Psychophysical Studies Of Motion Perception In Autism Spectrum Disorders

by

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Author's declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Introduction

Studies have shown considerable evidence of visual dysfunction in Autism Spectrum Disorders (ASD). Motion perception research in ASD reports a superior performance in processing motion information of fine details and neglects global information. However, there are many variabilities in these experimental results, particularly in adults with autism. Several theories have been put forward as the underlying cause(s) of motion deficits in autism. These include: enhanced local domain information processing at early visual area V1; abnormal processing at the higher visual cortical area MST including V5/MT; and/or abnormal functional and structural connectivity between and within cortical networks that are recruited during different motion processing tasks. In this study, we used multiple motion perception tasks in order to activate different visual neural networks that may contribute to perception of specific motion domains in order to understand visual perception abnormalities in autism.

The specific aims of each experiment included in this thesis are as follow:

- Chapter 3: To investigate the theory of enhanced local details and neglected global picture, using- for the first time- local/global motion coherence stimuli in autism.
- Chapter 4: To investigate the neural response biased found in autism in response to radial optic flow. We used optic flow stimuli in self-heading direction discrimination tasks.

- Chapter 5: To investigate whether speed parameter is normal in autism-based on the previous outcome- using drifting grating stimuli in a speed discrimination task.

Participants and Methods

This study recruited two groups of subjects –one with ASD (*n* = 14), and another with Typical Development (TD) (*n*= 14), age range (16- 40 years).

- Chapter 3 : We used Random Dot Kinatogram (RDK) as global coherence stimuli and employed it in two tasks : (1) Coherent Motion (CM) task, where coherence levels were varied and the subjects had to detect the global direction of the coherent dots, (2) CM with Form From Motion (FfM) stimulus where the FfM consisted of one of four different shapes embedded in the global RDK task.

- Chapter 4: We used RDK with optic flow stimuli, which investigated self-direction discrimination in two tasks: angle of eccentricity, and contrast sensitivity. In both tasks we randomized the dot density (15, 80 dots) and speed (4, 10 deg/sec) of the moving stimulus dots.

- Chapter 5: We used a pair of drifting gratings with a spatial frequency 2 cycle/ degree, oriented vertically and drifting perpendicular to the direction of orientation, and varied the speed (2, 6 deg/ sec) and the stimuli presentation (250 – 500ms)

Results

- Chapter 3: Although adults with autism showed comparable performance in reporting global direction similar to the control group, their ability to process global properties, when FfM shape was embedded, declined (Mean threshold ASD: MC= 13.58, CM-FfM=

30.65) In addition, ASD required more time to respond to global coherence even when their performance was comparable to that of the control group.

- Chapter 4: No significant group differences were found for low dot density (15 dots), while high dot (80 dots) density showed low sensitivity to OF motion in the ASD group compared to the TD. Contrast sensitivity task, however, showed lower sensitivity in the ASD group for detecting OF motion when dot density was low (15 dots) and no differences at higher dot density (80 dots) was found. Both tasks showed no group differences in the dot speed changing and no significant differences in response time were observed.
- Chapter 5: No group differences ($p = 0.226$) in sensitivity to speed-discrimination task were found between the ASD and control group in all parameters used in this experiment. The response times were also comparable between both groups ($p = 0.855$).

Conclusions

- Chapter 3: Motion perception in ASD found enhanced to local details particularly when motion stimuli involve both local/global information segregation at the same time. We suggest increased internal neural noise and worse external noise filtering as cause of poor global performance in this type of task.
- Chapter 4: There were selective impairments in OF processing that may related to altered neural connectivity between the activated visual areas in ASD. Another suggestion might be related to long neural trajectory within higher visual areas, ex. MST.
- Chapter 5: Normal motion processing may be found in ASD, however, it this might triggered by task complexity and the visual neural areas that are involved in processing motion information.

The overall results suggest selective impairments in visual motion perception in ASD. These impairments would depend upon the task requirements and therefore on the activated visual networks that contribute to different aspects of motion information processing. The present studies provide novel findings in defining deficits in motion perception in autism, which thereby may contribute in understanding disturbed visual function in ASD.

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Dedication

To my husband Luai and my children Adam, Tala, Yara for being with me, supporting me and believe in me, and for drawing the smile on my face every time. For my parents and brothers and sisters, for being always proud of me.

Will never do this without you.

Love you all

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List of Abbreviations

%	Percent
AQ	Autism Quotient
AS	Asperger Syndrome
ASD	Autism Spectrum Disorders
BM	Biological Motion
C	Control group
cpd	Cycle per degree
CM	Coherent Motion
d-stream	Dorsal- stream
F	Female
FfM	Form-from Motion
fMRI	functional Magnetic Resonance Imaging
GMT	Global Coherent Task
HFA	High Functioning Autism

IQ	Intelligence quotient
LSF	Low spatial frequency
M	Male
MST	Medial Superior Temporal area
MT	Middle temporal visual area (V5)
OF	Optic Flow
PLD	Point Light Display
RDK	Random Dot kinematograms
RT	Response Time
STS	Superior Temporal Sulcus
TD	Typical Development
v-stream	Ventral- stream
V1	visual area 1

Chapter 1

Visual Function In Autism Spectrum Disorders: A Critical Review

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1.1 Overview

Studies have shown considerable evidence of visual dysfunction in Autism Spectrum Disorders(ASD). Anomalies in visual information processing can have a major effect on the life quality of individuals with autism. We summarise the hypotheses and theories underlying neural aetiologies and genetic factors that cause these disorders, as well as possible influences of unusual sensory processing on the communications and behaviour characterised by the autistics. In particular, we review the impact of these dysfunctions on visual performance.

1.1.1 Key words

Autism spectrum disorders, colour vision, neural processing, vision tests, visual acuity, visual performance, visual search

1.2 Introduction

Autism spectrum disorder (ASD) is a developmental disability syndrome characterised by impairments in social communication and interaction defects. When ASD children start to interact socially, a number of features appear in daily activities, for example, learning difficulties, repetitive behaviour, social and communication parries and abnormal interests. These represent the first symptoms of autism spectrum disorder.[1] According to the estimate made in March 2014 by the US Center for Diseases Control (CDC), one out of 68 children is born with an autism spectrum disorder; males are more likely to have autism than females. The number with ASD in the population increased by 2.8 per cent from 2002 to 2012.[2] Research from the Autism and Developmental Disabilities Monitoring Network, US showed an increase from one per 165 in 2002 to one per 68 children in 2012 diagnosed with autism spectrum disorder.[3] Both improved clinical diagnoses of developmental conditions and heightened awareness of the

symptoms among parents and public are posited as contributors to the reported increase in ASD prevalence.[3] The new (DSM-5) diagnostic criteria include all subgroups defined by DSM-IV and intellectual disability (ID) disorders under one umbrella, which may serve to facilitate access to appropriate services and supports for individuals who have ASD in addition to intellectual disability.[4] There is a great debate in the scientific community as to how much of the increase is real and how much is reclassification. Therefore, the numbers of the current prevalence of ASD might include individuals who previously would have been identified as having intellectual disability or being quirky or eccentric. Symptoms of ASD can be diagnosed as early as two to four years and may vary throughout a child's life.[5] In some cases, signs of ASD might start as early as six months old.[6] Anomalous visual disorders are associated with this condition. Several studies of ASD reported impairments in visual perception, facial recognition and movement gestures that are reflected on their social, behavioural and communication skills.[7–9] Vision research has linked abnormal performance in visual tasks by autistic individuals to specific dorsal dysfunction and disturbance in connectivity between brain regions in visual cortex; however, the main reasons are still unknown. In this review, we summarise the findings and discuss areas where visual impairments are linked.

1.3 Diagnosis of ASD

Various diagnostic protocols have been used to diagnose ASD. The purpose of this section is to clarify the subgroups of DSM-IV; however, this review will not distinguish between these groups but instead will refer to ASD or autism according to DSM-5 to avoid confusion or misunderstanding.

In 1910, Eugen Bleuler,[10] a Swiss psychiatrist was the first to introduce the word autism. It came from the Greek word autos (meaning self); however, his term defined syndromes of

schizophrenia. The contemporary terminology of 'autistic' was first used in 1939 by Hans Asperger,[11] who was working at Vienna University Hospital at that time. He described what has been later defined as Asperger's syndromes and he used the phrase 'autistic psychopathy' to describe the syndromes of four children that he explained as having 'a lack of empathy, little ability to form friendships, one-sided conversation, intense absorption in a special interest and clumsy movements.' Alternatively, he called it 'little professors' syndromes'.[12] Meanwhile, Leo Kanner[13] reported 11 cases, all of whom shared the same unusual behaviours. Kanner's first paper 'Autistic aloneness' described the modern sense of autism. Silberman[14] discusses the history of this disorder. Since Kanner[13] and Asperger,[11] the definition of autism has evolved. In 1967, the International Classification of Diseases, Eighth Revision (ICD-8) listed what they called 'infantile autism' under schizophrenia, whereas the Diagnostic and Statistical Manual of Mental Disorders, Second Edition (DSM-II), published around the same year, specified 'schizophrenia, childhood type' without any reference to autism. Later, the DSM-III[15] published what is called the 'pervasive developmental disorder' that includes 'childhood onset pervasive developmental disorders' and 'infantile autism'. In the DSM-IIIR the names of the subgroups were changed to 'autistic disorder' and 'pervasive developmental disorder – not otherwise specified (PDD-NOS)'. By the release of DSM-IV,[16] there were three subgroups 'Asperger's disorder,' 'childhood disintegrative disorder' and 'pervasive developmental disorder – not otherwise specified (PDD-NOS)', which was also recognised by the International Classification of Diseases, Tenth Revision (ICD-10). In May 2013, the new version of DSM-5 eliminated the subgroups and replaced them by 'Autism spectrum disorder'.[4] No diagnostic subtypes (for example, Asperger's disorder and PDD-NOS) are listed; the idea was to measure the core feature of autism spectrum disorder' by a severity scales:

1- Social communication (SC)

2- Fixed interest and repetitive behavior (FIRB).

Each scale ranged from 1 to 3; the higher scores will indicate that an individual suffers from several core deficits and/or greater severity of impairment. The severity and range of symptoms for a child diagnosed with ASD may fall anywhere on the scale between 'high functioning' and 'severe developmental delay'. Both IQ and chronological age are usually associated scales, which categories ASD.[17] Visual function of patients with autism spectrum disorder often reported from individuals who are able to complete the communication, attentional and sensory demands of the testing. Therefore, less is known about individuals with ASD, who have more limited communication or functional skills.[7,18] Reszka et al[19] showed that most of the individuals classified with the DSM-IV autism, Asperger syndrome, or PDD-NOS also meet the DSM-5 diagnostic criteria of ASD; however, there has been much discussion of how the new criteria have affected diagnosis and treatment of ASD, practically in identifying high-functioning ASD.[20] These debates suggest that DSM-5 is limited to identify all sub-groups of autism, which limits the diagnosis, detection of underlying casual factors, and treatment planning.[21] For more details about the diagnostic criteria and subgroups of ASD, the reader is advised consult the reviews by Ousley and Cermak[4] and Bryant.[22]

1.4 The Biology And The Neuroscience Of ASD

From a neurobiological perspective view, ASD is associated with abnormal connectivity between brain regions. This could include a weakening of already formed connections or a failure of certain connections to establish correct organisation de novo.[23] Genetic and biological research of autism found that both the environmental and genetic factors increase the risk of ASD.[24]

These factors may however induce disruptions to cortical connection in utero or during the developmental stage.[25–27]

1.4.1 Developmental and Genetic Factors

The influences of genes and environmental factors on cortical development can vary between individuals and between functional areas, which suggests that specific disruptions may depend on the timing of the environmental insult. For example, zinc (Zn^{2+}) deficiency severely affects brain function and neural maturation during developmental stages, leading to severe brain impairment in learning and memory in autism spectrum disorders.[28] Based on family and twin studies, results have shown higher rates of ASD within the monozygotic twins (92 per cent) than dizygotic (10 per cent).[29] Therefore, the risk to having a sibling born with autism to families with an ASD child is high. The disturbance of severity of ASD varies among individuals, however, autistic siblings within one family may share the same severity and associated features as evidence of heritability.[30] On the other hand, Hallmayer et al[31] suggested that the consideration of monozygotic twins causing autism is incomplete where environment is a contributing factor. The results point to a possible aetiological heterogeneity of autism, which explains the different aetiologies between individuals with autism. Therefore, current genetic research is working on differentiation between individuals in order to distinguish relevant genes. According to the Genome-Wide Association Studies (GWAS), genetic variants in ASD can be either inherited or caused (which is often the case) by de novo mutations.[32] So far few genes are known to cause autism. Based on genetic studies, autism has inheritance based on interaction of many genes.[33] The disorder, however, does not follow the same predicted patterns of inheritance seen in monogenetic disorders, such as X-linked disorders.[34] Genetic mutation may be combined with other environmental factors to cause the differentiation in the autism spectrum.[24,31] Studies in

genetic variants have reported single nucleotide polymorphisms (SNPs) to have a major role in causing autism.[34] Genomic studies have identified replication and de novo variations in several gene mutations that affect protein formation and functioning that have been linked to ASD.[23,34,35] The PAGES (Population-Based Autism Genetics and Environment Study) in Sweden, the largest study of this kind,[30] examined the genetic variants spread across the genomes in more than 1.6 million families with more than 14,000 cases of autism. The study found that an inherited common variant accounts for the bulk of the genetic risk for strictly defined autism. Furthermore, the study identified some mutations that are not part of the "common variant" but nevertheless increased the risk of autism in individuals with the common variant.[30] However, other factors, such as the environmental and the epigenetics factors might also contribute in the variations risks in this group.

1.4.2 Epigenetic Factors

Epigenetic factors refer to the heritable changes in gene activity that are not caused by changes in the DNA sequences but rather by one of the following factors: changing the chromosomal histone modifications, chromatin remodeling, transcriptional feedback loops[36] and RNA silencing.[37] Any of these factors may lead to endocrine-disrupting chemicals that believed to interact with the neurodevelopment of autism. In fact, Qiu et al[38] has reported that epigenetic factors have more influence than alternation of the DNA sequences in autism, as the covalent modifications of DNA tend to create an interface between the changing environment and the fixed genome. Studies have linked gene-environmental factors that are likely to contain susceptibility loci for autism on human chromosomes to several environmental causes such as: parental ethanol exposure,[39] paternal age,[40] changes in the digestive tract or new diet,[41] oxidative stress, brain inflammation[42] and / or early brain injury.[43] The reader can refer to Grabrucker [28] for

more details. This altered modification in DNA is linked to various neurodevelopmental alterations in the CNS formation in autism, such as disturbed cortical and subcortical cytoarchitectonics, abnormal cell differentiation with reduced neural size and altered synaptogenesis.[44] Studies on vision have related these anomalies to the differences in local versus global visual motion perception[45] and to the excitatory-inhibitory disturbance [46] that is likely to underline altered visual information processing as well as the social characteristics in ASD.

