

Eagle-Eyed Visual Acuity: An Experimental Investigation of Enhanced Perception in Autism

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Background: Anecdotal accounts of sensory hypersensitivity in individuals with autism spectrum conditions (ASC) have been noted since the first reports of the condition. Over time, empirical evidence has supported the notion that those with ASC have superior visual abilities compared with control subjects. However, it remains unclear whether these abilities are specifically the result of differences in sensory thresholds (low-level processing), rather than higher-level cognitive processes.

Methods: This study investigates visual threshold in $n = 15$ individuals with ASC and $n = 15$ individuals without ASC, using a standardized optometric test, the Freiburg Visual Acuity and Contrast Test, to investigate basic low-level visual acuity.

Results: Individuals with ASC have significantly better visual acuity (20:7) compared with control subjects (20:13)—acuity so superior that it lies in the region reported for birds of prey.

Conclusions: The results of this study suggest that inclusion of sensory hypersensitivity in the diagnostic criteria for ASC may be warranted and that basic standardized tests of sensory thresholds may inform causal theories of ASC.

Key Words: Autism, enhanced perception, optometry, sensory hypersensitivity, sensory threshold, visual acuity

Autism spectrum conditions (ASC) are neurodevelopmental and are diagnosed on the basis of difficulties with social interaction and communication, along with narrow interests and repetitive behavior (1). Although these core deficits are necessary for a diagnosis of ASC, reflecting a focus on social impairments, first reports of the condition by Kanner (2) in the 1940s also noted that individuals with ASC show enhanced perception of details. Individuals with ASC often report sensory abnormalities (3,4), and one recent study by Leekam and McGeer (5) found that 90% of the autistic children whom they tested showed sensory abnormalities according to the Diagnostic Interview for Social and Communication Disorder. Sensory hypersensitivity previously formed part of the *DSM-III* diagnostic criteria of autism (6), although it was excluded from the most recent diagnostic manual, *DSM-IV* (1).

Sensory abnormalities may underpin a number of behaviors such as stereotypies, aversions or preferences for certain stimuli (7), as well as resistance to change and need for sameness, narrow interests and obsessions, and even hypersystemizing (8). This research in the field of ASC should aim to investigate differences in sensory perception and their origins to better understand the etiology of and possible interventions for ASC.

Different decades have seen varied interest in empirical sensory research in ASC. In the 1950s, there was little sensory research in ASC, with more emphasis on psychodynamic theories (9). The 1960s and 1970s saw a focus on relatively high-level aspects of perception such as coding of meaning, pattern-recognition, and cognitive integration (10,11). Over the last 3 decades, research has been predominantly concerned with assessing the proximal causes of social dysfunction, such as face and voice processing (12,13), social-cognitive causes such as

mindblindness (14), or high-level cognitive abnormalities such as executive dysfunction (15). Only recently has empirical sensory research received renewed interest, with studies of perceptual discrimination (16,17).

Enhanced visual perception in ASC was first illustrated empirically by the Block Design and Embedded Figures subtests of the Wechsler intelligence scales, on which individuals with ASC score significantly higher, relative to performance on other subtests and to age-matched typical control subjects (18–20). These tasks require the identification of a target feature in the presence of complex distractors. The higher scores of individuals with ASC suggests that either their visual perception at the local level is superior to control subjects or that processing at the global level is impaired, causing less interference and resulting in faster and more accurate performance in tests of perception at the local level. Plaisted, O’Riordan, and Baron-Cohen (16) also found that the superior primary visuospatial perceptual skills in ASC were illustrated by the findings of faster reaction times and greater accuracy in conjunctive search tasks in children with ASC. Systemizing is the ability to predict lawful events, changes, and patterns in stimuli, and findings of “hypersystemizing” in ASC (8) may be secondary to an underlying superiority in attention to detail.

