Visual Perception and Visual Dysfunction in Autism Spectrum Disorder: A Literature Review

Elizabeth Milne PhD [a] and Helen J Griffiths PhD DBO [b]

[a] Department of Psychology, The University of Sheffield.

[b] Academic Unit of Ophthalmology and Orthoptics, The University of Sheffield, Royal Hallamshire Hospital.

Corresponding author: Elizabeth Milne. Department of Psychology, Western Bank, SHEFFIELD, South Yorkshire, S10 2TP

+44 (0) 114 2226558

+ 44 (0) 114 2766515

E.Milne@Sheffield.ac.uk

Acknowledgements

This work was supported by the Economic and Social Research Council (research grant RES-000-22-1868). The authors would like to thank Charlotte Westerman for helpful comments on an earlier draft of this work.

This is a reprint of an article published in the British and Irish Orthoptic Journal (2007). Volume 4, pages 15 – 20.

Abstract

Aim: To describe autistic spectrum disorder (ASD), and to review the evidence for associated visual dysfunction in the disorder.

Method: An initial literature search was performed using Web of Science with the key words: autism and sensory; autism and vision; autism and visual; and autism and oculomotor. Papers which reported investigation of basic vision in autism were obtained, and any additional references listed in these articles that referred to other relevant data but didn't emerge from the original search were followed up.

Results: There is evidence that basic visual function may be affected in individuals with ASD, however the mixed nature and limited number of empirical studies conducted make it difficult to draw clear conclusions as to specific deficits and areas of spared visual function in ASD.

Conclusion: It is likely that patients with ASD may present to the orthoptic department. Specific vision screening of this population may be indicated, and further study based on large well defined samples would be of significant value.

Autistic spectrum disorder (ASD) is a pervasive developmental disorder defined and characterised by qualitative impairments in communication, social interaction, and imagination, accompanied by a restricted range of interest and often stereotyped, repetitive behaviours and mannerisms. The exact cause and aetiology of ASD are still unknown, although it is recognised to be a disorder of neurobiological origin. ASD occurs more frequently in males than in females, approximately with a ratio of 4:1.[1] It is likely that more children than adults are currently diagnosed with ASD as awareness of the disorder has grown in the last 20 years. The actual number of people who have ASD is difficult to ascertain, the National Autistic Society suggests that at least half a million families are affected by ASD in the UK alone. A meta-analysis of 32 international epidemiological surveys carried out between 1966 and 2001 estimated that it occurs in 27.5 out of 10,000 children[2], although a recent study which investigated a sample of 56,946 children in South London estimated that the prevalence of ASD within this group of children was 116.1 out of 10,000[3].

Within the spectrum of autism disorders there are three main classifications: classic autism which is sometimes termed 'pure autism' or 'Kanner's autism' (after the physician Leo Kanner who first defined the disorder in 1943); Asperger's syndrome (independently identified by Hans Asperger in 1944); and Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS). The benchmark for diagnosis is a list of behavioural symptoms documented in the Diagnostic and Statistical Manual (currently DSM-IV) published by the American Psychiatric Association.[4] Symptoms which indicate a diagnosis of classic autism include: impairment in the use of non-verbal behaviour such as limited eye contact, reduced facial expression and limited use of gestures; failure to develop peer relationships; lack of joint attention (sharing interests with others); a delay in, or lack of,

development of spoken language; inability to sustain conversations with others; idiosyncrasies of language; lack of spontaneous or imaginative play; restricted and stereotyped interests; and repetitive and stereotyped movements. Asperger's syndrome shares many of the symptoms of classic autism, but with no clinically significant delay in either language or cognitive development. The diagnosis PDD-NOS is given when many of the symptoms listed above are present and there is a degree of impairment in all the triad features (social interaction, communication and markedly restricted repertoire of activities and interests) but the range of impairments is not sufficient to meet a diagnosis of either classic autism or Asperger's syndrome. In addition, the terms low- and high-functioning are sometimes used to differentiate those children with ASD who also have learning difficulties and those who do not. Throughout this review we will use the term ASD to refer to the spectrum of autistic type diagnoses including classic autism, Asperger's syndrome and PDD-NOS.

