) found no significant correlation between autistic traits and orientation discrimination thresholds in neurotypical individuals. Therefore, it may be the case that orientation discrimination superiorities do not exist in neurotypical individuals who possess a high level of autistic traits. Alternatively, we put forward the suggestion that the conflicting results found by these studies might be due to the different methodologies that they employed. Bertone and colleagues altered the difficulty of their orientation discrimination task through contrast levels. Participants in their study had to indicate whether contrast-modulated first order gratings were horizontal or vertical. Brock et al. took a different approach, manipulating the difficulty of their task through the angle of difference between the gratings. Specifically, Brock et al. used target gratings oriented at 90 degrees, which participants had to identify from distracter gratings which deviated from 90 degrees. This is important, as numerous studies have demonstrated superior performance on a wide range of perceptual tasks employing stimuli aligned at cardinal rather than oblique angles, a phenomenon known as the oblique effect (Appelle, 1972). The oblique effect is demonstrated in orientation discrimination thresholds, which have consistently been found to be higher for stimuli oriented at oblique rather than cardinal angles (e.g. Westheimer and Beard, 1998). Therefore it is possible that the use of a horizontal target grating, as used in Brock et al.'s study, may give rise to 'ceiling effects' and a reduction of inter-participant variability thus masking any relationship between autistic traits and orientation discrimination thresholds (c.f. Edden, Muthukumaraswamy, Freeman & Singh, 2009). In support of this position, previous research has shown that migraineurs show reduced orientation discrimination thresholds compared to non-migraineurs, but only when oblique stimuli, and not vertical stimuli are used (Tibber, Guedes & Shepherd, 2006).

A possible lack of inter-participant variability in cardinal orientation discrimination thresholds could underlie why Brock and colleagues did not find variation in orientation discrimination thresholds between individuals with different levels of autistic traits. Whilst Bertone and colleagues introduced greater difficulty into their task through altering the contrast of the gratings, the paradigm employed by Brock only required participants to make discriminations between stimuli deviating from cardinal angles. Therefore the ease of the task may mean that it is not sensitive enough to ascertain whether variability in orientation discrimination thresholds is associated with different levels of autistic traits.

The present study aimed to re-visit the hypothesis that orientation discrimination thresholds are correlated with level of self-reported autistic traits. We used the AQ (Baron-Cohen et al., 2001) to measure autistic traits and an orientation discrimination task which measured both vertical and oblique orientation discrimination thresholds (Edden et al., 2009).

It was reasoned that requiring participants to make oblique-oblique discriminations would introduce enough difficulty into the task in order to increase inter-participant variability, and reveal any superiorities that may exist in those with a high level of autistic traits. If the non-clinical autistic phenotype is associated with increased sensitivity to small differences in orientation, then we would expect to see lower oblique orientation discrimination thresholds in those with a higher level of autistic traits. We also included the vertical discrimination condition as a non-significant correlation would confirm that there is no relationship between autistic traits and cardinal orientation discrimination thresholds (c.f. Brock et al., 2011).

Methods

Participants

We recruited 116 healthy volunteers from the student and local community population with normal or corrected to normal vision. Participants were excluded if they did not complete 1 or more parts of the orientation discrimination task (described below). This led to 14 participants being excluded. A further eight participants were excluded from the analysis as either their vertical or oblique orientation discrimination threshold was more than 2 standard deviations above the group mean. 94 participants were included in the final analysis (42 male, 52 female; mean age 24.48; age range = 18 – 61). The study received full ethical approval from the Department of Psychology University of Sheffield ethics committee. Participants provided informed written consent, in accordance with the declaration of Helsinki.

Questionnaire

Participants completed paper copies of the AQ, a 50 item self-report questionnaire that measures autistic traits in the general population (Baron-Cohen et al., 2001). Participants are required to state whether they agree or disagree with a series of statements which describe different social and communication centred preferences. Each item is scored as a 0 or a 1, with 1 indicating the presence of an autistic trait. The maximum score on the AQ is 50, and higher scores are indicative of a higher level of autistic traits.