Despite the recent resurgence in interest in sensory perception research in ASC, it is surprising that no studies to date have used basic and standardized optometric tests of visual acuity (threshold). Visual acuity can be measured in the general population using various standardized methods. A test commonly used by optometrists is the Snellen chart (21), which comprises 11 lines of letters of different sizes that the patient is asked to read aloud from the top. Subsequent rows have increasing numbers of letters at decreasing size and the smallest row a patient can identify indicates his or her visual acuity, expressed in the form 20:X, where “average” vision is denoted as 20:20, or the detail one sees accurately from 20 feet away. Poorer vision would be in the region of 20:40. This equates to being able to see detail accurately from 20 feet away that an average individual could see accurately from 40 feet away. Acuity of 20:10 represents excellent vision and is generally thought to be the upper limit of typical human visual acuity.

Although Snellen charts are still the most widely used measure of visual acuity, they have received criticism because

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Table 1. Descriptive Characteristics of the Control and Autism Spectrum Conditions (ASC) Groups

Variable	Control Group (n = 15)			ASC Group (n = 15)			Cohen's <i>d</i>
	Mean	SD	Range	Mean	SD	Range	
Age	27.60	11.52	19–63	38.93	14.42	22–62	.86
Verbal IQ	122	7.64	111–136	121	9.95	107–143	.11
Performance IQ	121	6.86	108–134	124	7.99	114–141	.40
Full IQ	122	8.75	112–137	121	10.62	105–140	.10
Education Level	3.46	1.35	2–5	3.60	1.42	2–5	.10

of other factors that may influence results (22). For example, the number of letters increases while their size decreases. This introduces two variables, rather than just one, so that one cannot dissect whether difficulties are due to one factor or the other. Furthermore, some studies suggest that crowding of letters in lower rows makes them inherently more difficult to read (23). Also, because the charts are freely available, some people may simply memorize the Snellen chart before being tested with it to give the impression that their vision is better than it is. Although this is unlikely to be a common source of error, it is yet another shortcoming of the test. A final issue is that there are fairly large, and uneven, jumps in acuity level between the rows.

Subsequent visual acuity tests have sought to remedy such issues so that they can provide a more accurate measure of an individual's visual abilities. One example of such a test is the Freiburg Visual Acuity and Contrast Test (FrACT), which has shown high test-retest reliability (24). Here we report the first study to use this measure in ASC not only to fill a gap in vision science but also to test the possibility that higher-order cognitive differences (e.g., in visual discrimination, attention to detail, and systemizing) may be secondary to lower low-level visual thresholds.

Methods and Materials

Thirty participants were invited to our laboratory in Cambridge to take part in the experiment. The ASC group comprised $n = 15$ adult males, 8 of whom were diagnosed with high-functioning autism (HFA) and 7 with Asperger syndrome (AS). All the participants with ASC were recruited from a volunteer database (<http://www.autismresearchcentre.com>) and had been diagnosed according to international criteria (1) by a professional clinician in a recognized center. Each participant was asked to provide documentary evidence of diagnosis to take part. Fifteen adult males from the general population with no prior history of any psychiatric diagnosis were recruited through local advertisements and served as a typical control group. All participants were screened for any preexisting optical conditions and all had normal or corrected vision.

Participants were administered the Freiburg Visual Acuity and Contrast Test (FrACT), a standardized optometric test that uses the Landholt-Coptotype (24)¹. The gaps in the C-shape range from .4 mm to 25 mm and appear in one of four positions: up, down, left, or right. Participants sat at a fixed distance of 60 cm from the computer screen and were instructed to identify the location of the "missing" part of the C-shaped stimulus by selecting one of the 4 arrow keys of the keyboard, according to the position of the gap (top, bottom, left, right).

¹The visual acuity task was part of a set of tasks that took place over one and a half hours, but task order was randomized and matched for the control and ASC groups to account for any order effects.