1.5 Brain Development In ASD

Early brain overgrowth with a subsequent reduction or plateau in the first few years of life, followed by an abnormal growth pattern during adolescence is the most common indicator in ASD.[47] Enlargement coinciding with exaggerated cortical thinning seems to be more localised in the frontal region of the brain, which exhibited an abnormal volume of both grey and white matter compared to the frontal cortical region in non-ASD individuals of similar age.[48] As a result, deficits in local connectivity with increased long-range connectivity have been proposed to develop after 24 months of age, suggesting abnormal neural growth trajectories in autism.[47] Although autism may not account for certain deficits and their severity might vary and overlap with other syndromes, they are not synonymous with global intellectual disability or mental retardation. Research, however, suggests that a key component of ASD is abnormal connectivity between the frontal and temporal lobes that disrupt higher-order processing. For example, reduced activity in the superior partial loci (e.g., cytoarchitectonic abnormalities) may affect on visuo-spatial attention in autism.[49] Studies have shown that abnormalities in the cerebellum can also affect cognition, verbal abilities, and higher-order executive functions.[50,51] The main defect of the cerebellum in autism was found in the postero-lateral hemispheric region including

decreased numbers of Purkinje cells (PC) in autistic conditions. For example, Whitney et al[52] study compared six autism cases with five matched controls and used stereological techniques to count the density of Purkinje cells in the posterolateral cerebellar hemisphere. In the autistic cases, two had mild Purkinje cell decrease and one showed severe Purkinje cell decrease and three were normal. The author suggested that decreased Purkinje cells in the ASD brain may be linked to high intrauterine testosterone in the mother's womb, which results in neural developmental abnormalities;[53] however, the reduced level of Purkinje cells in autistic brains remains unclear (Figure 1-1).[54]

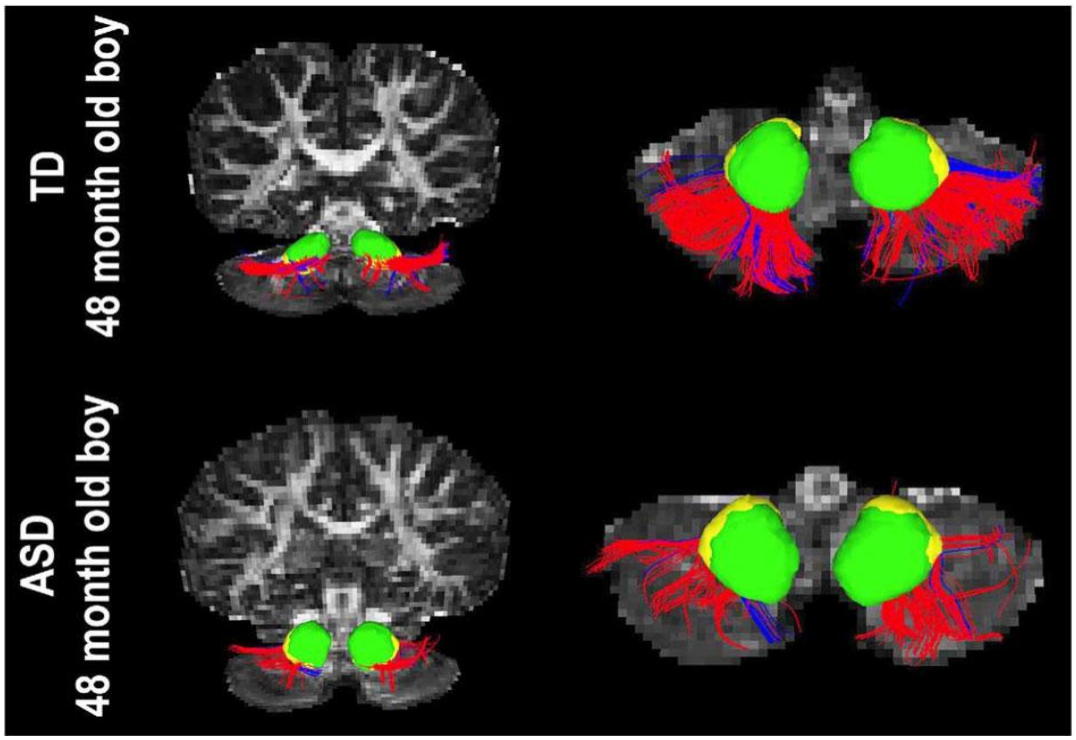

Figure 1-1 Reduced connectivity between the posterior-lateral cerebellar cortex with the dorsal dentate nucleus (red) and the ventral dentate nucleus (blue) in a boy with autism spectrum disorder, (bottom) compared with a typical developing boy (top).

For a good review of cerebellar defects in autism, see Fatemi et al,[55] MRI studies that explained the significant differences between ASD children and typical developing children (TD) in the trajectories connectivity between the posterior-lateral cerebellar cortex in both the ventral dentate

nucleus (VDN) and dorsal dentate nucleus (DDN) due to the decreased number and size of Purkinje cells. Related studies identified the posterior cerebellum to control the adaptation of saccadic eye movements by monitoring the difference between expected and observed movement outcomes.[56] Mosconi et al[57] showed reduced vermal activation during saccadic eye movements that reflects on the reduced rate of adaption during gaze shifts, which proves that cerebellar vermis is disrupted in this disorder. In addition, studies reported abnormalities in the neuronal migration of the anterior cingulated cortex (ACC).[58] This area, in particular, participates in a variety of functions and emotional information processing including the frontal visual field. The anterior cingulated cortex induces early learning, emotional responses and social interaction. Results related anterior cingulated cortex to the theory of 'mind' through reducing connectivity between the adjacent frontal cortex and temporo-parietal junction.[59] This theory, later, explains the defects found in children with autism in visual detection, and tasks motivation to thier social and communication difficulties as well as difficulty in interpreting facial expressions.[60] The analysis of functional neuroimaging data has revealed perturbations of task-related brain activity for both social and non-social tasks in ASD. Brain responses of individuals with autism to visual stimuli are highly variable in comparison with brain responses of matched controls. This suggests that ASDs are not only dysfunctional in the integration of information across distributed brain networks but also in the basic function of primary cortices. The increased neural variability in autism was specifically associated with alterations occurring in regions implicated in high and low visual perception and neural connectivity fluctuations, which create unstable visual processing. There are several hypotheses about the neural basis of autism that is way beyond the scope of this review; however, the reader is advised to consult Lichtenstein et al [33] and Baribeau and Anagnostou[47] for more details.

1.6 Magnocellular And Parvocellular Pathways In ASD

Electrophysiological research suggests that specific neurological differences contribute to the functional differences observed in individuals with ASD.[61] Research on the magnocellular pathway showed significant defects in children with autism in image processing.[62] A study by Greenaway et al[63] on autistic children, showed reduced contrast sensitivity in response to three steady pedestal parameters that measured the magnocellular and parvocellular functions. The results showed typical impairments in visual attention in the autism group compared to the healthy control group. This can be attributed directly atypical lateral visual connectivity and high levels of endogenous noise that account for the defect in the magnocellular area.[63] Research on adults with ASD, however, did not show the same magnocellular abnormalities.[64] This raises the question, whether such abnormalities are overcome in teenagers and adults and/or if they might have lasting effects on the cortical area in autism. Grinter, Maybery and Badcock[65] evaluated dorsal and ventral stream function in individuals with developmental disorders by measuring performance on visual tasks using visual stimuli such as Glass patterns, random dots kinematograms, and luminance-modulated noise patterns. They found that tasks which rely on dorsal stream processing exhibited larger ASD-related deficits;[65] however, they also found evidence of impairment of higher-level integration and global processing in the ventral stream that might be consistent with the hypothesis ASD is associated with dysfunction in mirror-neuron system in autism.[66,67]

Visual defects in ASD might vary in onset, severity and behaviour patterns. Bogdashina[68] pointed out that some unusual behaviour ASD-related is linked to visual sensory impairment. She grouped them into hypersensitivity and hyposensitivity. Hypersensitivity, on the one hand, is characterised by focusing on small details, fear of dark and bright lights, avoiding

eye contact and tending to look down most of the time. Hyposensitivity, on the other hand, is characterized by an affinity for bright light and moving objects, standing for a long time gazing at people, and using hands to define small details or edges. Here, we aim to evaluate visual functions in ASD, such as visual acuity and colour vision and other common measurement approaches. The reader is referred to other literature reviews [9,69,70] for more details of vision in autism.

1.7 Visual Impairments In ASD

1.7.1 Refractive Errors

Refractive errors have been found abnormal in ASD, however, these findings were based on few studies that have covered this area, which also had small samples of the autism population. In addition, subjects included in these studies were autistic according to the DSM-IIIR criteria. As these diagnostic criteria were narrower, these individuals had more severe levels of autism and may not be comparable to current subject cohorts. Another limitation is that they used a study design,[71] therefor, the results might be vulnerable to selection bias and gaps in recall and data. Without a large scale and/or prospective study, there are too many variables to draw an accurate conclusion that might affect the degree to which these results can be generalised. In addition, running a full refractive examination on children with autism sometimes can be very difficult if not impossible to achieve.

One of the early studies that managed to perform full vision test on 98 per cent of the participants (34 children with ASD) used the Teller Acuity test.[72] They reported a 44 per cent incidence of refractive errors with astigmatism and hypermetropia (17.6 per cent for both). Denis et al[73] completed a full ophthalmic examination for six girls and four boys with autism. Seven of ten

cases were more than 1D hypermetropic and six had astigmatism. No cases of myopia were reported in this study, which might be attributed to the small sample. However, Ikeda et al[74] followed 154 children (79 per cent) with ASD from 1998 to 2006 and found refractive errors in 29 per cent of the cases and hyperopia was also the most common. Ikeda et al did not report if the children had corrections to their refraction errors and if there were any improvements in vision. On the other hand, Black et al[75] found that with correction, 32 per cent of the autistic sample (44 children, with 29 per cent of the cases having refractive errors) reached the visual acuity of 6/6. Mixed astigmatism and anisometropia were the most common refractive errors in the Black et al study. Ezegwui et al [76] also measured refraction errors in a group of 18 Nigerian children with ASD (13 male): they found that 22.2 per cent of the children had astigmatism, 11.1 per cent had hypermetropia, and mixed astigmatism and anisometropia were also found in some children. The data of this and other studies are summarised in Table1-1.

Study	Year	Number and gender with ASD	Astigmatism (%)	Hypermetropia (%)	Myopia (%)	Other findings (%)	Study type
Scharre and Creedon[72]	1992	32 M 2 F	17.6	17.6	8.8	5.8% anisometropia	Prospective
Denis et al.[73]	1997	4 M 6 F	60	70	_	60% strabismus	Prospective
Ikeda et al.[74]	2013	122 M 32 F	3.89	16.88	5.8	1.95% anisometropia	Retrospective
Black et al.[75]	2013	44 3:1 M/F	18.2	9.09	11.36	6.81% anisometropia	Retrospective
Ezegwui et al.[76]	2014	13 M 5 F	22.2	11.1	-	-	Retrospective

Table 1-1 Refractive error incidence in individuals with autism spectrum disorder (ASD)

Previous research suggests that the incidence of refractive errors among individuals with ASD is comparable to the incidence within the typically-developed population.[7,71] However, these conclusions are tentative because measuring visual acuity and refractive errors in individuals with ASD is challenging due to several factors such as:

- Children with ASD often are not fully cooperative and therefore may not complete a full visual test.
- Charts usually used to test visual acuity (Snellen chart, HOTV test, E chart, et cetera) are insufficient and may give misleading results due to a misunderstanding of the task and/ or visual disorder related to ASD-specific defect.[77]
- Issues related to social and communication difficulties may easily mislead diagnosis and correction of refractive errors and other ophthalmic disorders at an early stage of life.[78]

Considering these factors, Singman et al[79] conducted vision examinations using the PlusoptiX photoscreener (a vision screener founded 2001 in Nuremberg, Germany)[80] on 25 children who reported with autism. Vision screening using the PlusoptiX uses an examination distance of one meter, no flashlight is required and it measures both eyes simultaneously. The PlusoptiX was 88 per cent more sensitive in reporting refractive errors and identifying risks of amblyopia according to the results compared to regular refraction; however, it is uncertain if patients were really gazing at the PlusoptiX or were attracted by the sound it released. Kancherla and Braun[81] suggested that the difficulties in diagnosing children with visual impairment associated with ASD can delay the diagnosis after the age of five. Therefore, it is important to examine vision in ASD using the most reliable methods.

1.7.2 Eye Movement Defects

Impairment of eye movements is one of the significant clinical features associated with ASD. Rosenhall, Johansson and Gillberg[82] compared 11 autistic children with a control group of the same IQ, age, and sex. The study examined binocular vision using auditory brainstem response

audiometry and a non-predictive saccade task. They recorded three angles (20°, 40° and 60°) of voluntary horizontal saccades. Although six of the autistic children were found to have abnormal eye movements, four had hypometric saccadic movements and difficulties in performing smooth pursuit eye movements and low velocity movements. Rosenhall, Johansson and Gillberg[82] suggested that saccadic movement disorders might be due to brainstem dysfunction in autism. No further explanation has been given for the smooth pursuit movement disorder in this experiment because of the small sample; however, the results were consistent with the findings of Takarae et al,[83] who studied smooth pursuit eye movement in 60 individuals with ASD (mean age of 20 years) and compared them to an age and gender matched control group. The test used neuropsychological tasks and an eye monitor. The results showed no differences in saccadic latencies between the two groups but a significant lower sensitivity in the autistic group in right saccadic movements, and in gaining smooth pursuit of moving objects. In all tasks, reduction was more pronounced in older individuals with autism than young subjects. Results suggested that a functional disturbance in the cerebellar vermis in autism can affect the final visual motor pathway that causes pursuit disturbances. On the other hand, early studies found no abnormalities in the saccadic and eye movements in autism.[84,85] Controversially, outcomes in ASD-related deficits in pursuit eye movements can be explained in terms of impairment in spatial working related to changes in pre-frontal cortex and posterior cingulate connectivity. Recent research suggests that cerebellar dysfunction also contributes to deficits in gaze control and saccadic movements as well as learning disability and language abnormalities in ASD.[84–86] Mottron et al[86] found that children with autism tend to look at objects using 'lateral gazing', which means that they moved their pupil to the edge of the temporal corner eye socket and turned the head is in the opposite direction. This behaviour attempted to stimulate peripheral

vision of moving objects to reduce the amount of information produced by central vision. One suggestion is that the delay of the cerebellum to transfer information from subcortical structures and visual and parietal cortices of moving objects is consistent with the increase in the variability in saccade metrics.[87] Slowed saccades have been also demonstrated with inactivation of the caudal fastigial nucleus and the cerebellar vermal lobules VI and VII, where post-lesion resulted in increased duration of the saccade consistent with cerebellar impairment that altered the oculomotor system.[88]

Mosconi et al[57] measured the effect of ASD on adaptation rate and amplitude variability in an intrasaccadic target displacement task known to elicit saccadic adaptation reflected in an amplitude reduction. The results showed that 30 per cent of individuals with ASD have slower adaptation rate than typical developing children in electing saccadic movements across trials compared to only six per cent of the typical developing children group, who failed to adapt to the saccadic amplitude. Mosconi et al suggested reduction of the neural plasticity within the learning center area of the oculomotor vermis might be due to abnormality in cerebellar neurons, which is consistent with the previous reports.