In addition to problems in social behaviour, communication and imagination, many individuals with ASD report abnormal sensory processing[5,6] and there is a range of anecdotal and observational evidence of atypical responses to sensory stimuli in ASD[7-9]. This can include either hyper- or hypo-sensitivity to sight, sound or touch. In the visual domain, avoidance of eye contact, fixation on parts of objects, e.g. the spinning wheels of a toy car, and hyper-sensitivity to flickering lights are typically cited as evidence of unusual sensory profiles. Within the cognitive psychology literature, people with ASD are said to have an unusual cognitive style [10,11,12]). For example, individuals with ASD tend to focus more on small details within a scene and are less able to integrate information in relevant context. Evidence for this occurs across domains. In language for example, it has been demonstrated that children with ASD display a very literal, pragmatic understanding of the spoken word and are less

influenced by sentence context when understanding homographs ("there was a tear in her eye" / "there was a tear in her dress") than typically developing children[13]. However much of the research on cognitive styles in ASD has focussed on the domain of visuo-spatial perception. For example, it has been demonstrated that individuals with ASD show superior performance on visual search tasks in which they are required to identify a target stimulus, such as a red letter X from an array of distractors, such as red letter Ts and green letter Xs[14]. Additionally, people with ASD can detect a target figure embedded within a more complex figure more rapidly than typically developing matched controls[15]. In contrast it has also been reported that participants with ASD are less able than matched controls to detect coherent motion amongst noise[16] and are less posturally reactive to optic flow[17]. Recent research using psychophysical threshold detection tasks suggests that participants with ASD are more sensitive to simple visual stimuli, i.e. stimuli defined by first order characteristics such as luminance, but less sensitive to complex visual stimuli, i.e. stimuli defined by second order characteristics such as texture or contrast, than matched controls[18,19]. Despite this array of interesting findings, the exact origins of atypical perception in ASD remain unclear.

There has been an assumption in the field to date that basic aspects of perception are unaffected in ASD and that deficits in higher-order, cortical systems, such as those that underpin attention or perceptual integration, are the cause of the unusual perceptual style said to characterise ASD. There are a small number of published studies however, which indicate that aspects of low level vision are compromised in ASD. Unfortunately, these papers generally consist of a limited number of subjects who are not always clearly diagnosed. There is a more clearly defined literature based around oculomotor control in ASD as the results of such

studies provide insight into the functional integrity of multiple brain systems, although this again is based on a small number of papers. The aim of this literature review is to summarise the published research on visual function in ASD in an attempt to raise awareness of the importance of empirical investigation of vision in this population, and to consider whether any meaningful conclusions about vision in ASD can be drawn from the data presented to date.

Clinical signs and symptoms

Two main types of study design have been used to investigate the incidence of clinically relevant visual problems in people with ASD: retrospective surveys and small screening studies. The screening studies are hampered by small sample sizes whereas the surveys generally include data from many participants but lack detailed investigation of either visual function or ASD symptomatology. For example, a relatively large retrospective population based study of 152,732 Finnish children aged 3 to 18 years identified 187 with autistic disorder from hospital records. The number of these children with visual problems was high, with 36 (19.3%) having impaired vision, correctable to >0.1 logmar units (6/7.5 Sns equivalent), and 7 (3.7%) being blind.[20] While this suggests that the incidence of visual impairment in children with ASD is greater than in typically developing children, no further details as to the type of visual problems were given. Kaplan et al.[21] reviewed questionnaire data held at an independent American Autism Research Institute and reported that from a sample of 469 children whose parents reported symptoms commensurate with a diagnosis of pure autism, 27% were reported to be cross-eyed which was interpreted by the authors to reflect strabismus. Of 7,171 children whose reported symptoms were commensurate with a diagnosis within the wider spectrum of autistic disorders 19.7%

were defined as having strabismus. Given that the incidence of strabismus in the normal population is reported as 2-5% [22-24], these data suggest that the occurrence of strabismus is greater in individuals with ASD than in the typical population. However, in this study neither the diagnosis of the individuals nor the detection of strabismus was achieved by standardised methods.