The C-shape started at a fixed size and decreased in size with each correct answer. After each incorrect response, the figure appeared at a slightly larger size in the subsequent trials until a correct response was recorded (method of limits approach). Participants had 3 sec to respond on each of the 150 trials, which equates to a maximum test time of just under 6 min. The protocol required that the task should be stopped if any participant appeared to be suffering fatigue or lack of concentration, and the task program was set to abort if they did not respond on three or more consecutive trials. Participants were encouraged to go as quickly and accurately through the test as possible. The results generated a Snellen decimal, a measure of visual acuity, in which a value of 1.00 represents "average" 20:20 vision. Snellen values above 1.00 represent increasingly accurate vision (20:10 vision = 2.00), and values below 1.00 represent worse vision (20:40 vision = .50).

All the participants were also administered the Wechsler Abbreviated Scales of Intelligence (25) to determine IQ score and the ASC group was also asked to complete the Autism Spectrum Quotient (AQ) (26) as a validation check on diagnosis.

Results

All participants were able to complete the task and were included in the final analyses. Kolmogorov-Smirnov tests indicated that none of the variable ranges were significantly skewed. Table 1 shows descriptive characteristics for the control and ASC

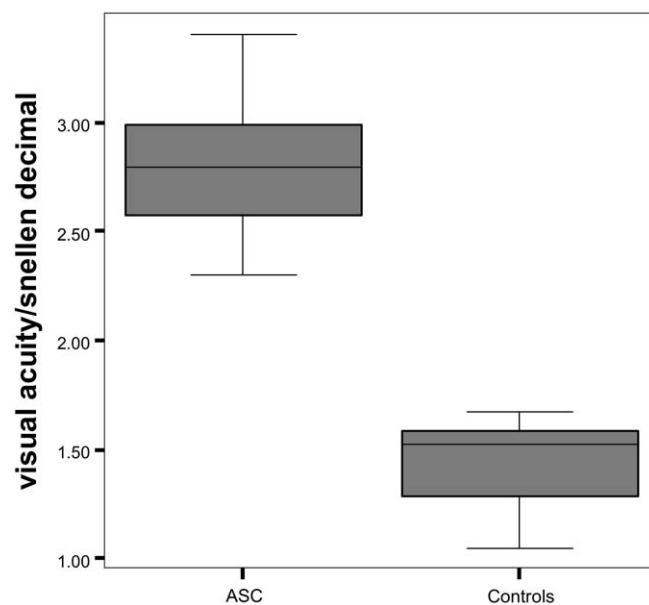


Figure 1. Boxplot showing the data for the autism spectrum conditions (ASC) and control groups.

groups. There were no significant differences between the ASC and control groups for full-scale IQ [$t(30) = .28; p = .42$] or for verbal IQ [$t(30) = .31; p = .79$] or for performance IQ [$t(30) = 1.10; p = .12$]. There were also no differences between the groups for socioeconomic status (both groups came from a mix of occupations) or educational level (both groups had 60% with university level education and were matched for qualifications according to the following 5-point scale: 1 = *no formal qualifications*, 2 = *“O” Level/GCSE or equivalent*, 3 = *“A” Level, HND or vocational qualification*, 4 = *university degree*, 5 = *postgraduate qualification*). The groups were also matched for handedness (all right-handed according to self-description) and for numbers of normal versus corrected vision (6/15 corrected in the control group vs. 5/15 for the ASC group). The ASC group were significantly older than the control group [$t(30) = 2.38; p < .03; d = .86$]. AQ scores for the ASC group (mean = 36.6, SD = 7.1, 82.4% scoring 32+) were similar to the findings from previously published studies (mean AQ score = 35.8, SD = 6.5, 80% scoring 32+) (26).

Results showed that the ASC group scored a mean acuity measure of 2.79 (SD = ± .37), which was significantly better than the control group mean of 1.44 [SD = ± .26; $t(30) = 4.63; p < .001$; see Figures 1 and 2].