Eye contact, gaze abnormalities and facial recognition are types of behaviour that characterise individuals with ASD and have been related to the disturbances in eye movements irrespective of the diagnostic category.[89–91] Several results for assessing eye movements in autism suggested that ASD-social impairments might be related to limited vision proceeding to variant visual cues. The implications of these eye movements limitation might vary between facial and object recognition. So far, studies have highlighted the influence of impaired eye movements on ASD-related to their disorders of facial recognition, and therefore it is important

to find the link between disturbance in neural networks in ASD compared with typical developing children.

1.7.3 Contrast Sensitivity

Bertone et al[64] measured contrast sensitivity using simple (first-order) and complex (second-order) grating presented at horizontal and vertical direction and randomized to stimulate two different pathways in the ventral stream. The study also used luminance grating (0.5 cpd) flickered at 6 or 1 Hz to stimulate the magnocellular and parvocellular pathways respectively (Table 1-2). Thirteen autistic individuals were compared to a control group. Bertone et al found that contrast sensitivity for first-order stimuli was higher (i.e., detection threshold were lower) in ASD observers than control observers, whereas contrast sensitivity for second-order stimuli was lower in ASD observers. No significant group differences were seen in the flicker sensitivity task. The authors interpreted the results as showing that ASD is associated with a deficit in the magnocellular pathway specified by lateral inhibition in the visual system that affected different levels of visual processing. Jemel et al[92] measured early visual-evoked potentials (VEP) to drifting sinewave gratings at three spatial frequencies (SF) ((Low)0.8, (Medium) 2.8, (High) 8 $c.deg^{-1}$) and presented at four contrasts. The results of 16 observers with ASD and 14 controls found no significant group differences for VEPs for LSF gratings. VEPs enclose an initial negative-going deflection (N80) peaking for MSF and HSF, showed lower amplitudes in ASD observers. These differences in N80 peaks in ASD suggested that ASD is associated with abnormal processing of medium-to-high spatial frequencies. These early abnormalities on processing visual perception have the impact of abnormal development in the early visual system; however, Morton et al[93] suggest that there is an enhanced activation seen in VI of autistic compared to typical developing children. On the other hand, Koh, Milne and Dobkins[94]

found no evidence of an ASD-related deficit in processing high spatial frequencies, although these results are problematic because the Koh et al study had a small sample size and didn't include an age/gender/number-matched control group (Table 1-2). Kéïta et al,[95] measured detection thresholds of 21 with ASD and a matched-control group of 15 participants using static and drifting luminance gratings presented with and without noise, and texture contrast (i.e., second-order) gratings. In the static version of the experiment, results showed that autistic subjects are more sensitive to luminance-defined, high spatial frequency stimuli and no group difference was reported for gratings containing noise, whether defined by luminance or texture. Based on these results, the authors suggested that ASD is associated with abnormal connectivity in early stages of visual processing that process luminance-defined patterns, but compensatory mechanisms minimize deficits at later stages that process texture-defined (i.e., second-order) patterns. Vandenbroucke et al [96] suggested that ASD-related deficits in visual processing reflect changes in horizontal inhibitory connections in early visual areas, as well as increased neural noise.[9] That leads to atypical disturbs between feedforward, horizontal and feedback activity.[97] Taken together, it is evident that it remain unclear how ASD affects low level visual processing. The variability in methods used to examine visual processing within the visual cortex, in combination with small samples, makes it difficult to compare results across studies. In addition, impairments between age groups and syndrome severity often decline with age. This suggests further investigation to determine whether such improvements in performance among adults with ASD are the result of compensatory factors or the result of the changes in low-level factors related to neural plasticity.

Amplitude of the luminance modulation										
Study	No. A	Age A	No. C	Age C	Stimuli type	Lmin – Lmax cd/m2	Grating frequencies (cpd)	Drift frequency (Hz)	Life-time (ms)	Results = A to C
Bertone, Mottron, et al. 2005[64]	13	22:3	13	20:5	Static	0.0 – 0.5	0.75	0	750	High sensitivity to first-order
					Texture	0.0 – 1.0	0.5	6		Low sensitivity to second-order
					Flicker	0.01 – 35.40	6	1		No difference
Jemel, Mimeault, et al. 2010[92]	16	18 – 31	14	20 - 33	Vertical spatial Frequency	Values of 4 %, 8 %, 32 %, or 90 %	LSF = 0.8 MSF = 2.8 HSF = 8	90	-	LSF = No difference, MSF + HSF = low
Kéita, et al. 2014[95]	21	13-33	15	14-24	Contrast Texture	0.5 – 99.50	0.5, 1, 2, 4, 8	75	500	HSF = Low sensitivity LSF=high sensitivity
Koh, Milne and Dobkins, 2010[98]	10	15:1	25	15:7	Static	Mean = 23	0.5, 2, 4, 8, 12, 16, 20	100	250	No difference

Table 1-2 study results that covered contrast sensitivity in autism spectrum disorder.
A. autism, C. control, cpd: cycles per degree, LSF: low spatial frequency, MSF: medium spatial frequency, HSF: high spatial frequency .

1.7.4 Color Vision

The few studies that directly address color performance in ASD suggest there is poor color perception in autism. Franklin, Pilling and Davies[99] and Franklin et al[100] carried out a series of color-detection experiments on high functioning children with autism using various tasks, such as recognition memory, a search task and a target detection task. They found a general reduction in sensitivity to color detection rather than having a specific colour defect such as tritanopia (blue-yellow) or deuteranopia (red-green). Franklin et al[99] worked with 19 high-functioning

autistic (HFA) children (mean age of 14 years) attending special-school and 14 matched typical developing children as a control group. The first experiment assessed the visual search task by identifying the odd-one-out of a colored squares presented among 15 distractors. They also assessed color memory using delayed matching-to-sample task which required children to identify a colored target presented first alone and then after a delay the target appeared with paired color stimulus. The experiment was done with three colored stimulus pairs and the statistical results reported significantly higher errors in the ASD group than the TD children group in both tasks. A second experiment using a threshold discrimination task investigated color discrimination task of the subsystem of colour vision (red-green or blue-yellow). There were 14 high-functioning autistic children compared to 14 typical developing children. The first part of the task was to define a boundary line between the two halves of different colored circles that varied in colors but had constant luminance for chromatic threshold. Results showed a higher threshold in chromatic discrimination in high-functioning autistics compared to matched age and non-verbal control group. Both experiments suggested that a true deficit was found in color perception in ASD and no task difficulty or/and experimental differences can account for the group differences. This pattern of findings agrees well with those from previous studies.[100,101] These results however suggested that those with ASD have reduced sensitivity to color differences that might arise from impairments in both the retina and visual cortex. Color processing starts at the retina, where cones with photopigments are sensitive to certain wavelengths. Then, information is processed to the lateral geniculate nucleus at the primary visual areas, where two different pathways will carry chromatic information and luminance to the visual cortex.[102] Several studies have found that other visual areas, mainly in the ventral occipitotemporal cortex as well as the dorsal pathway are involved in color processing.[103,104] As

ASDs are attributed in visual perception, this might disturb processing of color information between visual pathways. Another explanation is that it could be similar to the causes of decline in chromatic sensitivity found in the elderly,[105] due to neural noise increases, or cone photoreceptors become less sensitive. Therefore, such deficits might account for the reduced chromatic discrimination shown by those with ASD. Alternatively, reduced chromatic discrimination could arise from atypical connectivity in the neural area of the visual cortex with cortical areas that later lead to a general reduction in chromatic perception.[100] Neurophysiological research, such as fMRI of chromatic discrimination in ASD, is essential to test the plausibility of a neural basis to chromatic sensitivity.

1.7.4.1 Color Processing Differences In ASD

The link between color discrimination efficiency in autism and visual functions has been presented in some studies.[106–109] The findings suggested using colors combined with training methods to improve different levels of visual function in ASD. For example, colored filters showed improved performance in individuals with ASD on visual perception, social tasks and reading.[109] The proposed mechanism is that colored filters reduce cortical hyperexcitation, which increased by the cortical noise in ASD, especially in primary sensory cortices. Ludlow, Wilkins and Heaton[109] were the first to use color overlays, namely, 'a colored transporting plastic sheet that can be placed over printed text without interfering with clarity' and the results showed an improvement in reading speed in an ASD group of 13 per cent; however, Wilkins, Sihra and Myers[110] explained that there is an overall improvement in reading speed as a result of enhancement of the function of rods and cones to chromatic energy that stimulates the response mechanism of reading. Autistic responses are not the same for all colors, as overlays work on

reducing the contrast and minimise the luminance scattered in the visual pathway due to neurological defects in the visual cortex,[104] which can explain the slow reading speed using white more than darker colours.[101] Wilkinson and McIlvane,[111] however, showed that children with ASD performed better with the color-based clustering method in search and match experiments rather than specifying one color in a pattern. A case has also been reported linking color-processing differences to obsession and phobia.[112] The explanation for the mechanism of these findings is still unknown; however, further research on color defects in autism compounded with gaze direction, visual attention and neuroimaging should be considered to define the exact areas of impairment and its relationship to other visual perception deficits in this group.

1.7.5 Visual search

Experiments using 'embedded figures' and 'block design' tasks to investigate visual attention and visual search have revealed that individual with ASD are better at detecting local details and neglecting global information compared to control subjects, no matter what the IQ or age.[113] Several studies[114–116] suggest that the ability to detect specific details embedded in an overall picture is the result of overcoming the stimulus of the whole pattern to see specified targets. To this extent, Frith[117] first introduced The Weak Central Coherence theory that was developed further by Frith and Happé.[118] Happé [118] suggested that autistics have the ability to see local information but are relatively poor at extracting the gist or meaning of events. Happé's theory was based on the fact that abnormalities in the superior temporal sulcus in the dorsal stream and/or neurological deficits in the anatomical development of the visual system and image processing areas affected the local and global perception[119] and has been extended by other research.[114–116] The fMRI study by Boucher et al[120] found significant differences in the

neuroanatomical volume between certain limbic structures such as the amygdala and hippocampus and other areas in the medial temporal lobe in autism compared to the control group. Boucher et al[120] suggested that these neuropsychological impairments are connected to the deficits in the socioemotional perception and impaired memories in ASD by reducing the spatial working memory abilities, which found to altered the search strategy in autism.[121] This area and others in the brain, where abnormalities have been demonstrated in studies of autism, have focused on what is called 'the social brain',[122] which is related to the social and behavioural characteristic abnormalities in ASD. Neuroimaging results showed atypical function in the social brain areas in ASD that was associated with their visual searching, such as face recognition, especially for unfamiliar faces[123] which is the most reliable early signs of the disorder among affected children;[124] however, Joseph et al[125] compared 21 children with ASD to a similar matched control group to examine memory enhancement and visual perception in target-detecting tasks using dynamic and static search methods. In both tasks, groups were asked to detect the letter 'T' among 'L's in different random selected patterns. In the static method, one frame was used for random a position of the T, while different frames were used for the dynamic search method with interval time of 500 ms between frames. They also used eye tracking to examine spatial attention behaviour throughout the search process. The results showed no difference in the efficiency of searching with the dynamic method between the two groups. The authors argue that autistic children do not memorise the targets. In fact, they moved their eyes searching for the target in the same way as the control group, while in the static searching task, the autistic children's performance was less accurate. The results showed a significant correlation between the severity of ASD (according to the Autism Diagnostic Observation Schedule)[126] and static searching. Joseph et al[125] explained the differences in "search" reflect

better target/distractor discrimination by ASD observers rather that differences in "search" per se. These features seem to be specific to ASD; however, research evidence from other groups on neuro-developmental disorders that have similar learning disabilities or neuropathology, such as Williams syndrome and fragile X syndrome, have shown distinct search deficits compared to control groups.[127,128] The 'enhanced perceptional functioning' theories proposed by Mottron et al[93] and others have found that both low-level (discrimination) and mid-level (pattern detection) perceptual processes are enhanced in ASD. Following to the hypothesis that linked behaviour and interests of autism to their superior performance on visual search, Blaser et al[129] used task-evoked pupil responses, which measure the involuntary reaction of pupil diameter that happens during visual attention tasks. The idea behind this method is that pupil diameter varies during target detection, and there is a positive correlation between increasing searching task difficulty and pupil diameter. Blaser et al[129] found that autistic children have increased pupil response during the experiment and performed better than the control group. His suggestion was that children with autism might not use the same searching strategy as normal developing children but they are using extra focusing attention that makes them in constant hyperphasic states. Thereby, their performance decreased on tasks that require shifting of attention and increased on tasks that benefit from focused attention and reduced distractibility on fixed objects. In a related review Kaldy et al[130] cover most of the experimental and task methods, which have been used to measure visual attention in ASD in the last 15 years. They concluded that many types of repetitive behaviour of those with ASD came from the unusual visual attention interests, which could be restricted to objects more than people or to the whole environment and later will be reflected by poor social engagement, skills and general attention. Kaldy et al[130] also note that

training experiences could improve visual attention that might improve the communication development in autism.