Screening studies which involve recruiting a selection of people who have been diagnosed with ASD and examining their visual function are able to specifically outline the visual status in people with ASD from clinical examination. This technique can be empirically rigorous, but when only a small number of participants are recruited and the selection criteria are not properly outlined, it can be difficult to draw reliable conclusions from the data. Denis et al.[25] carried out an ophthalmological investigation on just 10 children who were diagnosed with ASD. The children were aged between 1 and 14 years, the mean age was 8.5 years and only 2 children were less than 8. This revealed a high incidence of hypermetropia (70%) and astigmatism greater than 1 dioptre (60%). Strabismus was found in 6 cases (60%) of which 4 of these were exotropic. In addition, pallor of the optic disc in 4 of the 10 children on fundus examination was reported. It is unclear how the participants in this study were diagnosed however, as it is very unusual for a child to have a confirmed diagnosis of ASD at only one year of age. In addition, the selection criteria for this study were not stated, and the participants were tested in an Ophthalmology department, therefore it is possible that rather than being a representative sample, selection was biased by participants who had already been referred to investigate visual problems. Furthermore, it is difficult to draw reliable conclusions from a sample of ten individuals given the degree of variation of refractive error in the normal population. In a larger study, Scharre and Creedon[26] studied 34 children who were diagnosed as

having ASD based on DSM-III criteria with an age range of 2 to 11 years. In this study, participants were recruited from a day school at a child development centre, and participants with neurological conditions other than autism (e.g. seizures) were excluded. Ocular motility and optokinetic responses were assessed with a hand-held rotary drum. Voluntary smooth pursuit was elicited in only 5 of the 34 children. The majority demonstrated a series of saccadic fixations in place of smooth pursuit movements. Typical optokinetic nystagmus responses were obtained in only 3 of the 34 and complete absence of the response occurred in 3 children despite accurate fixation of the drum. Binocular grating acuity was measured with Teller cards and found to be in the range of 6/4.5 to 6/480. Monocular acuity was not assessed due to difficulties with occlusion. A significant refractive error was found in 44% of children: myopia ≥1.00DS 8.8%; hypermetropia ≥1.00DS 17.6%; astigmatism 17.6%; anisometropia ≥1.00DS 5.8%. Strabismus was found in 21% of the children, the majority of these (6/7) having intermittent exotropia. These data concur with the finding from Kaplan et al.[21] and suggest that, even in a well controlled sample, strabismus is considerably more likely to occur in children with ASD. Combined with the finding of a high incidence of refractive error, these reports suggest that this group may be vulnerable to the development of amblyopia and hence particularly in need of visual screening. However, in a further study which involved extensive medical screening of 25 clearly diagnosed and randomly selected individuals with autism[27] only two individuals with autism had abnormal ophthalmological examination and one of these individuals had additional medical complications namely rubella encephalopathia and cataract. The nature of the ophthalmological examination given was not reported however.

There is some evidence, published in the late 1980s, that individuals with ASD may have abnormal retinal function. By recording electroretinograms (ERG) which measure the amplitude of electrical activity produced by the retina following stimulation with light flashes, Ritvo et al.[28] demonstrated that out of 27 participants with ASD 48% of the sample (13 individuals) had abnormally low b-wave amplitude, suggesting abnormal rod function. Selection criteria for this study were based on whether or not the individuals with ASD were considered to be able to be tested without sedation, and the participants were screened for any medical or neurological problems known to influence ERG. An additional study was published in 1989 which reported that 11 out of 22 (50%) participants with ASD had subnormal b-wave amplitudes,[29] however this was reported by the same research group and it is unclear whether or not this represents an independent study with a different sample of participants.