There were no significant correlations between visual acuity score and any other control variables included in the study (see Table 2). For both the control and ASC groups, there was no significant difference in acuity scores for normal versus corrected vision [control group: $t(15) = -.17; p = .66$; ASC group: $t(15) = .29; p = .87$]. Additionally for the ASC group there was no significant difference in visual acuity score according to specific diagnosis [HFA vs. AS; $t(15) = .11; p = .93$] and no correlation between AQ and visual acuity score ($r = .147$).

Discussion

The Snellen score of 2.79 for the ASC group represents acuity 2.79 times better than “average” and translates to vision of 20:7. Expressed differently, the ASC group could discriminate the same

Table 2. Group Correlations Between Visual Acuity Score and Covariates

Covariate	Control Group	ASC Group
Age	-.217	.186
Verbal IQ	.118	.252
Performance IQ	.129	.318
Full IQ	.138	.244
Education Level	-.297	-.144

Correlations are Pearson correlations and all are nonsignificant. ASC, autism spectrum conditions.

detail of an object at 20 feet as a person with “average” vision would see from 7 feet away. To put this in perspective, birds of prey have visual acuity approximately 2 times better than that of humans (27,28), which approaches the results seen with the ASC group. A visual acuity score of 1.44 for the control group translates to a ratio of 20:13, which is better than “average” 20:20 vision but still lies within the typically found limits of human vision, which can be as great as 20:10 (29). The ASC group, at 20:7, indicates superior visual acuity that lies outside this typical range.

The results cannot be attributed to the differences in age between the groups because the ASC group was older than the control group, and visual acuity declines with age (30,31) and because the significant difference was seen even after covarying for age. If anything, this suggests that, had the groups been age matched, there might have been an even greater difference in visual acuity between the ASC and control groups.

There was no significant difference in visual acuity score between the HFA and AS participants within the ASC group and no significant correlation between acuity and AQ scores. We did not make any specific predictions about this before the study, but in line with comparisons to the control group, we might have expected there to be a positive correlation between AQ and visual acuity scores and perhaps for the HFA subgroup to attain higher visual acuity scores. Our results suggest that increased visual acuity applies to individuals across the autistic spectrum. Because the sample size is quite small, we cannot rule out the possibility that differences would be found between subgroups or that acuity might correlate with AQ, in a larger sample of participants.

The results of this study call for a search for possible mechanisms underlying enhanced perceptual functioning and attention to detail seen in ASC. This may be at the level of neural hyperexcitation and is likely governed by factors that give rise to normal variation in visual acuity in typically developing individuals. For example, the fovea of the human eye is responsible for central high resolution vision, as is measured by visual acuity tests, and research has shown there to be a direct correlation between foveal cone cell density and the level of visual acuity (29). However, the *decline* in visual acuity that occurs over the course of normal (nonpathological) aging cannot be attributed to cone density because numbers remain stable over the second to ninth decades of life (32). In this case pre- and postreceptor processes have been suggested as mediating the age-related decline in acuity (33).

Methylation of neurons increases in aging animals and has been shown to cause depletion of levels of dopamine (DA) (34). In animals, the controlled depletion of retinal DA has been correlated with a decline in visual acuity that mimics the effects of aging in human studies (35). Human studies of neurologic disorders have also provided evidence for the role of DA in visual acuity. Parkinson’s disease (PD) is both age-related and associ-