1.7.6 Depth and stereopsis

Children with autism are mostly associated with 'locally oriented' perception and enhanced low-level operation.[131] Their abilities in processing three-dimensional images also grounded on superior local details (e.g., 3-D drawing).[93] As we explained previously, several hypotheses have been proposed that this hyper-local orientation might be due to undeveloped (or under-developed) neural perceptual mechanisms in autism, resulting in abnormalities in the magnocellular pathway that enhanced processing defects.[132] For example, Giovannini et al[133] reported that people with ASD underestimate distances in matching tasks compared to a matched control group. Mitchell et al[134] suggested that top-down perception effects are actually developed in ASD, which may explain their reduced sensitivity to some visual illusions. For example, participants with autism shown great ability to draw the 'devil's fork' and 'penrose triangle' relatively easily, and they were less distracted by the impossibility of the whole image.[135] In a different study, Mitchell et al[136] used the shaped illusion task in which observers need to ignore distortions induced by 3-D cues, and found that ASD performance was better than the normal group, and they were less affected by the illusion of the images. On the other hand, Sheppard, Ropar and Mitchell[131] found that individuals with ASD could draw three-dimensional objects with the same accuracy as the control group by using global strategy starting from drawing the figure's outlines first then forming the 3-D inner lines. Ropar and Mitchell suggested that the enhanced perception of the top-down or higher-order might take precedence. In an experiment that studied the effect of practice on searching strategies in autism, Gonzalez et al[137] used the

luggage-screening task with 13 ASD adults and 13 of the normal population. The task uses 3-D screen images of luggage with low and high clutter and participants have to specify the included items. The results revealed similar errors attributed to time and speed reaction between the two groups at the first part of the screening; however, the ASD group showed greater improvement in performance after several trials, suggesting that the more the ASD group became accustomed to the task, the more they remained focused and the better they inhibited distractors. This could give us an indication that autistic people see objects differently or are not influenced by most of the details of the 3-D images when compared to the general population.

1.7.7 Visual field

Studies of ASD-related changes in vision have presented stimuli in the central visual field; however, Milne et al[138] were the first to study the visual field in ASD. Eleven participants with ASD were matched and compared to 21 controls. They used perimetry to assess the vision field between 30° and 85°. The task was to determine a flashing light with different illumination levels in 12 positions along eight axes. The performance ASD individuals was impaired to controls, especially for stimuli presented in the nasal side visual field. Other aspects of the results suggest that these impairments are likely to be related to a defect of rod-function more than underlying neurocognitive or perceptual problems; however, the test stimuli were presented in the peripheral field and the test was held in a dark room, which was most likely rod-mediated. Therefore, data presented from this study cannot provide a direct test for visual field deficits in autism. Rutherford et al,[116] however, tested visual attention in those with ASD using the 'useful field of view'. Their aim was to study if the superiority of autism in advanced visual search tasks is extended to peripheral field tasks. Each participant was tested in three conditions: a central

letter identification task, a peripheral target localization task, and a divided attention task in which central letter identification and peripheral target localization were performed simultaneously. The examined area covered 4° to 20° and the findings indicated that ASD performance was the same for all fields of the test points which may agree with previous findings that suggest that ASD might have visual field impairments beyond 30°.[138] Accordingly, the small number of participants in Milne et al[138] cannot really reflect all visual field defects in autism. The evidence of visual attention in ASD proved a possible top-down role for the frontoparietal attentional mechanisms in the integration of spatiotemporal information and specific zoom-out attentional difficulties[139] that might also contribute to the findings of Milne et al.[138] Attempts have been made to explain spatial attention between central and peripheral field in autism using different task properties. A study by Ronconi et al[140] used 'coherent dot motion' (CDM) stimuli for a directional discrimination task. The dots were presented in the central view (fovea and para-foveal) then in the peripheral view (16° to 21°). In the peripheral task, the central dots completely disappeared, so that the participants are forced to enlarge their attentional visual field to relevant task information. The study also measured the deficiency in the perception of the visual field in the ASD group and the adaptation time needed to shift focus from central to peripheral field by using an attentional zooming task. The results showed a high threshold in the CDM response in both central and peripheral fields of view and a deficiency in zoom-out attention, which suggested that impairment might be selective to the central view in those with ASD. A positive relationship, however, was seen between the severity of ASD and higher impairment in the CDM and attentional tasks. The authors propose that the magnocellular-dorsal (M-D) stream defect found in ASD can be responsible for the rapid change in the stimuli, such as flicker and motion in the visual system.[141] These results supported other

findings that those with ASD are intact in low-level M-D stream information processing and impaired in the high-level perception.[142,143] The superiority in processing low-level information in the central field has been attributed to the performance of high-level attention in the peripheral field stimuli, which induced high threshold in detection of the direction of the motion dots. This abnormality in processing motion perception could be improved by influencing the attention in the peripheral visual field in children with ASD using practicing tasks for this demand. In conclusion, given that visual field attention appears to be abnormal in ASD, the reduced sensitivity to peripheral information cannot be generalised for several reasons, for example, the small number of participants in those studies limited the results; only a few researchers have investigated the non-central vision, and different paradigms in the previous studies had the impact on disturbed attention and misunderstanding of task requirements.

1.8 Motion perception and driving performance in autism

Motion perception is relatively impaired in ASD.[144] In this part our aim is to link between motion perception defects in ASD and driving for the purpose of further research in this area. Since driving is the means of independence and self-identity, it is important to study the ability of those with ASD to react to the 'big picture' for any given driving situation. Our future aim is to understand whither the visual defects found in autism would stop them from responding to actions in roads, such as time to collision or time to cross a busy intersection? Driving studies in elderly have linked motion perception with other visual impairments as the main visual defects that affect elders'[145] ability to control the vehicle, to interact with other vehicles on the road, and to avoid traffic accidents; however, to apply for a driving license, the major visual area that is covered is visual acuity. It has been reported that there is no link between acuity and safety on

roads.[146] In fact, results proved that motion perception is linked to the poor performance in driving among the elderly.[147] There are no studies which have related such impairment to the driving performance and safety in autism. Furthermore, DeLucia and Tharanathan[148] have shown that brief delays in adequate response to relevant moving targets in a driving environment are likely to have potentially dangerous consequences and reduced ability to adequately discriminate speed or time-to-contact, which could lead to unsafe and problematic driving behaviour. Cox et al[149] conducted a survey of parents of autistic children who learned or are already driving. The results showed that their children do not have the skills for driving. These include the ability to make quick decisions in the context of sudden environmental demands and skills of notes of environmental warnings on roads, which are all primary to proficiency for a driver. Our hypothesis proposes that individuals with ASD will be distracted by their superiority in processing local details at the expense of the global picture. Thus, their driving performance is reduced.

1.9 Summary

In this review, we summarised the research on various aspects of visual perception and performance of individuals with ASD. Studies presented visual impairments as the ultimate cause of some social and communication impairments in ASD.[150] Other research preferred to relate the social problems in autism as the main cause of misinterpretation of receiving or processing visual information. In other words, individuals with ASD receive visual information correctly but they fail to interpret it because of their inadequate social and communicative analysis of the visual scene.[64] Overall, visuo-perceptual processing in this group is characterised by superior performance on static spatial tasks and inferior performance on dynamic tasks.[65,151]

However, the general idea suggests there are deficits in the dorsal stream processing and atypical neural connectivity network of visual cortex. This altered low-level perceptual information reduces lateral inhibition that impaired several visual areas, such as a decrease in contrast sensitivity and visual attention. Performance differences between several visual tasks for those with autism spectrum disorders, proposed by a number of studies are attributed to task demands, stimulus paradigms and/or scale changes in the development of the syndrome, which differentiates performance between children and adults for the same tasks.[152] From our point of view, there is one main question that emerges from this review. The concerns about the impact of DSM changes should be considered in the context of sweeping changes occurring in vision research. The new criteria DSM-5 tended to have more severe impairments than individuals meeting DSM-IV. Also, it eliminated Asperger's and PPD-NOS from the criteria for autism and encompasses them under related disorders. A lack of consistency in the definition complicated the interpretation of new findings in visual impairments in ASD in relation to previous approaches. Some areas of potential autistic visual disorders were consistent, for example, atypical dorsal stream processing in autism. Researchers found that DSM-5 offers greater specificity but may result in reduced sensitivity, especially for specific subgroups and from higher-functioning autism. Therefore, we can argue that the controversial performance in processing visual tasks may arise as a result of changes in the inclusion criteria for subjects with ASD for recent vision research rather than those before 2013 (when DSM-5 was first established). It is also worth mentioning that insight into the aetiology of ASD is still limited; however, disorders that are caused by a single gene might share the same social impairments as autism but may vary in onset and severity and were excluded from the criteria at a later stage. For example Rett's disorder was included in DSM-IV, even though it was not thought to be a

form of autism. Subsequent to Rett's inclusion, a specific geneticaetiology was found. The removal of the condition from DSM-5 reflects intent to avoid distinctions between medical and psychiatric disorder.[153] Therefore, further investigation for visual impairments in ASD diagnosed under the new criteria should be considered to observe to what extent visual impairments are accurately related.

Chapter 2: Do Different Experiment Tasks Affect Psychophysical Measurements Of Motion Perception In Autism Spectrum Disorders? An Analysis

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Lakshminarayanan	Y			Y

2.1 Overview

There is a rapid increase in the number of individuals with Autism Spectrum Disorders (ASD). Research on motion perception in ASD has shown deficits in processing motion information at the higher visual cortical areas (MT/V5). Several hypotheses have been put forth to explain these deficits as being due to enhanced processing of small details at the expense of the global picture or as a global integration abnormality. However, there is a lot of variability in the results obtained from experiments designed to study motion in adults with autism. These could be due to the inherent diagnostic differences within even the same range of the autism spectrum and/or due to comparison of different experimental paradigms whose processing by the same visual neural areas could be different. In this review, we discuss the various results on motion processing in ASD, as well as the theories of motion perception in autism.

2.1.1 Key words

Autism spectrum disorder, high functioning autism, motion perception, biological motion, form perception, random dot kinematogram, local motion, global motion.

2.2 Introduction

Autism spectrum disorder (ASD) is a developmental disability syndrome characterized by impairments in social communication and interaction defects. The prevalence of autism from the Centers for Disease Control and Prevention[154] show one of 68 children is born with ASD, of which 43.9% are classified with High Functioning Autism (HFA). The term HFA refers to

average or above-average intellectual ability in the range of IQ >85, among other higher-functioning cognitive abilities, such as emotion recognition, expressions, social interaction, and executive function (EF), with a special emphasis on individual and group problem-solving.[11,117] Individuals with HFA and Asperger's syndrome (AS), which is within the autism spectrum, may have the ability for general societal interactions and have close-to-normal life activities, eg, studying, working, and driving. Most studies collect data from people with ASD who generally have average to high IQ and do not have severe abnormalities or other related development issues that may make data collection difficult. In this review, we will still denote individuals with HFA as within the general term ASD, which is the general convention in the literature, unless otherwise specified term been used in a study, then we will use that term for comparison reasons.

Some aspects of visual function, such as refractive error, strabismus, and color vision, are found to be normal in ASD; however, contrast sensitivity, motion perception, visual movement, and visual search may be more affected among the autism group when compared to a typical-development (TD) group.[155] Studies of visual motion perception have shown that individuals with ASD have exceptional perceptual abilities for detecting local details in the environment, but are incapable of capturing the whole without giving full attention to the constituent parts.[8,46,156] Indeed, Castelli et al[157] showed that the ability of individuals with ASD to perform well on the standard Wechsler block-design task was due specifically to their advanced segmentation ability when compared to a normal-development group. Related research using static images with embedded-figure test[114] suggested that children with autism have superior performance in detecting embedded figures than normal children and non-autistic children with intellectual disability. Other studies, however, have shown enhanced detection of local targets, with a typical global bias.[158,159] Mottron et al[160] used various local/global tasks, including traditional tasks of

hierarchical processing, configural processing, and a disembedding task that contained letters presented either individually or in the pattern of the same letter. Target discrimination of the global scene in both tasks (hierarchical or configural) showed no group differences; however, individuals with autism were faster than the TD group in processing local details within embedded pictures than isolated ones on the disembedding task. Research findings vary in indicating a local processing bias or a global processing deficit, and often contradict one another. Several reviews have discussed these findings of differences in motion perception in ASD, and whether these differences are sensory symptom-related and/or due to social and perceptual knowledge latency in early childhood.[9,161,162] Bias in local/global visual processing relevant to stimuli and task dependence has also been investigated.[152] This suggests a reconsideration of the idea of impaired global (or rather, biased) processing between local/global information, with dominant intact or enhanced performance on tasks necessitating static spatial information processing and poor performance with dynamic information analysis.[46,86,160,163] Our review here is selective, focusing on cases of adults with ASD and their sensitivity to various paradigms in processing coherent motion. The published results are often contradictory, for example, in experiments on "Form-from Motion" (FfM), which includes detection of biological motion (BM), performance is found to be intact in form motion, with reduced sensitivity to BM,[156,164] and cases where researchers divided the autism group into HFA and AS and found that atypical perception was HFA-related, not AS. Comparing the consequences of task relevance and autism group subdivision allows conclusions about the abnormalities found in motion perception in autism. We conclude this article by addressing recent studies directly comparing different types of motion integration, and suggest a possible synthesis of the otherwise-contradictory and confusing results found in the literature.

2.3 Theories

Various investigators across multiple cognitive domains in autism have proposed different hypotheses falling between single domain-specific or domain-general mechanisms.

2.3.1 Weak central coherence

Proponents of the theory of Weak Central Coherence (WCC)[165] explain that people with ASD have enhanced segmentation of local details and weak ability to discover the global meaning. For example, ASD shows superior performance on embedded-figure and block-design tasks (Figure 2-1); (i.e., static target design within a complex large picture, including local details, where participants are required either to respond to what they only see or if they can see the global pictures).[113]

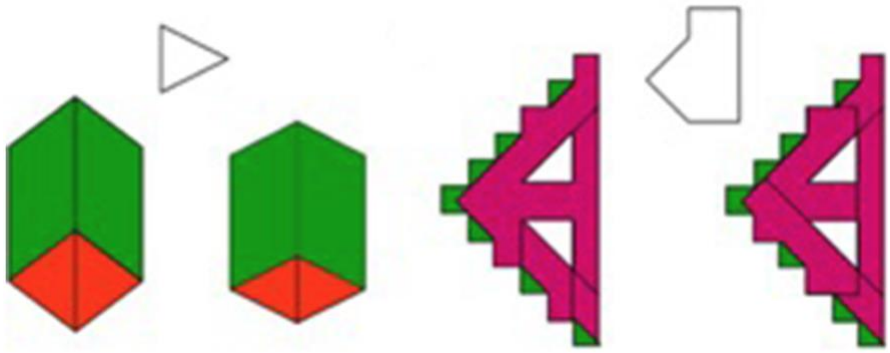

Figure 2-1 Sample of embedded-figure task: (A) simple; (B) complex.