Orientation discrimination task

Orientation discrimination thresholds were measured using a two-alternative forced choice adaptive staircase procedure based on that described by Edden et al. (2009). The sequence of events in each trial is illustrated in figure 1. On each trial a reference grating and a target grating were presented sequentially, each for 350ms, separated by a 500ms delay. The circular gratings (diameter 4°; spatial frequency 3 cycles/degree; contrast 99%; mean luminance 83 cd/m^2) were created in MatLab (MATLAB, 6.1, The MathWorks Inc., Natick, MA, 2000) using the PsychToolbox set of functions (Brainard, 1997). Participants completed the experiment in a completely dark room. The stimuli were displayed on a linearised AMW MR19C-ABAD LCD monitor with a spatial resolution of 1280 x 1024 pixels and a temporal resolution of 60Hz. Participants were seated 57cm away from the monitor which had a circular aperture placed over it in order to remove any orientation cues provided by the edge of the screen.

Participants were asked to judge whether the target grating had been rotated clockwise or anti-clockwise compared to the reference grating. Each run consisted of four randomly interleaved staircases. There were two conditions, in one condition the reference grating was oriented at 0 degrees (vertical) and in the other it was oriented 45 degrees clockwise from vertical. Two staircases were used for each condition. One presented the clockwise transformations of the stimulus and the other presented the anti-clockwise transformations.

Responses were recorded by the participant using the left and right arrow keys on a keyboard. A one-up three-down staircase method was used, which converged on 79% correct performance (Leek, 2001). The initial target grating was presented at 5 degrees away from the reference grating. The initial step size was 1 degree which decreased by 75% after every reversal.

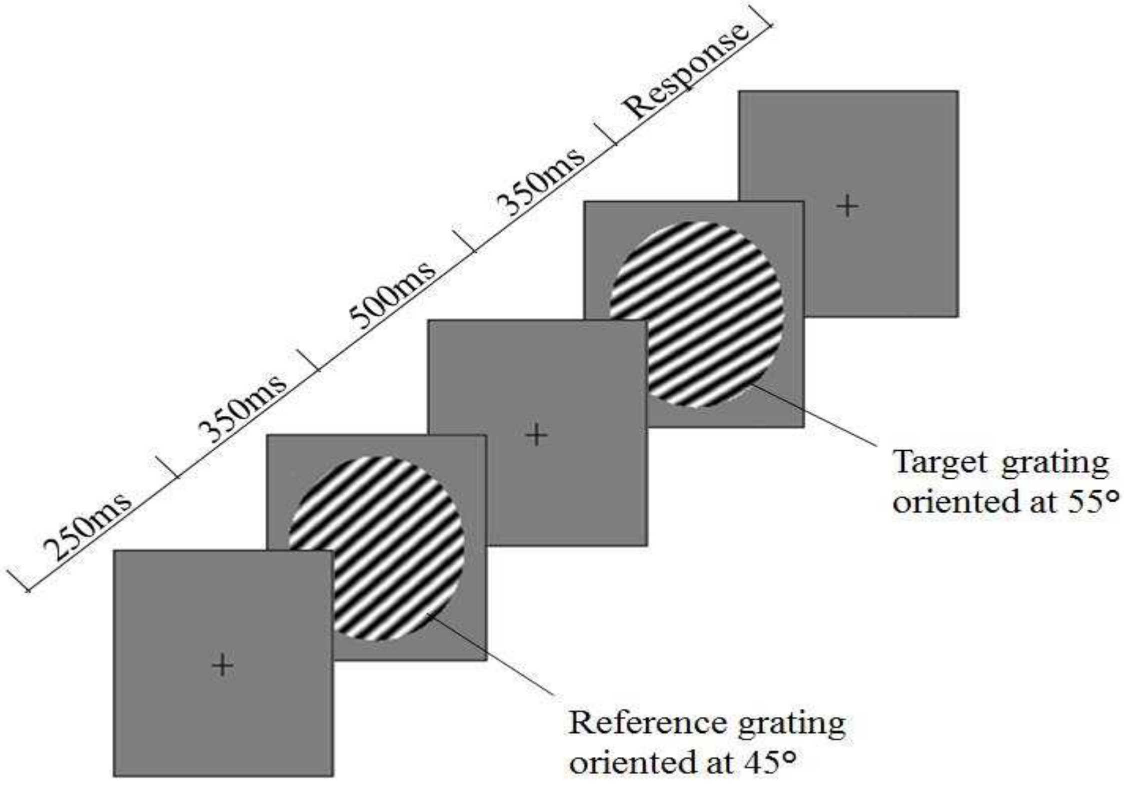

Fig. 1.