In summary, although some of the data have clear limitations such as small sample sizes and lack of information regarding the history, diagnosis and selection of the participants, this small collection of studies suggests that the incidence of visual disturbance may be greater in people with ASD than in the non-autistic population. In particular, higher incidence of refractive error, strabismus, reduced smooth pursuit and atypical OKN have been reported, and reduced rod function has been implicated. We suggest that further study is needed in order to support or refute the prevalence of such visual dysfunction in ASD. In order to collect reliable data in this area it is necessary to ensure the co-operation of the participant which can be difficult when testing children who may not enjoy the close personal contact, novel environment or sustained attention required to accurately complete vision screening. In these circumstances, pre-teaching and familiarisation with the personnel and instruments

encountered during visual screening may help. This has been assessed empirically by Bachman et al.[30] who developed a pre-teaching session which allowed children to see, touch and manipulate the instruments/ testing equipment to be used in vision screening and gave the children demonstrations of what the different tests (monocular and binocular acuity, cover testing, stereopsis, pupillary response, oculomotor skills, retinoscopy and ophthalmoscopy) would involve. Following pre-teaching, 102 out of 105 children aged between 3 and 5 with developmental delay including Downs syndrome, autism, physical handicap and cognitive impairment successfully completed all screening procedures.

Oculomotor control in ASD and implications for brain circuitry.

In addition to evidence of abnormal visual function in ASD, there is also evidence for abnormalities in oculomotor control and saccade generation, although reports vary as to the exact nature of this abnormality. An initial investigation of oculomotor control measuring corneo-retinal potentials during a saccade task, reported that from a sample of 11 children with autism or autistic like symptoms, 6 (55%) displayed hypometric saccades and 4 (36%) had reduced saccade velocity.[31] These children were aged between 9 & 16, and were selected from a pool of 54 children fulfilling DSM-III criteria for autism selected on the basis of their ability to participate in oculomotor testing.

In general, studies of eye movement in ASD have been carried out in order to test hypotheses about particular brain circuitry which may be compromised in the disorder. For example, dysfunctions of cerebellar systems (vermal lobules VI and VII) and cortical systems have been proposed in ASD.[32] [33] The vermal areas of the cerebellum are largely involved with guiding the motor precision of saccades hence

dysfunction would lead to abnormal saccade metrics whereas the dysfunction of prefrontal cortex and associated areas would allow normal saccade metrics but would give impaired saccadic tasks requiring higher cognitive control such as antisaccades and oculomotor delayed-response tasks (memory-guided saccades). However, in addition to providing information about the integrity of cortical systems in ASD, these studies also provide information as to the integrity of the oculomotor system in ASD. Minshew et al.[34] used oculomotor paradigms to test the cerebellar and neocortical systems in 26 high-functioning clearly diagnosed autistic adolescents, young adults and matched controls. They found that saccade metrics were normal in the autistic group, hence determining no disturbance of function from the cerebellar vermal lobules VI and VII. Deficits were found in the autistic group for the antisaccade and oculomotor delayed-response tasks however, indicating dysfunction in circuitry of prefrontal cortex rather than in the perceptual system per se. This result contrasts with the finding from Rosenhall et al.[31] who reported hypometric saccades and reduced saccade latency in ASD. However, it is generally consistent with a recent study of saccade initiation in 11 high-functioning autistic adolescents,[35] which reported impairment in generating predictive saccades and inhibiting saccades when they were not called for, despite no impairment in disengaging fixation and no differences in saccade latency, amplitude or peak velocity.

In addition to abnormalities in high level saccade metrics, other data suggest abnormal smooth pursuit in ASD. This has been interpreted to reflect reduced functional connectivity, the co-ordinated activity of distributed but functionally related brain regions, rather than abnormality in any single brain area. To evaluate the integrity of brain areas involved in various aspects of smooth pursuit a detailed analysis of pursuit in 60 high functioning autistic participants (mean age of 20 years)