However, related research where local/global were included in the task showed normal perception in the autism group.[119] Hence, WCC fails to explain the diversity of results on global/local performance of individuals with ASD that included in different tasks. Therefore,

Happé et al[118] proposed that global perception could be typical in autism, but autistic people have a biased "cognitive style" towered local details compared with the remaining population. However, other groups using specific tasks that require global integration of local details (eg, Random Dot kinematograms [RDK]) have reported impairments in global processing.[166,167]

2.3.2 Enhanced perceptual function

Mottron et al[93] proposed the enhanced perceptual function (EPF) theory which suggested that superior function and increased independence of auditory and visual perceptual processes are responsible for the distinct pattern of cognitive, behavioral, and neural performance observed in autism. They also suggested that the use of "high" vs "low" level information processing to qualify autistic performance may be misleading. They explained the superior involvement of perceptual regions in so-called high-level tasks by the significant superiority of "perceptual" processing that impacts social and behavioral abilities in ASD. This theory, however, argues that people with autism are able to process global information despite any qualitative or quantitative deficiency in local-level processing. Therefore, the perception of global picture is a relatively optional characteristic in ASD, while it is mandatory in the general population.[168]

2.3.3 Theory of mind

Both theories (WCC and EPF) have been criticized as being either too narrow or too general to explain the full range of autistic symptoms, thereby giving rise to the theory of mind (ToM), which is currently the most dominant theory in ASD cognition. Corcoran[169] explained the profound difficulties in social communication and stereotyped and even repetitive interests and

activities on “false belief ” tasks, where ASD participants showed less ability to “read” others’ minds or explain and solve or deal with social situations. The ToM does not explain the relationship between social integration processing and atypical visual processing, with the exception being difficulties in processing facial expressions.[9] However, combining the ToM, or “mentalizing”, as Hill and Frith[170] prefers to call it, and systemizing WCC and EPF should give rise to the core aspects of neurocognitive atypicalities in ASD.[171] In other words, emphasizing the relationship between the ability of recognition and interpretation of all the details of a complex scene would reveal the core of cognitive functions in autism. Pellicano[172] examined whether autism differences in cognitive skills at early developmental stages can change along with other emerging skills in various cognitive domains or whether these skills are developed independently. This study measured performance on several cognitive domains, including ToM, EPF, and WCC, in children 3-7 years old with autism, and then these were evaluated 3 years later in the same children performing the same experiments. The results showed that early EPF and WCC skills were longitudinally predictive of change in children’s ToM skills. On the other hand, cognitive performance between EPF and WCC was not linked over the 3-year period, even when variance due to age was taken into account. Verbal ability and nonverbal ability differences in cognitive performance remained stable as well. These results, however, agreed with earlier longitudinal studies on children with autism. Booth et al and Happè et al[171,173] found temporal stability in individual differences within ToM, EF, and CC over a longer period. Again, there are few precise predictions about visual performance that come from these theories. Therefore, it is unclear if these visual abnormalities of local/global processing in autism are experienced due to abnormal neural connectivity and integration in the visual cortex or difficulties with visual attention and eye movements (especially for scene-exploration tasks).

2.4 Visual attention in ASD

Visual perception is determined not only by the visual inputs, which refers to bottom-up processing, but also by top-down processing based on prior knowledge. Such knowledge develops through experience-dependent plasticity or during development, and includes contextual modulation of perception.[174] Although our review selectively discusses findings from the viewpoint of local vs global processing in ASD, it is essential to understand top-down attention in autism. For example, Maekawa et al[175] studied top-down and bottom-up visual information processing in adults with HFA using event-related potentials while presenting non-social spatial attentional stimuli composed of black–white windmill patterns. They found that HFA subjects were faster, but not more accurate, in detecting the target. Event-related potential data, however, showed abnormal lower visual level processing in HFA individuals, specifically a reduced P1 amplitude and P300 latency (300–500 ms) which suggested that while findings suggested that autism group has enhanced reliance on bottom-up attention,[176] the abnormal P300 finding indicated that top-down attentional processing was impaired in HFA. Typical behavioral and attentional perception to objects and non-social stimuli has also been found in related studies. For example, Loth et al[177] suggested that the effect of prior knowledge on the conscious perception of degraded visual stimuli is intact for object stimuli, but not for face recognition. This pattern of results was even more pronounced in the results of eye tracking, which showed that the top-down effect on perception of faces was not only reduced but also virtually absent. However, research on attention the effects of ASD on allocation to social and non-social stimuli has yielded mixed results. Using eye tracking as an index of attention of main areas of gaze produced interesting results in this group.[178] Findings showed that ASD individuals had overall

reduced social attention compared to TD individuals and that diminished social attention may start as early as 6 months of age and remain constant across ages.[178] However, it is possible that unchanged social attention might be generated from accumulated deficits of long term atypical experiences in adults, whereas data from children represent a time in which symptomatology profiles are still emerging.[179] Tegmark added that social attention differences in ASD appear to be modulated by the complexity of the social context.[178] Visual attention gaze patterns for different dynamic and static social/non-social stimuli in children and adolescents with ASD have shown that ASD groups exhibit atypical gaze patterns associated with social stimuli, e.g., they will gaze more at the body and give decreased attention to the eyes.[180] All of this is correlated with the severity of social attention and hence social communication capabilities. Few studies have examined the factors of attention and gaze stability in adults with ASD, and results are controversial.[181–183] That leaves the question open as to whether social attention abnormalities in ASD are due to specific difficulties with processing social information, are more related to visual processing abnormalities found in autism, or a combination of both. However, there have not been studies link this reduction in attentional engagement to enhanced perception of local details and/or to decreased global perception or both, which is found in autism. Therefore, further investigation is required to define the ASD-specific attention profile across social and non-social dimensions, and its relationship to motion-perception processing.

2.5 Motion processing in adults and adolescents with ASD

Interpretation of global motion scenes often requires integration of both spatial and temporal information conveyed by low order neurons with small directional receptive fields at V1 and

high order extended receptive fields, primarily in the Middle Temporal (MT), and Medial Superior Temporal (MST) area.[184]

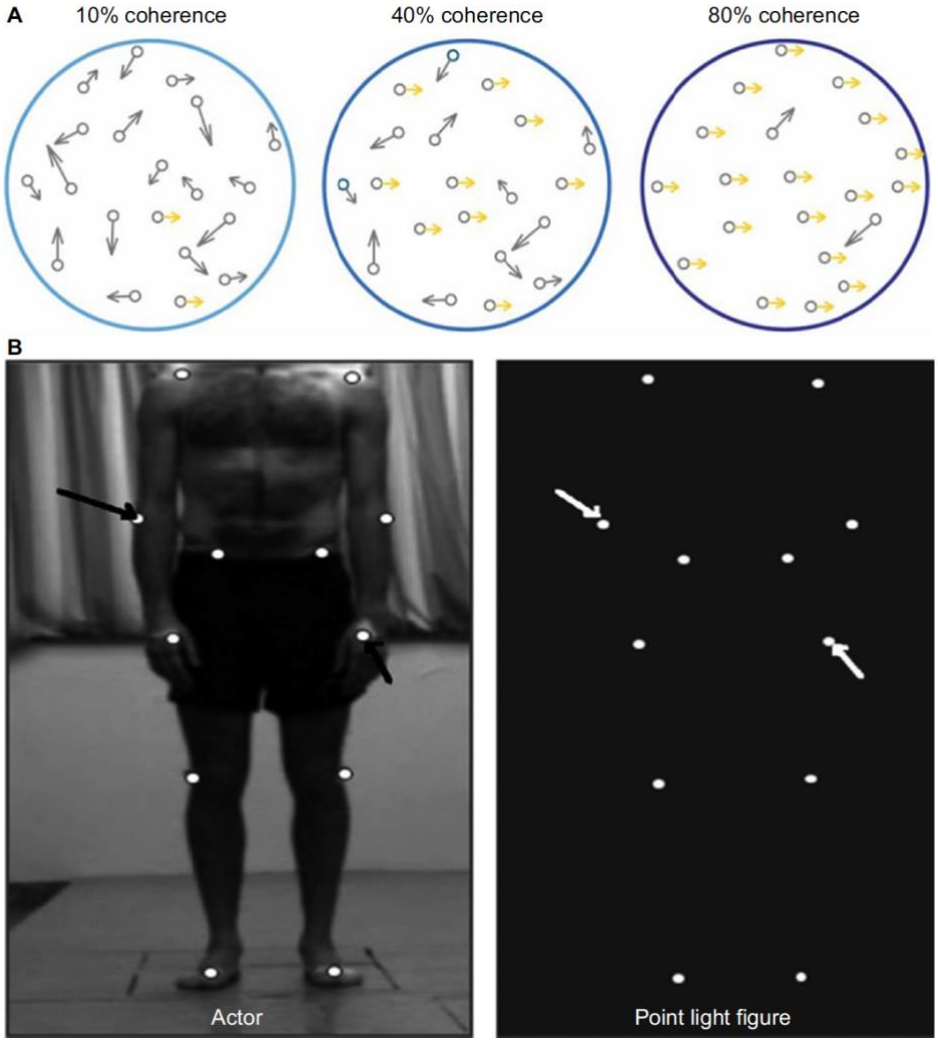

Figure 2-2 Motion perception stimuli.

(A)RDK stimuli with differing coherence levels.(B) Point-light display generated by small lights attached to main points on the human body (actor), which create biological motion stimuli.

Researchers usually use a single moving point or contour to study local motion processing, eg, discriminating direction of a moving sine wave grating with spatiotemporal variations in luminance over time, which refer to simple, first-order motion (luminance-defined), which can

be processed based on one point source, and this type of motion perception is enhanced for persons with autism.[64] However, the ability to process second-order (texture-defined or non-Fourier) stimuli, which measures response to more than one point in space, has been found to be intact in autism.[64] Global motion, on the other hand, can be studied using RDKs, where several dots or contours move relatively to one another, requiring the perceptual system to integrate individual local motions into a globally coherent motion (Figure 2-2 (A)).[185] Usually, RDK stimuli are used to measure the motion-coherence threshold, where a certain percentage of dots move together (coherent signal) in the same direction while the remaining moving dots move in random directions (noise). The threshold for coherent motion is then defined by the percentage of coherent dots required to accurately detect the direction of coherent motion at some predefined probability level.[186] Another form of the RDK task is the measurement of perception of FfM. This is generated from a number of dots that move in a specific spatial relationship to generate a structure or shape that can be defined only by the motion of the constituent dots. RDK is also used to study BM, which is the perception of human figures. These stimuli are generated by a few points of light that are attached to the joints of a moving human (Figure 2-2 (B)).[187] FfM and BM perception – which is another FfM task – involve both the dorsal and ventral stream pathways.[188] Functional magnetic resonance imaging (fMRI) studies suggest that deficits in BM perception could support a theory of dorsal stream dysfunction if MT/V5 reductions are associated with activity decrease in the right-hemisphere posterior superior temporal sulcus (STS), an area particularly sensitive to BM.[189,190] Studies of visual motion perception in autism across different ages and using different tasks have proposed normal first-order motion perception[46,64] and abnormal second-order motion perception.[8,191] Results of coherent-motion tasks, however, show mixed sensitivity in local/global motion in autism. While several studies

have reported decrease in performance in coherent global perception in autism,[166] others have shown normal results when compared with a control group.[160,192] A meta-analysis by Van Der Hallen et al[152] suggested that it is not enhanced local visual processing nor a deficit in global visual processing, but a slow global processing that required longer time to respond. They also suggested that there were no direct effects of age, IQ, or sex on performance in autism. Long-duration stimuli presentation or/and long response time seems to impact enhanced performance of participants with autism.[8,193–195] In addition, Koldewyn et al[45] suggested an effect of task paradigms on perceptual performance in ASD.[162] Of all of the divergent results of research on motion perception in autism, the issue of individual differences in visual motion sensitivity among individuals with ASD using RDK stimuli remains unresolved, and is a very important paradigm for research on motion perception.

2.6 RDK stimuli and autism

Our review here is selective, focusing on studies that use RDK stimuli to investigate global forms of motion perception in adults and adolescents with HFA, because of the following observations:

- Evidence of fully mature motion processing occurs after the age of 11 years[196]
- Aspects of early visual processing, such as crowding and visual attention, are relatively mature after age 10 years and are positively correlated with severity level in autism[9,197]
- Hadad et al[162] addressed the parameters affecting global motion perception in individuals with abnormal early visual input, such as in ASD, from infant stage to adult

- RDK stimuli are particularly suited to assessing global motion processing; however, different paradigms of RDK (eg, signal/noise, FfM) can integrate different cues and thus subserve the perception of different types of movement.[198]

Moreover, we also discuss findings from studies on children with autism for comparative purposes, since studies that examine those specific paradigms in adults with autism are not available in the literature.

2.7 Local/global perception in ASD: study findings

The perception of global motion is of interest. Table 2-1 summarizes some of the data that have been accumulated over the recent years in studies of motion perception in adults with ASD. However, measurements of the sensitivity to spatial and temporal factors of global motion are not always controlled across studies.