Schematic diagram of the orientation discrimination task.

Participants completed a practice run which continued until each of the four staircases completed 2 reversals. Participants then completed 2 runs which finished when each staircase had reached 10 reversals. Participants had a short self-timed break of around 1 minute between each run. As the design incorporated 4 interleaved staircases, with a one-up three-down design, we did not want either of the runs to become too long. Therefore if participants hit 120 trials on any one of the staircases, on either of the runs, the task terminated. These participants were categorised as not having completed the task and were excluded from any analysis, as described in the method section, fourteen participants were excluded on these grounds. The first two reversals for each run were discarded before computing the threshold by averaging over the last 8 reversals. Thresholds were estimated separately for the oblique and vertical conditions by averaging across the thresholds obtained for the clockwise and anticlockwise staircases, over both of the two runs.

Results

The AQ scores for our sample ranged from 2 to 42, with a mean of 16. This is the distribution of AQ scores we would expect to see in a neurotypical population based on previous studies (Baron-Cohen et al., 2001; Brock et al., 2011). A classic oblique effect was observed with orientation discrimination thresholds being significantly higher in the oblique than in the vertical condition ($t(93) = -24.687$, $p = <.0001$). The mean orientation discrimination threshold in the vertical condition was $1.3 \pm 0.62°$, whilst in the oblique condition it was $5.7 \pm 2.01°$.

There was a significant effect of age on orientation discrimination thresholds in both the vertical ($r= -.257$, $p <.013$) and oblique conditions ($r= -.247$, $p <.019$).

Relationship between Orientation Discrimination Threshold and AQ Score

The relationships between AQ score and vertical discrimination threshold, and between AQ score and oblique discrimination threshold are presented in figures 2A and 2B respectively. Bonferroni-corrected Pearson correlation coefficients indicated that, as predicted, there was a significant negative linear relationship between oblique orientation discrimination thresholds and AQ scores ($r= -.356$, $p <.0001$, $R^2 = .127$). There was no significant relationship between vertical orientation discrimination thresholds and AQ scores ($r= -.164$, $p =.114$, $R^2 = .027$). We also calculated the magnitude of the oblique effect by subtracting each individual's vertical threshold from their oblique threshold, and found a significant relationship between the magnitude of the oblique effect and AQ scores ($r= -.356$, $p <.0001$, $R^2 = .127$). This result indicates that higher AQ scores are associated with a reduction in the oblique effect.

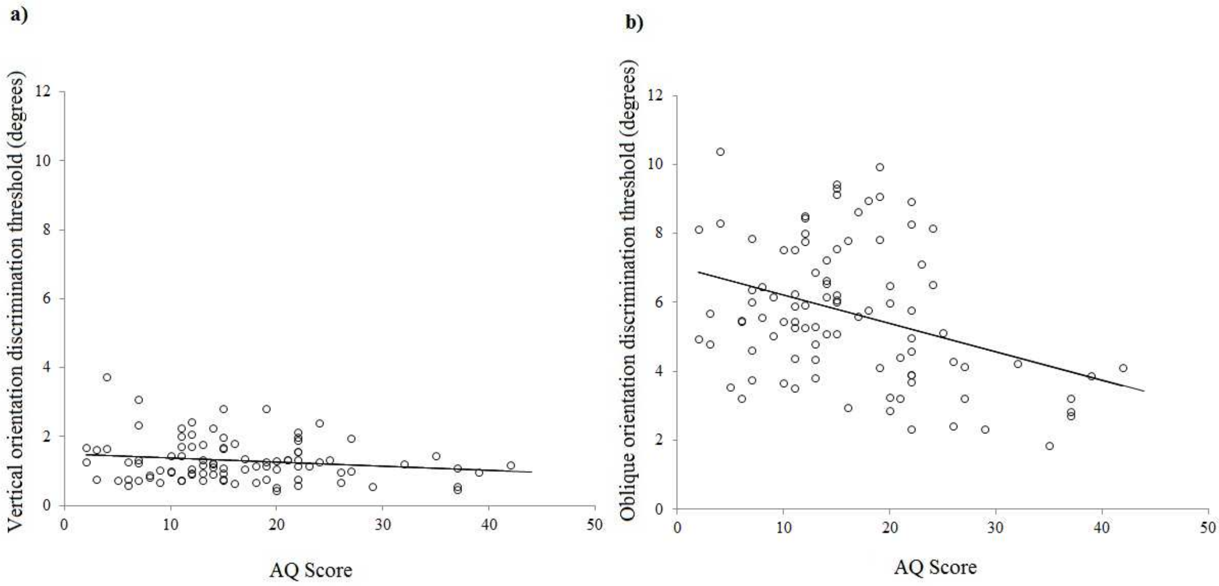

Fig. 2.