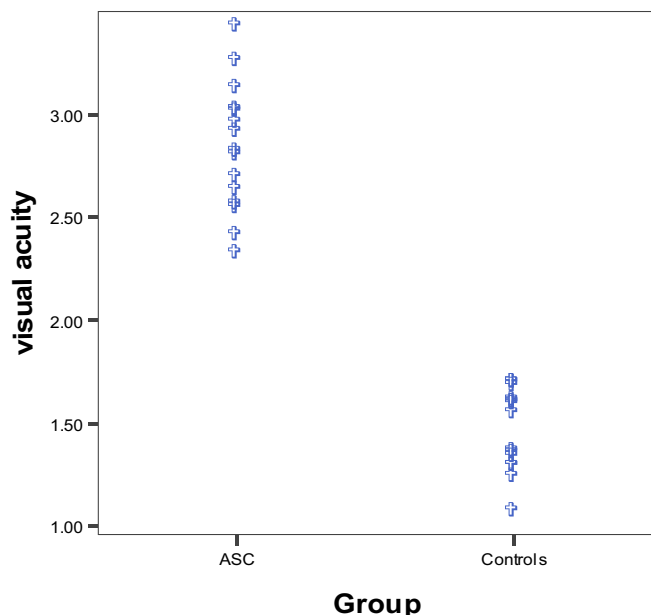


Figure 2. Graph showing the range of data for the autism spectrum conditions (ASC) and control groups.

ated with a relatively higher incidence of visual dysfunction (36). Furthermore, the symptoms of PD are thought to be caused by the degeneration of DA neurons in the substantia nigra and a deficiency of DA in the neostriatal DA terminals (37), both of which may be influenced by methylation processes (38). An implication of this is therefore that regional levels of methylation, DA neuron density, and striatal DA levels might also mediate typical variation in visual acuity.

From these lines of evidence we may postulate that our findings of significantly enhanced visual acuity in ASC may be due to atypically high numbers of foveal cone cells or to dopamine receptors at the retinal or neural level (and perhaps increased levels of dopamine in these areas), which may be caused by *hypomethylation*. Other neurotransmitters, such as γ -aminobutyric acid (GABA), that play a role in neural excitation may also be relevant (39), especially because genes controlling GABA have been implicated in ASC (40). However, although the mechanisms outlined earlier have been evidenced in typically developing populations and neurologic disorders, they remain purely speculative in the case of increased visual acuity in ASC. Further studies of ASC are needed to pinpoint the underlying neurobiological mechanism that gives rise to superior visual acuity, and because ASC is genetic (41), genes involved in sensory neurophysiology may also play a key role.

Exactly how significantly enhanced visual acuity translates to higher cognitive and diagnostic features of ASC needs to be further clarified. We suggest that the results presented here provide further evidence for enhanced local processing (42) at an increasingly basic level. Visual acuity is defined as the spatial-resolving capacity of the visual system, such that higher visual acuity equates to higher spatial-frequency abilities (the ability to detect local detail). Low-level spatial frequencies provide information about the global properties of a stimulus (43). Faces are made up of distinct features of high-spatial frequency but require us to integrate features at the global level so that we extract all the necessary information from them. Consistent with this, event-related potential and functional magnetic resonance imaging studies have shown that low-level spatial frequency is more effective than high spatial frequency for face processing (44) and emotion recognition (45). Individuals with ASC, who have atypically high spatial-frequency abilities, may not be able to “overcome” this ability to process the global information in a dynamic stimulus. This could contribute to the face-processing abnormalities (46) and deficits in emotional perception seen in ASC (47–49). Finally, these findings may underlie the cognitive strengths observed in ASC, such as superior perceptual discrimination (16) and hypersystemizing abilities (8).

The use of standardized tests such as the FrACT is favorable in terms of comparability and reliability of results. However, we acknowledge that it does not necessarily represent the most ecologically valid way of testing the impact of basic visual abilities in everyday life. Future studies should use more socially relevant paradigms.

The potential significance of the results necessitates replication of the study with larger numbers of age-matched participants. It would also be prudent to extend investigation to females and to children with ASC to test for sexually dimorphic or developmentally sensitive differences. Such a disparity in visual acuity in childhood, for example, would support the existence of an innate difference in ASC that is not explained by compensatory processes that may have taken place by adulthood. It will also be important to examine sensory thresholds in other sensory

modalities in ASC to test whether the apparent hypersensitivity is specific to vision or general to all the senses.

Sensory hypersensitivity formed part of the earlier diagnostic criteria of autism (*DSM-III*), although it is not included in the current criteria (*DSM-IV*). The results of this study suggest that, with further investigation, inclusion of such criteria may be warranted and that basic standardized tests of sensory thresholds may inform causal theories of ASC.

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