Jones et al[203]	Sutherland and Crewther[202]	Saygin et al[194]	Brieber et al[193]	Atkinson et al[201]	Freitag et al[200]	Tsermentseli et al[199]	Study
ASD:14–16 years (n=89) TD:14–16 years (n=52)	ASD: adults High AQ (n=14) Low AQ (n=15)	ASD: adults (n=16) TD: adults (n=20)	ASD: 13–19 years (n=13) TD: 13–19 years (n=15)	ASD: 18–58 years (n=13) TD: 17–54 years (n=16)	ASD: mean 17.5 years (n=15)	ASD: 17–40 years (n=10) TD: 17–40 years (n=20)	Participants
GMT RDK	Navon target GMT	RDK PLD	GMT	PLD/FLD (emotional/ Non-emotional)	PLD	Glass pattern GMT	Stimuli
MC FM	Local/global MC	FM BM	MC	BM,MC	BM	FM MC	Motion perception
1.01 10 dots	Unspecified	Unspecified	6	Unspecified 6	15	4 4	Dots per square degree
2.5	Unspecified	Unspecified	1.8	Unspecified 2	Unspecified	5.8 5.8	Speed (°/second)
Unspecified	Unspecified Limited-life dots=100	Unspecified	1,000	3,000 200	1,500	250 250	Stimulus duration (ms)
Unspecified	Unspecified	Up to 2,000	1,200	Unspecified 2,600–7,600	8–20 seconds	Unspecified	Interval (ms)
Intact	High AQ: impaired at low contrast High AQ:	Intact Intact	Intact	Impaired at emotional FLD Impaired	Impaired	AS-Impaired AS-Intact	ASD results

Peiker et al[107]	Robertson et al[8]	Chen et al[205]	Roberston et al[185]	Koldewyn et al[192]	Yamasaki et al[204]
ASD: 24–45 years (n=13)	ASD: 15–27 years (n=21)	ASD: 13–18 years (n=19) TD: 13–18 years (n=17)	ASD: adults (n=20)	ASD: 11–19 years (n=16)	ASD: 20–39 years (n=13)
TD: 23–46 years (n=14)	TD: 15–23 years (n=22)		TD: adults (n=20)	TD: 11–19 years (n=16)	TD: 20–39 years (n=12)
Band-pass filtered	GMT	GMT	GMT	GMT	GMT
				PLD	Radial
MC	MC	MC	MC	MC	MC
				BM	OF
Unspecified	1.85	5.19	1.85	2.2	0.16
				13	
2.4–3	5	Standard=5.25	5	4.5 and 9	5
		Task: 5.41, 5.51, 5.78,			
750	200, 600	300	200, 400, 1,500	2,000	750
1,000	2,000–8,000	500 or 3,000	2,500	Unspecified	1,500
Intact	Impaired only in the 200 ms condition, low	Intact (enhanced performance in long interval	Impaired only in the 200 ms condition	Intact	Intact
				Impaired	

Table 2-1 Psychophysical studies on global motion perception in adults and adolescents with HFA.

Abbreviations: AS, Asperger's Syndrome; ASD, autism-spectrum disorder; AQ, autism quotient; BM, biological motion; FLD, full-light body; FM, form from motion; GMT, global motion task; HFA, high-functioning autism; MC, motion- coherent; OF, optic flow; PLD, point-light display; RDK, random-dot kinematogram; TD, typical development.

Therefore, contradictory results among comparable studies of motion perception in autism have been found, hence, make it very difficult to draw firm conclusions. For example, Tsermentseli et al[199] compared motion sensitivity between adults with autism and adults with dyslexia and a control group. They used Spencer and O'Brien's[206] motion paradigm, which revealed higher coherence thresholds in children with ASD . Tsermentseli et al[199] found that adults with autism had a high motion-coherence threshold, but only for individuals with HFA and not AS. On the other hand, Atkinson[201] found higher thresholds for coherent motion in individuals with autism using an RDK stimulus. However, in this study the autism group was composed mostly of adults with AS (n=12; HFA, n=1). In both studies (Tsermentseli & Atkinson) [199,201] the AS group had similar full-scale IQ and mean age (FIQ: 107.8, age: 23.3 years, and FIQ: 106.2, age: 30.9 years, respectively). Tsermentseli et al used Glass pattern task with a target area that formed circular patches defined by correlated dot triplets. The dots of the circular batch moved either to the right or to the left of the screen among randomly oriented dots (Figure 2-3).

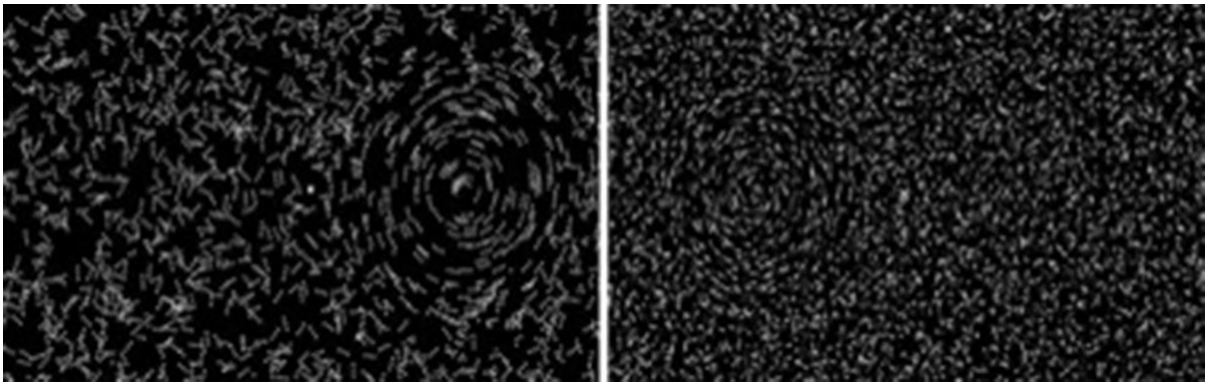

Figure 2-3 Image of Schematic of stimuli used by Tsermentseli et al, for form coherence (left) and motion coherence (right).

On the other hand, Atkinson used white RDK dots that moved on a black background to the left or right of the screen. Parameter differences that affect global motion perception in adults with autism have been discussed elsewhere.[162] For example, dot lifetime (limited or unlimited, which affects the ability to track individual dots) and speed have been found to elevate the threshold of coherent motion in autism (Table 2-1). However, in the study by Atkinson and Tsermentseli, dot lifetime might not have created a difference, since the stimuli duration in both studies was very short (~250 ms).[207] Also, the effects of speed may in fact increase the threshold for motion coherence if the dot spatial displacement is large, which was the case in Tsermentseli et al,[199] even though no differences in AS were found. Van der Hallen et al[152] suggested that slow global processing in individuals with ASD was the cause of the different findings, and that ASD participants need more time to respond. However, in both studies in our example, the time given to participants to respond was long (Table 2-1). One possible explanation for differences in findings between the studies of Atkinson and Tsermentalisi, therefore, might be the modified psychophysical task used. Glass patterns are primarily random stimuli that generate perception of global motion. Glass patterns with concentric structure are considered to be easier to perceive than other types of correlated dot images (e.g., radial and translational patterns).[208] Evidence from fMRI[204] shows that Glass patterns are processed in two stages: primary visual area V1 and higher-order areas of the MT area, yet the sensitivity to curvature and global form present in Glass patterns exist as early as the primary visual cortex. This early sensitivity could actually explain the high performance of AS patients in motion coherence formed by the Glass pattern, since the primary visual area is found to be intact in autism.[193,209] Interestingly, Tsermentseli et al were the first to report impaired form processing in adults with AS. The authors suggested that more tightly integrated network among the dorsal and ventral streams in the visual system may

cause abnormal response. Therefore, the evidence from this study does not support the "dorsal stream vulnerability" hypothesis, since most experiments have shown that ASD subjects had high motion-coherence thresholds, but intact performance on form coherence tasks.[192,194,206] Impaired motion perception in autism may result from diffuse, a specific neural dysfunction of early neuro-integrative mechanisms, which lead to deficits in the perception of complex stimuli.[210] Robertson et al[8] employed fMRI to verify this theory, and found slow responses to elemental visual information at V1, which presumably alters the rate at which those local details are integrated into a global percept. The results were significantly different with shorter stimulus duration in the ASD group when compared with the control group, indicating that integration of local signals into global percept is delayed in ASD.[8] This results agrees with previous results of Robertson et al,[185] which showed short-duration stimuli (200 ms) decreased the performance of coherent motion in autism, but intact global processing was evidenced in ASD with longer stimuli presentation (e.g., 400 and 1,500 ms).[185] Typical functional brain areas have been reported in other fMRI studies of motion perception in autism and control groups.[192,193]Also, impairment in function or performance in one or more tasks is prevalent in autism studies. For example, limited dot lifetime increased threshold, as opposed to "infinite"-lifetime dots,[202] and slow dot speed (1.5°/second) reduced coherent perception, as opposed to fast speed (6°/second; Table 2-1). One could argue that the contrasting results can be attributed simply to spatial stimuli parameters. However, in all these studies (Table 2-1), a direct comparison to match age, gender, and IQ control groups revealed a decrease in coherent motion threshold in autism. A different factor, e.g., diagnostic variance among ASD populations, can also be considered. Spencer and O'Brien[206] divided their participants into those with HFA and those with AS, and found that motion-coherence thresholds differed significantly from controls for the HFA group, but not the

AS group. Milne et al[211] also found that only a subgroup of their ASD population (about 20%) had motion-coherence thresholds outside the typical range. This type of meta-data analysis would help in comparing among autism-syndrome subgroups and classifying the severity of coherent motion deficits among these groups. However, with the new criteria of DSM-V it will hard to observe such differences, and it might reflect in the high variances among the autism group.

2.8 Integration of FfM and BM in ASD

As noted previously, FfM and BM, which is a form of FfM, require spatiotemporal integration of local motion signals. Adding to its complexity, BM entails dynamic, hierarchically arranged pendular motions, which when viewed under optimal conditions group together to produce the global perception of biological activity. The processing mechanisms of BM and FfM are still being investigated, but evidence points to multiple visual brain areas being involved. It has been shown, for example, that the perception of BM activates occipital regions of the STS besides MT+, while coherent motion mainly activates the MT–MST complex.[212] This suggests that BM relies on input from both dorsal and ventral areas of the extrastriate visual cortex.[213] However, FfM using arranged patterns, such as concentric Glass patterns, activates a number of brain areas, such as fusiform/lingual gyri, middle occipital gyrus, and intraparietal sulcus.[213] Interestingly, the fact that all three motion-processing mechanisms are beyond V1 suggests that V1 response is determined by local spatial elements.[214] Comparison across these three types of display may thus be informative. Studies providing a direct comparison of performance across the different tasks in adults with autism, however, are minimal. Jones et al[203] tested visual processing of CM, FfM, and BM on a group of adolescents with autism compared to a control

group. All three motion stimuli were displayed with a random-dot (noise) background, which varied across the tasks. A psychophysical staircase method was used to determine the threshold. In this methodology, three noise dots were added after every two consecutive correct trials, and an incorrect response resulted in three noise dots being removed. In all three tasks, the dots ran at the same speed (Table 2-1) and had a limited lifetime (40 ms). The results showed no differences between the ASD group and the TD group in any of the three tasks. However, within-group differences were found among the ASD group. Autistic individuals with low IQ performed worse on all three visual processing tasks, but they were significantly worse in the BM task. This study suggests that these differences happened due to difficulties between the tasks and the stimuli, and also the diversity of symptoms defining the ASD disorder. On the other hand, Saygin et al[194] found no group differences between ASD and TD groups or within the ASD group processing BM and FfM stimuli. Compared to the Jones et al study, the Saygin et al study was conducted on ASD adults (mean age 33.75 years) while the Jones et al age group was younger (mean age 15.6 years). Although evidence of the developmental course for sensitivity to coherent motion is found by the age of 11 years, we could consider that ASD adolescents with low IQ may "catch up" with their peers without ASD at the adult stage. In addition, in Jones et al, the number of participants was larger, which allowed more diversity in the ASD syndrome among the group. This explanation may better predict the variable findings across both studies but cannot necessarily indicate typical neural processing in ASD. Motion-perception deficits have been found in individuals with developmental disorders, e.g., Williams syndrome[215] and dyslexia.[216] However, studies comparing perceptual difficulties between people with abnormal development and autism have shown distinct differences in processing CM and FfM in autism, even in those with high functioning level.[199] While several studies have found intact FfM in ASD, BM was

more distinctly affected.[160,191,192,201] Using fMRI, Koldewyn et al,[192] for example, demonstrated that an autism group showed lower brain function during the BM task compared to a TD group. Brain activity in BM in the TD group was notable in a large area in the bilateral parietal cortex, primarily along the intraparietal sulcus, right dorsolateral prefrontal cortex, centered in the inferior frontal gyrus, a cluster in the anterior cingulate cortex, and a region in the right posterior STS. The autism group showed activity at an area in the bilateral inferior temporal cortex, including cortex in both the lateral occipital and fusiform gyrus (Figure 2-4).

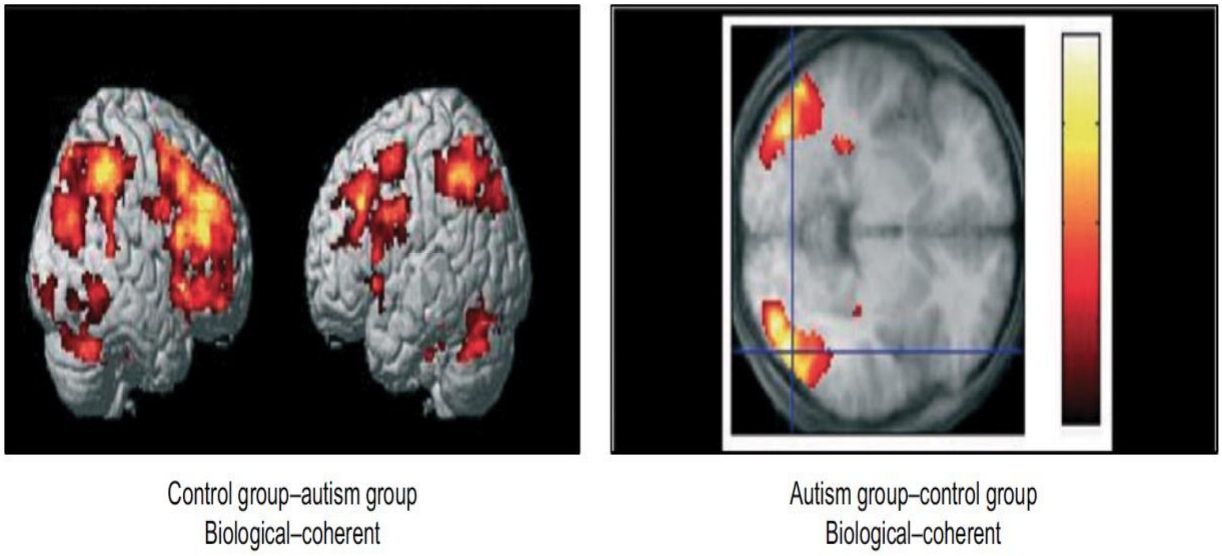

Figure 2-4 Activated areas for biological and coherent motion in ASD compared to TD.