a) Correlation between vertical orientation discrimination threshold and AQ score (N=94), b) Correlation between oblique orientation discrimination threshold and AQ score (N=94).

Discussion

The aim of the present study was to determine whether orientation discrimination thresholds are associated with the level of autistic traits an individual possesses. Whilst orientation discrimination has been found to be superior in individuals with ASD (Bertone et al., 2005) this has not been found to extend to individuals without a diagnosis of ASD but with a high level of self-reported autistic traits (Brock et al., 2011). We suggest that this is not because orientation discrimination superiorities do not exist in individuals with a high level of autistic traits, but rather due to the fact that the task used by Brock and colleagues was not adequately sensitive to reveal any orientation discrimination threshold differences that may be associated with autistic traits. We used a highly sensitive task requiring participants to make oblique-oblique judgements in addition to vertical-oblique judgements.

As expected, we found a strong oblique effect, indicating that participants found the oblique condition around 4 times harder than the vertical condition (Edden et al., 2009; Tibber et al., 2006). We also found a significant negative correlation between orientation discrimination thresholds and age, with an increase in age leading to lower orientation discrimination thresholds in both the vertical and oblique conditions. This is in contrast to previous findings which have reported orientation discrimination performance to increase with age (e.g. Betts, Sekuler & Bennett, 2007).

In support of our hypothesis we found that oblique orientation discrimination thresholds were significantly correlated with AQ scores. Individuals with a high level of autistic traits showed lower orientation discrimination thresholds, demonstrating superior performance. In addition, we found that those with higher AQ scores showed a smaller oblique effect. This finding echoes previous work on mirror symmetry in which individuals with autism were shown to have a reduced oblique effect (Perreault, Gurnsey, Dawson, Mottron & Bertone, 2011).

Also as predicted, vertical orientation discrimination thresholds were not significantly correlated with AQ scores. Therefore whilst our results support those of Brock et al. (2011) who found no correlation between horizontal orientation discrimination thresholds and autistic traits, they extend these findings, demonstrating that when a task is sufficiently difficult to generate substantial inter-participant variability, there is a significant relationship between orientation discrimination ability and autistic traits. Our results also demonstrate that there is no significant relationship between vertical orientation discrimination thresholds and

AQ scores due to a lack of inter-participant variability in vertical orientation discrimination thresholds.

Having established that individual differences in orientation discrimination thresholds are related to individual differences in autistic traits it is important to consider what factors may mediate this relationship. Inhibitory mechanisms have been highly implicated in the tuning curve of the orientation selectivity of cells, as orientation selective neurons become narrowly tuned to a particular orientation through lateral inhibition (Hubel and Wiesel, 1968). Variability in levels of inhibition would therefore lead to differences in orientation sensitivity, with higher levels of inhibition leading to an enhanced ability to discriminate between orientations. GABAergic inhibition in particular seems to be imperative in determining the orientation profile of neurons in V1. For instance, applying a GABA antagonist to block inhibition can reduce orientation selectivity (e.g. Katzner, Busse & Carandini, 2011; Sillito, 1975) whist the application of GABA leads to cells becoming more specifically tuned to a particular orientation (Li, Yang, Liang, Xia & Zhou, 2008). Most relevant to the current study, resting GABA levels have also been found to be inversely correlated with oblique orientation discrimination thresholds (Edden et al., 2009), suggesting that GABA mediated inhibition plays a major role in establishing the sharp orientation tuning of neurons, leading to enhanced orientation discrimination ability. We therefore speculate that variation in resting GABA levels may mediate the relationship between orientation discrimination thresholds and autistic traits.