and 94 age and gender matched controls was presented by Takarae et al.[36]. They tested both the initial 'open loop' period of pursuit and subsequent 'closed loop' stage, which rely on different brain systems. The 'open-loop' stage consists of the first 80-100ms after pursuit onset and is dependent on analysis of visual motion performed by contralateral extrastriate cortex (V5/MT)[37]. The closed loop stage of sustained pursuit follows this and relies upon memory for target velocity and predictions of target motion, and feedback about performance, the processing for this thought to be performed by the cortical eye fields and cerebellum. The ASD group were found to have normal pursuit latency, however, open loop pursuit gain responses were reduced when targets moved into the right visual field. Closed loop pursuit gain was reduced for oscillating and ramp targets in both directions. This difference in closed loop pursuit gain was more apparent in older participants (≥16 years) suggesting a reduced maturational achievement of the pursuit system in ASD. Takarae et al.[36] further suggest that these findings may reflect reduced functional connectivity of the visual pursuit system. This conclusion is echoed by Nowinski et al.[38] who investigated the frequency of square wave jerks (SWJs) during fixation as increased frequency of SWJs is a known consequence of cerebellar pathology[39]. From a sample of 52 high-functioning individuals with ASD (mean age 17 years, range from 8 – 46 years) and an age-IQ matched control group Nowinski et al.[38] found no increase in the rate of SWJs in ASD, nor differences in the degree of foveopetal drift during fixations. However the size of the first intrusive saccade in SWJs was increased, and the time interval for a second saccade to correct the intrusive saccade was reduced. These findings suggest grossly intact cerebellar control of motor function in ASD, and the authors concluded that atypical metrics of SWJs in the participants with ASD may be due to faulty functional connectivity in cortico-cerebellar networks.

In summary, studies of oculomotor control in ASD have found that in general, basic saccade generation is intact, although Rosenhall et al[31]. have reported abnormal saccades. However, higher level aspects of oculomotor control such as saccadic suppression are impaired[34]. In addition, there is no difference in the frequency of SWJs in ASD[38], however it has been reported that children with ASD make significantly more saccades in between stimulus presentations than either typically developing children, children with dyslexia, or children with ADHD[40]. Further, no differences have been found in pursuit latency in ASD, but young adults with ASD have been shown to have reduced open and closed loop pursuit gain[36].

Functional imaging of visual cortical organisation

Typically, brain imaging studies, using techniques such as positron emission topography (PET) and functional magnetic resonance imaging (fMRI) which measure brain activity while the participant views certain stimuli or engages in a particular cognitive task, have focussed on unravelling whether different patterns of brain activity occur when participants with ASD engage in high level perceptual, or cognitive tasks. For example there is evidence of reduced activation of brain areas involved in the perception of faces in participants with ASD[41], and evidence that the occipital cortex is overactive and parietal cortex is under active during the detection of embedded figures[42]. There has been limited investigation of activity in the so-called early visual areas, e.g. the striate cortex in ASD. However, one recent study used the technique of fMRI to investigate the retinotopic organisation of the visual cortex of adults with high-functioning autism[43]. The results showed that, in all 8 participants, the early visual areas were normally organised and showed a typical ratio between central and peripheral field representation. The authors therefore suggest that

any differences in the visual capacities of individuals with ASD are likely to arise from higher-level areas such as the extra-striate cortex. In contrast to this conclusion, Milne et al.[44] recorded EEG while 18 children / adolescents with ASD (mean age 12 years) and 18 matched controls viewed Gabor patches presented at a range of spatial frequencies. The visual evoked potentials (VEP) in the children with ASD reached a peak more quickly in the children with ASD than in the control group suggesting enhanced cortical perception, however the amplitude of the earliest part of the VEP which peaks at around 90 ms, was reduced in most of the participants with ASD suggesting abnormal neuronal activity in the striate cortex of participants with ASD.

Association between ASD and other medical syndromes.

There is no clear evidence of the timing and precise location of developmental disturbance of the brain in ASD, however its associations with Möbius syndrome [45], Goldenhar's syndrome[46] and thalidomide[47] have suggested an early insult in embryonic development (20-36 days after fertilisation)[48]. A Swedish study [45] of 22 patients with Möbius syndrome notes that 7 (32%) had autistic disorder or autistic-like condition, suggesting a high degree of over-lap between ASD and other developmental conditions which impact on the visual system. In addition, there is evidence that children diagnosed with Fragile X syndrome (FXS) also have a higher incidence of visual abnormalities than that reported in the typical population[49]. FXS is a genetic condition which has cognitive and behavioural similarities to ASD. From a group of 30 participants with FXS aged between 4 and 16 years, 30% showed strabismus. Of those with strabismus 70% showed esotropia. In addition a high degree of refractive error, usually hyperopia, was reported[49].