Interestingly, this activation increased when noise level was reduced in the BM stimulus and vice versa. The results agreed with a previous study of Koldewyn et al,[191] where they used a psychophysical task to investigate CM and BM in adolescent autistic subjects. Their results showed increased threshold in BM and intact FfM performance, as well as decreased sensitivity to CM. Impairments in processing both BM and CM have been shown in autism.[201] Suggesting

abnormal neural mechanisms behind processing the BM, which include processing of local/global details and integration between multiple visual neural areas, particularly at the STS.[217] The STS has an important role in processing body and facial movement,[218] and may be involved in the interpretation of any social signal with a temporal component. As such, those with ASD may be fairly unaffected in their perceptual processing of BM per se, but exhibit specific impairments in emotion-related judgments and emotion processing of the point-light displays (PLDs) that are used as BM stimuli (Figure 2-2(B)).[201,217,219,220] Hubert et al[221] found that those with ASD were able to detect BM given sufficient time, but they were not as good at emotional PLDs. Parron et al[222] also found differences in PLD with respect to emotional displays. Parron et al's study, however, suggests that adolescents with ASD are able to group points of light related to inanimate objects as well as TD individuals suggesting that global processing is intact. On the other hand, when these points have an emotional content, the performance of ASD group is decreased. Recent studies have related genetic influences on BM perception in autism.[223,224] It was found that sensitivity to local BM cues was negatively correlated with autistic traits through the dimension of social communication, with the covariation largely mediated by shared genetic effects. Therefore, to date the literature has provided a rather contradictory picture, due to the different paradigms, different variables assessed, and heterogeneity of participants, and thus more studies are needed to clarify these differences.

2.9 Specific Trajectories Of Motion Integration

2.9.1 Role Of Neural Noise

In processing complex spatiotemporal visual stimuli, neural "noise" often refers to the variation in neural responses that typically reduce the detection or discrimination of the signal and is parameterized by the signal: noise ratio. Sometimes, neural noise can enhance perceptual detection and discrimination via "stochastic resonance", a property of nonlinear systems in which addition of noise can facilitate detection and discrimination of subthreshold signals.[225] However, in autism, an emerging hypothesis postulates that excessive internal noise is a key factor influencing perceptual abilities.[226] Reduced perceptual efficiency in ASD that is due to both increased internal noise and bad external noise filtering while highlighting internal noise has implications for perceptual, behavioral, and cognitive abnormalities. Perceptual learning often refers to the exclusion of environmental noise (external noise) and reduction of additive internal noise, thus effectively enhancing the stimulus and/or multiplicative internal noise reduction.[227] In individuals with ASD, there is growing evidence that increased internal noise might play an important role in the reduction of their global visual perception.[9,228] Recent results from a group of children and adolescents with ASD showed both elevated internal additive noise and reduced ability to filter out external noise from stimuli, accompanied by no evidence for abnormalities in internal multiplicative noise.[226] Furthermore, there was an association between the level internal additive noise and the severity of core behavioral symptoms of ASD. The experimenters considered the factors that can reduce the ability to extract task-relevant structures from visual inputs, such as signal: noise ratio and stimulus complexity, which can influence those with ASD. Zaidel et al[228] suggested that heightened sensitivity to stimulus noise, rather

than integration deficits, may characterize ASD. They explain that ASD individuals have better performance when vestibular motion was paired with complete visual noise than processing visual stimuli information per se, which may overload their visual integration. Related studies reveal elevated internal noise in autism measured by blood-oxygen-level-dependent[229] and electroencephalograpy[230] responses to sensory stimuli. Contrary to these studies, others have suggested the opposite possibility of reduced internal noise in ASD, which would enhance detection and discrimination of local details at the cost of global ones.[225] Notably, a number of studies have challenged the "noisy-brain" hypothesis in ASD by demonstrating typical levels of variability in evoked electroencephalography[231] responses to sensory stimulation, as well as in psychophysically estimated internal noise.[232] At the core of this controversy lies the issue of whether this explanation applies to data reported in this review regarding the role of internal noise in directly affecting motion processing in ASD. A related question is does internal neural noise reduced as a function of age in autism, thus improving visual processing?

Research on age-related internal noise has shown increased neural noise as a function of age,[233] which may result in reduced visual processing performance in the elderly. However, to date there have been no studies comparing adult internal neural noise in autism to younger age for autism or TD groups. The mechanism(s) underlying elevated internal noise in ASD is also under debate. A number of neural models suggest that there is a proliferation of neural connections in the sensory cortex of individuals with ASD,[234–236] and thus misfiring synapses could easily result in noisy signals in the visual system. While it is possible to argue that adding a theoretical hypothesis to the conflicting theories of visual processing in ASD could be "noisy", we suggest that elevated internal noise and neural variability may explain some of the complex phenotypes in individuals with ASD.[237] This is further complicated by the fact that estimates of

neural variability are based on responses to noisy task stimuli, making it difficult to estimate the degree to which internal noise limits perceptual performance in ASD from external noise and/or both.

2.9.2 Role of Excitatory/Inhibitory Neural Responses

In typical populations, a "spatial suppression" is a counterintuitive behavior resulted in decrease the sensitivity to a motion stimulus when size and contrast motion increased. This is also affected by the contrast "gain control", which is an inhibitory mechanism to prevent overresponse to high-contrast stimuli.[238–240] These two visual responses are referred to as the excitatory/inhibitory (E/I) neurochemical balance in the context of visual motion perception. Abnormally weak spatial suppression, which is reflected in reducing the effect of increasing stimuli size, has been found in individuals with schizophrenia, as well as elderly people.[241,242] Foss-Feig et al[46] studied whether there were abnormalities in response-gain control in a group of children and adolescents with ASD compared to TD. They varied in size and contrast of drifting grating stimuli, using a two-alternative forced-choice method in a direction-discrimination task. The results showed that both groups exhibited increased threshold with increased stimulus size, and there was no overall group-performance difference for high-contrast levels. Interestingly, the autism group showed a twofold-enhanced performance for all stimuli sizes with high contrast than the TD group. For low-contrast stimuli, however, there were no group differences, and there was no correlation between contrast and size sensitivity with severity of autism syndrome for both contrast levels used in the experiment. This contrast-dependent enhancement of motion perception in ASD is qualitatively consistent with impairments in response-gain control, whereby inhibitory neural responses are atypically increased at high contrast. Notably, both response-gain control and

receptive-field size are affected by the E/I balance in the brain.[243] Schauder et al[195] replicated the Foss-Feig et al study, but examined stimulus-size changes affecting gain control in autism. Their results revealed low sensitivity in participants with autism to small stimuli, which suggests large receptive fields in ASD and elevated excitation levels. However, these findings agree with the results of a previous fMRI study in adults with autism.[244] Other studies ruled out E/I imbalance in the visual system of those with autism, but suggested that such an imbalance, if it exists, is likely to be small and thus does not explain the enhanced visual processing found in autism.[245] In particular, contrast sensitivity and first-order visual processes have been found intact in ASD.[94,98,209] Moreover, findings in E/I studies on autism do not really agree with the idea of E/I imbalance, which suggests that reduced center-surround inhibition affects weak spatial suppression that results in decreased effective stimulus contrast.[246] A hypothetical model has linked the E/I balance to γ-band activation, which is found in many visual cortical areas that are induced by different stimuli or tasks. This model proposes a temporal synchronization of neural activity for integration of object features across different modalities.[247] Based on this model, Peiker et al[248] suggested that altered γ-band modulation may result in high excitatory and weak inhibitory interactions during brain processing of visual inputs is also supported by the evidence of epilepsy in ASD. Therefore, disturbance of neural modulation at center-surround antagonism in the high-order visual cortical (eg, MT/V5) might explain the enhanced response gained in ASD. However, the conclusion that this theory can fully explain the behavioral, cognitive, and perceptual differences observed in those with ASD is still weak.[246]

2.10 Conclusion

We have detailed experimental evidence of deficits in visual processing in high-functioning adults and adolescents with ASD. Although different studies suggest different deficits, some important conclusions about the critical role of several factors in determining abnormal visual processing in autism can be synthesized. One possible reconciliation of the mixed and often contradictory data is the diversity in neural brain mechanisms in processing motion perception for different paradigms of motion stimuli. As explained earlier, RDK stimuli are widely used to evaluate motion perception in different forms, eg, global or FfM. Each of these stimuli methods may be processed differently in the brain. In particular, those methods that are processed through the integration of the MT+ complex and other visual areas, such as the STS, will result in different performance. Adding to this, differences in stimuli parameters make it difficult to compare results of one study to another. For instance, two parameters defining speed–spatial offset of signal dots in an RDK and the temporal interval between sequential animation frames, as well as their interaction with density, have an impact on the threshold for coherent motion in HFA.[162] These often-uncontrolled factors may also account for the inconsistent findings in adults with autism. Encouraging for future studies of motion perception in adults with ASD that consider the issues, for example, stimulus parameters that should be used for specific neural integration purposes, which activate particular visual neural areas in normal individuals and those with ASD.

In the second part of this review, we addressed studies that tested specific trajectories that may impact integration of motion perception in individuals with autism. Recent research allows the definition of neural noise sensitivity in ASD and offers some insight into the mechanism of integration of motion perception. Studies demonstrate a worse outcome after increasing internal

neural noise that regulate hyper/hyposensitivity within the same visual modality. We also discussed these differences in the context of gain control modulation, which might also account for enhanced or decreased activation to different impairments presented in ASD. In summary, studying motion perception using psychophysical methods opens a new vista in autism studies. Also, it is important to take into account all the factors mentioned herein, such as matching stimuli methods that account for similar specialized neural pathways, in order to understand better the mechanisms by which different areas of visual input are recruited to mediate motion skills.

Chapter 3: Is Global Motion Perception Affected In Adults With Autism

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Gholami	Y			
Lakshminarayanan	Y			Y

3.1 Overview

3.1.1 Background

The controversial results of local /global visual processing in individuals with Autism Spectrum Disorders (ASD) are major areas of interest. We investigated -for the first time- responses to combined local/global visual motion stimuli by embedding local motion details a surrounding global motion stimulus to better simulate the experience of an autistic individual under natural seeing conditions.

3.1.2 Methods:

We used the method of constant stimuli and Random Dot Kinematograms (RDK) to measure global coherence thresholds in one task. A second task included global coherent perception as well as the percept of an embedded defined shape of Form-from Motion (FfM). Twenty-eight individuals with Autism Spectrum disorder (ASD) and a Typical Developmental (TD) group participated in the study.

3.1.3 Results:

Although adults with autism showed comparable performance in reporting global direction similar to the control group, their ability to process global properties declined dramatically when FfM shape was introduced. In addition, ASD required more time to respond to global coherence even when their performance was comparable to that of the control group.

3.1.4 Conclusion

We describe several hypotheses to explain the results and discuss whether motion perception in individuals with autism is locally oriented or is a complex characteristic of motion information processing in this population.

3.1.5 Keywords:

Autism; visual motion; perception; Form-from Motion; global motion, random dot kinematograms.

3.2 Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by deficits in social communication and the presence of restricted and repetitive behaviors.[1] The ASD population shows a high prevalence of cognitive and sensorimotor impairments in comparison to the typically developed population (TD), as well as visual functions disorders.[155] Psychophysical studies have distinguished between local motion processing- i.e., sensitivity to the direction of motion of a moving element- and global motion processing- i.e., sensitivity to the overall motion of several local elements.[249,250] Measurement of global motion perception using Random Dots Kinatograms (RDK) involves integration of local details into global ones.[251] Results of measuring global motion perception using coherent motion in ASD have been controversial (see reviews by Bakroon & Lakshminarayanan,[144] and Simmons et al[9]). Nevertheless, ASD has been

associated with impaired face perception,[252] atypical biological motion perception,[220,221] and enhanced perception of local details.[64,205,232,253] However, findings of enhanced local details in autism are largely specific to processing of static stimuli.[113] Psychophysical studies show superior performance in ASD relative to controls when local information is most salient to a task and poorer performance when extracting global information is required (for more details see Happé & Frith, 1993,[254] and Happé et al).[255] Mottron et al[160] found that adults with autism are more profound in search for embedded figures rather than isolated stimuli compared to control. Similarly, in the study by Koldewyn et al,[45] found that children with autism showed the same enhanced ability in a hierarchical stimuli search task, but were able when instructed to grasp the global picture. On the other hand, results from Form-from Motion (FfM), which is generated from a number of dots that move in a spatial relationship to form a structure or shape, has been found to be intact in autism most of the time.[194,256]

Most experiments that have examined ASD-related changes in motion perception have studied global motion perception separately from FfM. However, most of what we experience every day is a combination of both local and global motion information. For example, an observer gets a sense of the direction of a moving car turning right with a background of number of cars heading in one or different directions, in addition to the random motion created by the local motor actions of pedestrians and/or bikes. Perceiving complex scenes such as this requires integration of form motion information as well as global motion at the same time. So what exactly is the difference, if any, how people with ASD process local details compared to global ones? To answer this question, Bertone et al[64] argued that studies where motion and form are assessed in autism, have used different paradigms that are not equivalent. For example, static visual forms i.e., images and pictures, is less complex in nature comparing to the complex dynamic of motion stimulus and

therefore dorsal and ventral functioning are not assessed at the same level of neural complexity. Indeed, Koldewyn et al[191] compared form and motion processing in autism, but the methods they used were not the same. The form stimulus was a non-noisy Glass pattern and the motion stimuli was an RDK composed of dots that moved horizontally against a noisy field. It's not surprising, therefore, the results came out contradictory, because participants could use different strategies to respond to form than motion. Imaging studies imply that while coherent motion may mainly activate areas of V3A and V5/MT,[257] static form information activates a number of brain areas including fusiform/lingual gyri (FG/LG), middle occipital gyrus (MOG), intraparietal sulcus (IPS). Braddick et al[249] suggested that form and motion coherence are both processed by independent networks, but these are not necessarily dorsal/ ventral segregated. Murray et al,[258] however, added that Superior Lateral Occipital (SLO) region may be important for integrating shape and motion cues, and there may be sub-regions in SLO specialized for processing the two types of cues at the same time. These divisions in visual areas activation would make it difficult to spiculate the reason(s) behind any bias towards local processing in those with autism, particularly, when global perception can be invoked when it is required, and when participants with autism are given longer time to respond.[160] Despite the fact there have been several separate experiments investigating form and motion processing in ASD, there has been no study that involves both types of information in one single motion task. In the present study, we employ a new stimulus paradigm that allows a better matching of the task processing requirements. This also enables us to examine whether performance of form and motion tasks are correlated in individuals with autism.