A logical extension to this hypothesis is that individuals with a high-level of autistic traits have increased resting GABA levels which, in turn, leads to enhanced orientation discrimination. This suggestion is consistent, in part, with the suggestion from Bertone et al (2005) that increased lateral inhibition, which is a corollary of increased GABA, underpins superior discrimination in individuals with ASD. However, this suggestion is at odds with other work showing reductions in GABA levels in ASD. Three studies to date have used MR Spectroscopy to measure GABA levels in children with ASD. Results have shown reduced GABA levels in frontal (Harada et al., 2011), auditory (Gaetz et al., 2013; Rojas et al., 2013), and motor cortex (Gaetz et al., 2013). However, no differences in GABA levels were found in lenticular nuclei (Harada et al., 2011) or occipital cortex (Gaetz et al., 2013). In addition, blood-plasma levels of GABA have been shown to be increased in children with autism (Dhossche et al., 2002), suggesting that it is premature to rule out the possibility that GABA levels are increased in autism. Certainly it is difficult to reconcile the clear relationship between orientation discrimination thresholds and resting occipital GABA levels (Edden et al., 2009), and evidence for enhanced orientation discrimination in individuals with ASD (Bertone et al., 2005) and as reported here individuals with high levels of autistic traits, with the suggestion that GABA levels are reduced in ASD.

In support of this position is the fact there are a number of limitations in measuring GABA levels. The studies which have measured GABA levels in ASD use magnetic resonance spectroscopy (MRS), which measures a mix of macromolecules and homocarnosine, as well as GABA (Gao et al., 2013). Also, MRS measures GABA in a relatively large area of brain, and it can be hard to localise this voxel to a particular brain structure (Puts & Edden, 2012). Therefore caution needs to be taken when interpreting findings of reduced GABA in ASD, due the presence of other factors in the signal, and the large area the measurement is taken from.

In summary, we report evidence that individual differences in orientation discrimination thresholds are related to individual differences in autistic traits. This relationship is present when orientation discrimination is measured using oblique-oblique discriminations but not when orientation discrimination is measured using vertical-oblique discriminations. We suggest that this is due to the fact that making vertical-oblique discriminations is easier than making oblique-oblique discriminations, and therefore tasks using these stimuli may not generate sufficient variance to yield significant correlations with other variables (c.f. Brock et al. 2011). In light of previous work demonstrating a relationship between orientation discrimination and resting GABA levels we put forward the suggestion that high levels of autistic traits and enhanced orientation discrimination may be mediated by increased levels of GABA.

Almeida, R. A., Dickinson, J. E., Maybery, M. T., Badcock, J. C., & Badcock, D. R. (2010). A new step towards understanding Embedded Figures Test performance in the autism spectrum: The radial frequency search task. Neuropsychologia, 48(2), 374-381. doi: 10.1016/j.neuropsychologia.2009.09.024.

Almeida, R. A., Dickinson, J. E., Maybery, M. T., Badcock, J. C., & Badcock, D. R. (2012). Visual search targeting either local or global perceptual processes differs as a function of autistic-like traits in the typically developing population. Journal of autism and developmental disorders, 1-15. doi: 10.1007/s10803-012-1669-7.

American Psychiatric Association. (2013). Diagnostic and statistical manual of mental disorders (5th ed.). Arlington, VA: American Psychiatric Publishing.

Appelle, S. (1972). Perception and discrimination as a function of stimulus orientation: the" oblique effect" in man and animals. Psychological bulletin, 78(4), 266. doi:10.1037/h0033117

Baranek, G. T., David, F. J., Poe, M. D., Stone, W. L., & Watson, L. R. (2006). Sensory Experiences Questionnaire: discriminating sensory features in young children with autism, developmental delays, and typical development. Journal of Child Psychology and Psychiatry, 47(6), 591-601. doi: 10.1111/j.1469-7610.2005.01546.x.

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The autism-spectrum quotient (AQ): Evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. Journal of autism and developmental disorders, 31(1), 5-17. doi: 10.1023/A:1005653411471.

Ben-Sasson, A., Hen, L., Fluss, R., Cermak, S. A., Engel-Yeger, B., & Gal, E. (2009). A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. Journal of autism and developmental disorders, 39(1), 1-11. doi: 10.1007/s10803-008-0593-3.