It has been suggested[50] that impaired visual function could be a direct factor in the development of autism symptoms. However given the paucity of empirical studies and the inherent circularity in determining causality from correlation we suggest that this interpretation is treated with caution. Even if direction of causality could be established, the screening studies cited above suggest that visual problems are neither necessary nor sufficient to give rise to a diagnosis of ASD. However, the increased frequency of visual problems in ASD, and the overlap between ASD and other conditions which impact the visual system suggest that atypical brain development in a range of systems may characterise the aetiology of ASD. If the visual input that a child with ASD receives is degraded or disrupted in some way, it is conceivable that both their visual experience of the world around them and cortical organisation in response to visual input may develop atypically, which may in turn give rise to other ASD specific symptoms. Further consideration of this suggestion will require a dual approach. From a clinical perspective it is necessary to screen for, and correct wherever possible, reduced visual function in individuals with ASD. From a research perspective it is necessary to establish whether there is a single, or multiple causes of the overlap between visual dysfunction and ASD; whether reduced vision occurs in a specific, homogeneous sub-group within ASD; and at what stage during development visual dysfunction and ASD become intertwined.

Conclusions

There is some, limited, evidence of increased incidence of refractive error and strabismus, abnormal pursuit gain and saccadic responses in individuals with ASD, yet as a corpus of work these data are limited. In order to further understand the nature of visual disturbance in ASD it is necessary to collect data from larger samples

of participants using standardised techniques, and, where standardised data are not available, to compare the performance of individuals with ASD with that of a well matched control group. Familiarisation with visual screening instruments and techniques may facilitate the collection of reliable data. It is also important to obtain sufficient information, using standardised instruments, about the individuals with ASD. It is possible that what is currently labelled "autism" or "ASD" is not a homogeneous disorder and instead reflects a heterogeneous subset of independent disorders with different aetiologies. In order to fully understand the role that atypical vision plays in this spectrum of disorders and the role that ASD plays in the development of the visual system, it is necessary to pay attention to the detail of the diagnosis of participants involved in future studies. The data reviewed above, although sparse, suggests that the visual system is implicated in ASD and that individuals with ASD are significantly more likely to have visual problems than individuals without ASD. We conclude that further research is warranted and that screening for visual dysfunction should be a priority for individuals with ASD. This is supported by current guidelines for vision screening in the UK which advocates that a specialist eye examination should be offered to all children with a neuro-developmental problem[51]. It is hoped that via future well controlled research studies a better understanding of vision in ASD will lead to deeper understanding of the neural correlates of the disorder, and importantly, to the development of targeted screening which will help to reduce some of the problems caused by abnormal vision in this population.

References

1. Yeargin-Allsopp, M. et al. Prevalence of Autism in a US Metropolitan Area. *JAMA* **289**, 49-55 (2003).
2. Fombonne, E. Epidemiological Surveys of Autism and Other Pervasive Developmental Disorders: An Update. *Journal of Autism and Developmental Disorders* **33**, 365 - 382 (2003).
3. Baird, G. et al. Prevalence of disorders of the autism spectrum in a popultion cohort of children in South Thames: the Special Needs and Autism Project (SNAP). *The Lancet* **368**, 210 - 215 (2006).
4. APA. *Diagnostic and Statistical Manual of Mental Disorders 4th edition* (ed. Association, A. P.) (American Psychiatric Association, 1994).
5. Grandin, T. *Thinking in pictures: and other reports of my life with autism. pg 73* (Doubleday, New York, 1996).
6. Williams, D. *Autism: An inside-out approach* (Jessica Kingsley, London, 1996).
7. Rogers, S. J. & Ozonoff, S. Annotation: What do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *Journal of Child Psychology and Psychiatry.* **46**, 1255 - 1268 (2005).
8. O'Neill, M. & Jones, S. P. Sensory-Perceptual Abnormalities in Autism: A Case for More Research. *Journal of Autism and Developmental Disorders* **27**, 283 - 293 (1997).
9. Davis, R. A. O., Bockbrader, M. A., Murphy, R. R., Hetrick, W. P. & O'Donnell, B. F. Subjective Perceptual Disotrotions and Visual Dysfunction in Children with Autism. *Journal of Autism and Developmental Disorders* **36**, 199 - 210 (2006).
10. Happé, F. Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Sciences* **3**, 216 - 222 (1999).
11. Happé, F. & Frith, U. The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders* (2006).
12. Mottron, L., Dawson, M., Soulieres, I., Hubert, B. & Burack, J. A. Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders* (2006).
13. Happé, F. Central coherence and theory of mind in autism: Reading homographs in context. *British Journal of Developmental Psychology.* **15**, 1 - 12 (1997).
14. Plaisted, K., O'Riordan, M. & Baron-Cohen, S. Enhanced Visual Search for a Conjunctive Target in Autism: A research note. *Journal of Child Psychology and Psychiatry* **39**, 777 - 783 (1998).
15. Shah, A. & Frith, U. An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry and Allied Disciplines* **24**, 613 - 620 (1983).
16. Milne, E. et al. High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines* **43**, 255 - 263 (2002).
17. Gepner, B., Mestre, D., Masson, G. & De-Schonen, S. Postural effects of motion vision in young autistic children. *Neuroreport* **6**, 1211 - 1214 (1995).

18. Bertone, A., Mottron, L., Jelenic, P. & Faubert, J. Motion perception in autism: A "Complex" Issue. *Journal of Cognitive Neuroscience* **15**, 1 - 8 (2003).
19. Bertone, A., Mottron, L., Jelenic, P. & Faubert, J. Enhanced and diminished visuo-spatial information processing in autism depends on stimulus complexity. *Brain* **128**, 2430 - 2441 (2005).
20. Kielinen, M., Rantala, H., Timonen, E., Linna, S. L. & Moilanen, I. Associated medical disorders and disabilities in children with autistic disorder - A population-based study. *Autism* **8**, 49-60 (2004).
21. Kaplan, M., Rimland, B. & Edelson, S. M. Strabismus in autism spectrum disorder. *Focus on Autism and Other Developmental Disorders* **14**, 101 - 105 (1999).
22. Graham, P. A. The epidemiology of strabismus. *British Journal of Ophthalmology* **58**, 224 - 231 (1974).
23. Lennerstrand, G. in *Wenner-Gran International Symposium* 5 - 21 (1987).
24. Stayte, M., Reeves, B. & Worthwam, C. Ocular and vision defects in pre-school children. *British Journal of Ophthalmology* **77**, 228 - 232 (1993).
25. Denis, D., Burillon, C., Livet, M. O. & Burguiere, O. Ophthalmologic findings in the autistic child. *Journal Francais D Ophtalmologie* **20**, 103-110 (1997).
26. Scharre, J. E. & Creedon, M. P. Assessment of Visual Function in Autistic Children. *Optometry and Vision Science* **69**, 433 - 439 (1992).
27. Skjeldal, O. H., Sponheim, E., Ganes, T., Jellum, E. & Bakke, S. Childhood autism: the need for physical investigations. *Brain & Development* **20**, 227-233 (1998).
28. Ritvo, E. R. et al. Electroretinograms in autism: a pilot study of b-wave amplitudes. *Amercian Journal of Psychiatry* **145**, 229 - 232 (1988).
29. Creel, D., Crandall, A. S., Pingree, C. & Ritvo, E. R. Abnormal electroretinograms in autism. *Clinical Vision Science* **1**, 85 - 88 (1989).
30. Bachman, J. A., Bachman, W. G., Franzel, A. S. & Marcus, M. C. Preteaching developmentally delayed preschoolers to aid vision screening. *Optometry and Vision Science* **71**, 713 - 716 (1994).
31. Rosenhall, U., Johansson, E. & Gillberg, C. Oculomotor findings in autistic children. *The journal of Laryngology and otology* **102**, 435 - 439 (1988).
32. Ritvo, E. R. et al. Lower purkinje cell counts in cerebella of four autistic subjects: initial findings of the UCLA-NSAC autopsy research report. *American Journal of Psychiatry* **143**, 862 - 866 (1986).
33. Courchesne, E. Brainstem, cerebellar and limbic neuroanatomical abnormalities in autism. *Current Opinion in Neurobiology* **7**, 269 - 278 (1997).
34. Minshew, N. J., Luna, B. & Sweeney, J. A. Occulomotor evidence for neocortical systems but not cerebellar dysfunction in autism. *Neurology* **52**, 917 - 922 (1999).
35. Goldberg, M. E. et al. Deficits in the initiation of eye movements in the absence of a visual trget in adolescents with high functioning autism. *Neuropsychologia* **40**, 2039 - 2049 (2002).
36. Takarae, Y., Minshew, N., Luna, B., Krisky, C. M. & Sweeney, J. A. Pursuit eye movement deficits in autism. *Brain* **127**, 2584 - 2594 (2004).
37. Lisberger, S. G. & Movshon, J. A. Visual motion analysis for pursuit eye movements in area MT of macaque monkeys. *Journal of Neuroscience* **19**, 2224 - 2246 (1999).