Bertone, A., Mottron, L., Jelenic, P., & Faubert, J. (2005). Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. Brain, 128(10), 2430-2441. doi: 10.1093/brain/awh561.

Betts, L. R., Sekuler, A. B., & Bennett, P. J. (2007). The effects of aging on orientation discrimination. *Vision research,* 47(13), 1769-1780.

Brainard, D. H. (1997). The psychophysics toolbox. Spatial vision, 10(4), 433-436. doi: 10.1163/156856897X00357.

Brock, J., Xu, J. Y., & Brooks, K. R. (2011). Individual differences in visual search: relationship to autistic traits, discrimination thresholds, and speed of processing. Perception-London, 40(6), 739. doi: 10.1068/p6953.

Cascio, C., McGlone, F., Folger, S., Tannan, V., Baranek, G., Pelphrey, K. A., & Essick, G. (2008). Tactile perception in adults with autism: a multidimensional psychophysical study. Journal of autism and developmental disorders, 38(1), 127-137. doi:10.1007/s10803-007-0370-8.

Constantino, J. N., & Todd, R. D. (2003). Autistic traits in the general population: a twin study. Archives of general psychiatry, 60(5), 524. doi:10.1001/archpsyc.60.5.524.

Dhossche, D., Applegate, H., Abraham, A., Maertens, P., Bland, L., Bencsath, A., & Martinez, J. (2002). Elevated plasma gamma-aminobutyric acid (GABA) levels in autistic youngsters: stimulus for a GABA hypothesis of autism. *Medical science monitor: international medical journal of experimental and clinical research,* 8(8), PR1-6.

Dohn, A., Garza-Villarreal, E. A., Heaton, P., & Vuust, P. (2012). Do musicians with perfect pitch have more autism traits than musicians without perfect pitch? An empirical study. *PloS one,* 7(5). doi: 10.1371/journal.pone.0037961.

Edden, R. A., Muthukumaraswamy, S. D., Freeman, T. C., & Singh, K. D. (2009). Orientation discrimination performance is predicted by GABA concentration and gamma oscillation frequency in human primary visual cortex. The Journal of Neuroscience, 29(50), 15721-15726. doi: 10.1523/jneurosci.4426-09.2009.

Gao, F., Edden, R. A., Li, M., Puts, N. A., Wang, G., Liu, C., ... & Barker, P. B. (2013). Edited magnetic resonance spectroscopy detects an age-related decline in brain GABA levels. Neuroimage, 78, 75-82. doi: 10.1016/j.neuroimage.2013.04.012.

Gaetz, W., Bloy, L., Wang, D. J., Port, R. G., Blaskey, L., Levy, S. E., & Roberts, T. P. L. (2013). GABA estimation in the Brains of Children on the Autism Spectrum: Measurement precision and regional cortical variation. NeuroImage. doi:10.1016/j.neuroimage.2013.05.068

Gregory, B. L., & Plaisted-Grant, K. C. (2013). The Autism-Spectrum Quotient and Visual Search: Shallow and Deep Autistic Endophenotypes. Journal of autism and developmental disorders, 1-10. doi:10.1007/s10803-013-1951-3.

Haesen, B., Boets, B., & Wagemans, J. (2011). A review of behavioural and electrophysiological studies on auditory processing and speech perception in autism spectrum disorders. Research in Autism Spectrum Disorders, 5(2), 701-714. doi:10.1016/j.rasd.2010.11.006.

Harada, M., Taki, M. M., Nose, A., Kubo, H., Mori, K., Nishitani, H., & Matsuda, T. (2011). Non-invasive evaluation of the GABAergic/glutamatergic system in autistic patients observed by MEGA-editing proton MR spectroscopy using a clinical 3 tesla instrument. Journal of autism and developmental disorders, 41(4), 447-454. doi: 10.1007/s10803-010-1065-0.

Hubel, D. H., & Wiesel, T. N. (1968). Receptive fields and functional architecture of monkey striate cortex. The Journal of physiology, 195(1), 215-243. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1557912/pdf/jphysiol01104-0228.pdf.

Jones, R., Quigney, C., & Huws, J. (2003). First-hand accounts of sensory perceptual experiences in autism: A qualitative analysis. Journal of Intellectual and Developmental Disability, 28(2), 112-121. doi:10.1080/1366825031000147058.