38. Nowinski, C. V., Minshew, N., Luna, B., Takarae, Y. & Sweeney, J. A. Oculomotor studies of cerebellar function in autism. *Psychiatry Research* **137**, 11 - 19 (2005).
39. Zee, D. S., Yee, R. D., Cogan, D. G., Robinson, D. A. & Engel, W. K. Ocular motor abnormalities in hereditary cerebellar ataxia. *Brain* **99**, 207 - 234 (1976).
40. Kemner, C., Verbaten, M. N., Cuperus, J. M., Camfferman, G. & van Engeland, H. Abnormal saccadic eye movements in autistic children. *Journal of Autism and Developmental Disorders* **28**, 61 - 67 (1998).
41. Schultz, R. T. et al. Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Archives of General Psychiatry* **57**, 331 - 340 (2000).
42. Ring, H. A. et al. Cerebral correlates of preserved cognitive skills in autism: A functional MRI study of Embedded Figures Task performance. *Brain* **122**, 1305 - 1315 (1999).
43. Hadjikhani, N. K. et al. Early visual cortex organization in autism: an fMRI study. *Neuroreport* **15**, 267 - 270 (2004).
44. Milne, E., Scope, A., Pascalis, O., Vigon, L. & Buckley, D. Atypical Visual Evoked Potentials in Autistic Spectrum Disorder. (submitted).
45. Johansson, M. et al. Autistic spectrum disorders in Möbius sequence: a comprehensive study of 25 individuals. *Developmental Medicine & Child Neurology* **43**, 338 - 345 (2001).
46. Landgren, M., Gillberg, C. & Strömland, K. Goldenhar syndrome and autistic behaviour. *Developmental Medicine & Child Neurology* **34**, 999 - 1005 (1992).
47. Strömland, K., Nordin, V., Miller, M. T., Akerstrom, B. & Gillberg, C. Autism in thalidomide embryopathy: a population study. *Developmental Medicine & Child Neurology* **36**, 351 - 356 (1994).
48. Miller, M. T. et al. Autism with ophthalmis malformations: The plot thickens. *Trends in American Ophthalmologic Society* **102**, 107 - 121 (2004).
49. Maino, D. M., Wesson, M., Schlange, D., Cibis, G. & Maino, J. H. Optometric Findings in the Fragile X-Syndrome. *Optometry and Vision Science* **68**, 634-640 (1991).
50. Kaplan, M. *Seeing through new eyes* (Jessica Kingsley Publishers, London, 2006).
51. Hall, D. M. B. & Elliman, D. *Health for all children* (Oxford University Press, 2003).