Kanner, L. (1943). Autistic disturbances of affective contact. Nervous child, 2(3), 217-250. Retrieved from http://www.neurodiversity.com/library_kanner_1943.pdf.

Katzner, S., Busse, L., & Carandini, M. (2011). GABAA inhibition controls response gain in visual cortex. The Journal of neuroscience, 31(16), 5931-5941. doi: 10.1523/jneurosci.5753-10.2011.

Leekam, S. R., Nieto, C., Libby, S. J., Wing, L., & Gould, J. (2007). Describing the sensory abnormalities of children and adults with autism. Journal of autism and developmental disorders, 37(5), 894-910. doi: 10.1007/s10803-006-0218-7.

Li, G., Yang, Y., Liang, Z., Xia, J., & Zhou, Y. (2008). GABA-mediated inhibition correlates with orientation selectivity in primary visual cortex of cat. Neuroscience, 155(3), 914-922. doi: 10.1016/j.neuroscience.2008.06.032.

Lockyear, L., & Rutter, M. (1970). A Five-to Fifteen-Year Follow-up Study of Infantile Psychosis: IV. Patterns of Cognitive Ability. British Journal of Social and Clinical Psychology, 9(2), 152-163. doi: 10.1111/j.2044-8260.1970.tb00654.x.

Milne, E., Dunn, S. A., Freeth, M., & Rosas-Martinez, L. (2013). Visual search performance is predicted by the degree to which selective attention to features modulates the ERP between 350 and 600ms. Neuropsychologia, 51(6), 1109-1118. doi: 10.1016/j.neuropsychologia.2013.03.002.

O'Riordan, M. A., Plaisted, K. C., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. Journal of Experimental Psychology: Human Perception and Performance, 27(3), 719. doi: 10.1037/0096-1523.27.3.719.

Perreault, A., Gurnsey, R., Dawson, M., Mottron, M., & Bertone, A. (2011). Increased sensitivity to mirror symmetry in autism. *PloS one,* 6 (4). doi: 0.1371/journal.pone.0019519.

Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced visual search for a conjunctive target in autism: A research note. Journal of Child Psychology and Psychiatry, 39(5), 777-783. doi: 10.1111/1469-7610.00376.

Puts, N. A., & Edden, R. A. (2012). *In vivo* magnetic resonance spectroscopy of GABA: A methodological review. *Progress in nuclear magnetic resonance spectroscopy,* 60, 29-41. doi: 10.1016/j.pnmrs.2011.06.001.

Robertson, A. E., & Simmons, D. R. (2012). The relationship between sensory sensitivity and autistic traits in the general population. Journal of autism and developmental disorders, 1-10. doi: 10.1007/s10803-012-1608-7.

Rojas, D. C., Singel, D., Steinmetz, S., Hepburn, S., & Brown, M. S. (2013). Decreased left perisylvian GABA concentration in children with autism and unaffected siblings. NeuroImage. doi: 10.1016/j.neuroimage.2013.01.045.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. Journal of Child Psychology and Psychiatry, 24(4), 613-620. doi: 10.1111/j.1469-7610.1983.tb00137.x.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design task?. Journal of Child Psychology and Psychiatry, 34(8), 1351-1364. doi: 10.1111/j.1469-7610.1993.tb02095.x.

Sillito, A. M. (1975). The contribution of inhibitory mechanisms to the receptive field properties of neurones in the striate cortex of the cat. The Journal of physiology, 250(2), 305-329. Retrieved from http://jp.physoc.org.eresources.shef.ac.uk/content/250/2/305.long.

Stewart, M. E., Watson, J., Allcock, A. J., & Yaqoob, T. (2009). Autistic traits predict performance on the block design. Autism, 13(2), 133-142. doi: 10.1177/1362361308098515

Tibber, M. S., Guedes, A., & Shepherd, A. J. (2006). Orientation discrimination and contrast detection thresholds in migraine for cardinal and oblique angles. Investigative ophthalmology & visual science, 47(12), 5599-5604. doi: 10.1167/iovs.06-0640.

Westheimer, G., & Beard, B. L. (1998). Orientation dependency for foveal line stimuli: detection and intensity discrimination, resolution, orientation discrimination and vernier acuity. Vision research, 38(8), 1097-1103. doi: 10.1016/S0042-6989(97)00248-4.