3.3 Methods

3.3.1 Participants

We tested 16 adolescents and adults (age range 16-40 years) with ASD, and 15 Typical Developmental (TD) control participated in the study. The autism participants were recruited through the Autism Ontario website, /Waterloo/region http://www.autismontario.com/client/aso/ao.nsf/Waterloo/waterloohome. Control participants were recruited from the University of Waterloo and the local area. Groups were matched for age, gender (5 female and 9 males in each group) and ~ academic level. ASD participants above the age of 16 years either had finished their college education, or were enrolled in graduate studies. Autism participants provided their medical reports assessed by an experienced clinician. Most of these participants were diagnosed at childhood based on standardized assessment procedures, such as Autism Diagnostic Observation Schedule (ADOS-G), The Childhood Autism Rating Scale (CARS), and The Autism Diagnostic Interview – Revised (ADI-R), and there were no updated reports subsequently. However, all autism participants completed the Autism Quotient Test of Baron-Cohen et al,[259] a 50-item self-administered questionnaire targeting sub-clinical autism-like traits. The AQ test was completed online, and mean score was 30, +/- 2.7. One participant from the autism group who scored 35+ was excluded from the study, who also has been found to have a sibling with severe autism. Two participants, one from the autism group and one from the control group were removed from the data analysis because of incomplete task completion. Exclusion criteria for the autism group included family history of ASD[98] or related developmental disorder, any known comorbid medical conditions, and/or under any psychiatric medications in the previous six months before the start of the study. Controls were excluded

from participation if they had ever received mental health treatment, taken psychiatric medications, been diagnosed with a genetic or neurological disorder, or had brain trauma/ injury, or had a sibling with autism. All participants had normal or corrected-to-normal visual acuity, contrast sensitivity, and depth perception (Table 3-1).

	Control (SD)*	ASD (SD)*	Group comparison
Age range (16-40 years)	25.92 (6.45)	26.75 (6.74)	p = .79
Visual Acuity (log Mar)	-0.13 (0.11)	-0.16 (0.09)	p = .44
Contrast test (log Mar)	1.93 (0.18)	1.82 (0.12)	p = .06
Stereo-acuity (second of arc)	20.71 (1.81)	21.35 (7.53)	p = .11

Table 3-1 Data on selected visual functions of experiment participants.

** indicates standard deviation. Note: visual acuity and contrast sensitivity were evaluated using the Freiburg test,[260] and Stereo-fly test were used for depth perception.*

Written consent was obtained from all participants and/or their parent/guardian, in accordance with the protocol approved by the University of Waterloo Research Ethics Committee and the Research Ethics Board at Wilfrid Laurier University.

3.3.2 Apparatus and Stimuli

We used the RDK global coherence stimulus in two tasks: (1) a Coherent Motion (CM) task, where coherence level was varied and the subject had to detect the global direction of the coherent dots; and (2)a Coherent Motion/Form-from-Motion (CM-FfM) task, where the FfM stimulus consisted of one of four different shapes embedded in the global RDK task. Both

stimuli were computer generated using Python software and displayed on a MacBook Pro-laptop (15.4-inch, 2880 x 1800 pixels, 60 Hz refresh rate), which was gamma-corrected. The stimuli were presented within a borderless square window at the center of the display ($4.8^{o} \times 4.8^{o}$), at a viewing distance of 100 cm. The stimulus consisted of 180 white dots (dot diameter: 0.4^{o}, speed: 2.8^{o}/s) displayed on a gray background (Figure 3-1) with 100% contrast.

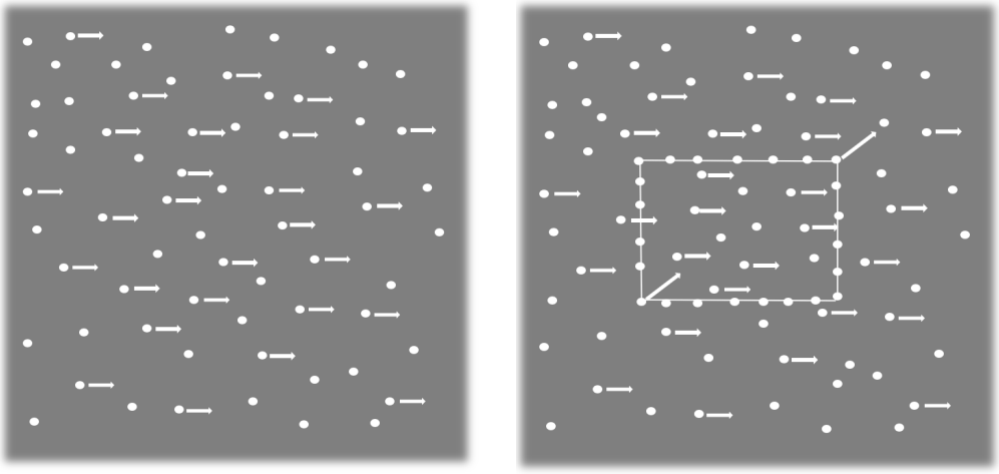

Figure 3-1 Stimulus display used in the experiment

Left: CM task included standard RDK stimulus, Right: CM-FfM task included global RDK and the embedded shape (rectangle in this case). The lines show the direction of the coherent motion and the level, the remaining dots represents the noisy dots that run in different directions. All line are for illustration purposes and were not presented during the stimuli.

The average dot density was roughly consistent across each task as well as between both tasks. Stimulus duration was 500 ms to prevent the use of serial search strategies in autism group.[159,253] A red fixation point appeared in the center of the screen during stimulus presentation to prevent participants from following one dot and thus perceive the global direction of the dots. However this fixation point disappeared in in-between trials to prevent an afterimage. Also, all dots had a limited life time, which means that each dot was presented for 40 ms and then disappeared with

subsequent reappearance in a different place. If the dot reached the edge of the square display window before the end of lifetime, it was ‘‘wrapped-around’’ so that it immediately reappeared at the opposite edge of the window. We chose these parameters of dot size, dot density and dots speed based on the results of a pilot study to ensure that (1) all dots were clearly and individually visible to the observer; (2) no dots overlapped and each dot was presented with the same displacement from other dots for both signal and noise dots; and (3) that there was a low probability of ‘‘false-matches’’ occurring between coherently displaced dots and shape dots in the CM-FfM task. All psychophysical testing was completed in a single session, with breaks taken as needed. Each participant completed the CM task first then the CM-FfM task. The task order was consistent between individuals and was counterbalanced within and between participant groups. Both tasks were conducted under photopic conditions and the participants used arrows on a key pad to respond to global direction with their dominant hand. The average time for completion of each task was 25 min with no breaks.

3.3.2.1 CM Task

Participants completed 2 blocks of 16 trials at each of 9 different coherence levels for a total of 288 trials in each task. On each trial, a fixed percentage of dots (0%, 5%, 10%, 20%, 40%, 50%, 60%, 80%, 100%) moved in a coherent direction (left, right, up, down) for the duration of the trial (Figure 3-1). Coherence in the display was defined as the percentage of dots moving in the same direction, rather than the ratio of noise percentage assigned by the Brownian movement of the random dots. We set the high coherence levels (for ex. 60% up to 100%) for performance comparison with the CM-FfM task at low signal/noise ratio. The 0% condition, however, was set for direct measurement of lapse rates “the rate of random errors made by participants measured at the tail-end of the psychometric function”, also to compare between high noise level (0%) and

zero noise level (100%) particularly at defining the shape in the CM-FfM task.[191] Coherence level and dot direction were randomized across trials. Participants performed the standard four alternative forced-choice motion discrimination task,[261] indicating the global direction of the coherent dots. All participants were instructed to keep their heads still on a head/chin rest and fixate on the fixation point for the entire duration of the time the stimulus was present. The main experimenter was monitoring participants performance throughout the test, but no feedback was given. All subjects had 10 trials practice run before the beginning of the task and all questions regarding the test were clarified.

3.3.2.2 CM- FfM Task

Here, the same protocol as described in the CM task was used; however, in this experiment, an FfM defined shape was embedded in the stimulus. The FfM shapes consisted of dots arranged in four shapes (triangle, square, circle, rectangle) and moved across the four diagonals of the stimulus aperture. Each shape subtended 3.45º at the test distance (Figure 3-1) and was composed of the same number of dots (30 dots) while the remaining 150 dots were either CM direction signal dot or noise dots, (including the dots that were present inside the central area of the shape configuration). Overall stimulus density was equivalent to the CM task, thus ensuring task comparability. As in the CM task, the global direction of each trial was varied randomly (right–left–up–down). We ensured that the shapes moved at a 45º angle from the coherent dots direction in each presentation, and was randomized throughout the task among the four diagonals. Participants were asked to respond to the direction of the coherent dots first by using the keypads, and then verbally name the shape they saw if they managed to see any, or otherwise guess. There was no feedback during the experiment. However, all participants were given 10 practice trials session and were informed about the shapes that were used in the task before they

started. It is important to mention that the shapes were actually perceived only when the apparent motion of the shape was processed.

3.3.3 Threshold Estimation

In both tasks, psychophysical thresholds were measured using the method of constant stimuli, in which 288 trials were randomized for 9 coherence levels. We fit a logistic function using custom Python scripts to define the threshold of each individual averages of correct responses, weighted by the number of responses at each coherence level. To obtain best fit, a SciPy tool for Python was used to best fit a sigmoid curve, constrained to values between 0 and 0.90,[262] assigned level was set at 25% guessing rate and threshold was estimated at 37.5%. we see that the cutoff at this level is consistence with previous finding using RDK stimuli for motion at being around 37.5%.[263,264]

Response time was also collected and was defined as the time between stimulus offset and the participant's response. An average of the RT of the correct trials was taken for each coherence level and for each participant, then we estimated overall performance based on grand average of RT. Outliers in the RT were all points more than 100 ms above the mean RT were removed and considered as rest time. As long as this "rest time" didn't occur more than 3 times per task, test will be retaken in other session. However, no participants required a retake of the test in both groups. In CM-FfM task, coherence threshold was estimated using same protocol as above. However, responses to the FfM shapes were collected verbally and in writing (and also audio recorded). Correct percentage was calculated for each coherence level of each participant, and then an overall percentage was calculated.

3.4 Results

The minimum number of coherent dots that participants could detect was estimated at 37.5% percent correct, which is above the guessing rate. Coherence Threshold (CT), was measured in 288 trials for each condition as described above. The average for CM and CM-FfM thresholds were used as dependent measures in a mixed model repeated measures ANOVA within-subjects factor (CM, CM-FfM), and between-subjects factor condition (ASD, TD). Multiple pairwise T-tests were also used to measure main differences between groups. Compared to controls, participants with ASD made significantly less accurate judgments about the direction of global motion when the FfM shape was embedded in the stimuli. On the other hand, both groups showed comparable performance to direction of heading when shape was not included (Table 3-2).

	CM	*CM- FfM*	*FfM correct response*
TD	11.86, (2.16)*	18.59, (5.62)*	79%
ASD	13.58 (2.54)*	30.65, (9.46)*	94%

*Table 3-2 Mean threshold scores, (standard deviation in the brackets)**

FfM information showing mean percentage of correct responses.

Individuals with ASD correct responses to the shape fluctuated between 90% and 100% at all coherence levels, while the control group average correct response rate increased in parallel to the increase of coherence level of the global motion, hence decrease noise level. Response time to global direction, however, increased for both groups in the CM-FfM task compared to CM task. While individuals with ASD took longer time to response to global direction in the CM-FfM task compared to controls.

3.4.1 A Typical Bias Toward FfM Information and Neglect The Global Motion In ASD

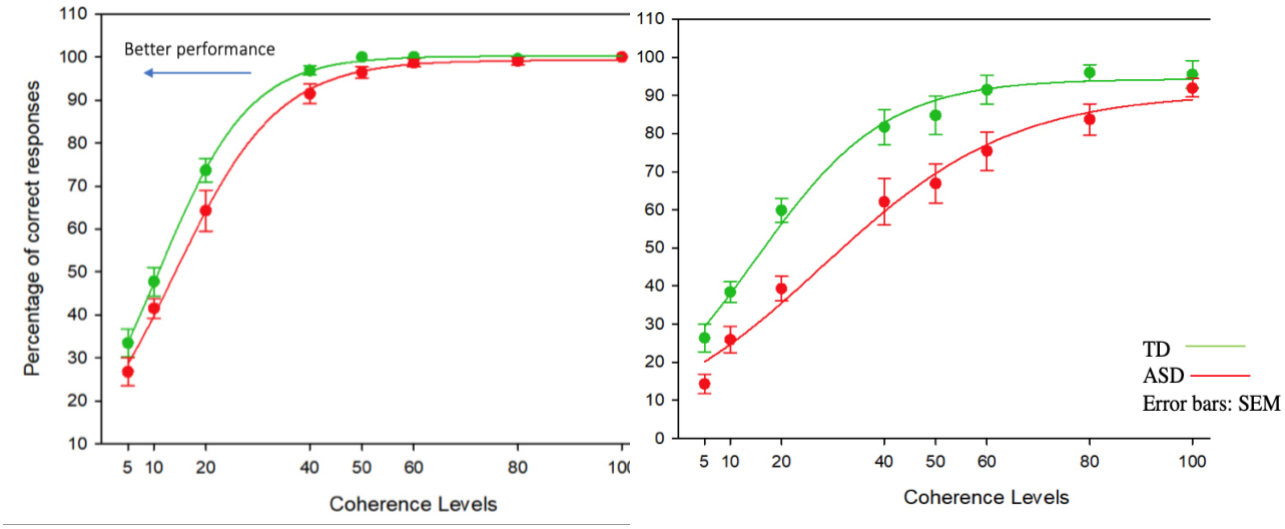

Figure 3-2 Psychometric curve of CM and CM-FfM tasks in both groups indicating the average correct responses at different coherence levels. Error bars: SEM

From the ANOVA results, statistically significant interaction was found between motion task type and groups ($F(1,26) = 16.232$, $p = 0.0001$), indicating that the effect of embedding the shape in the global coherence task differed between the ASD and control groups (Figure 3-2). The two-way interaction is illustrated in Figure 3-3: the effect of embedding the shape was greater in the ASD group than the control group, and the group difference was larger in the CM-FfM task than the CM task. A detailed pairwise statistical analysis results showed no significant difference between thresholds ASD (mean = 11.86 SD= 2.16) and TD group (mean= 13.58, SD= 2.54) in the CM task (t (25.336) = -1.930, $p = 0.065$), but a significant difference between thresholds in the ASD (mean = 30.65 SD= 9.46) compared to TD group (mean= 18.59, SD= 5.62) in the CM-FfM task (t (26) = - 4.1, $p < 0.001$) .

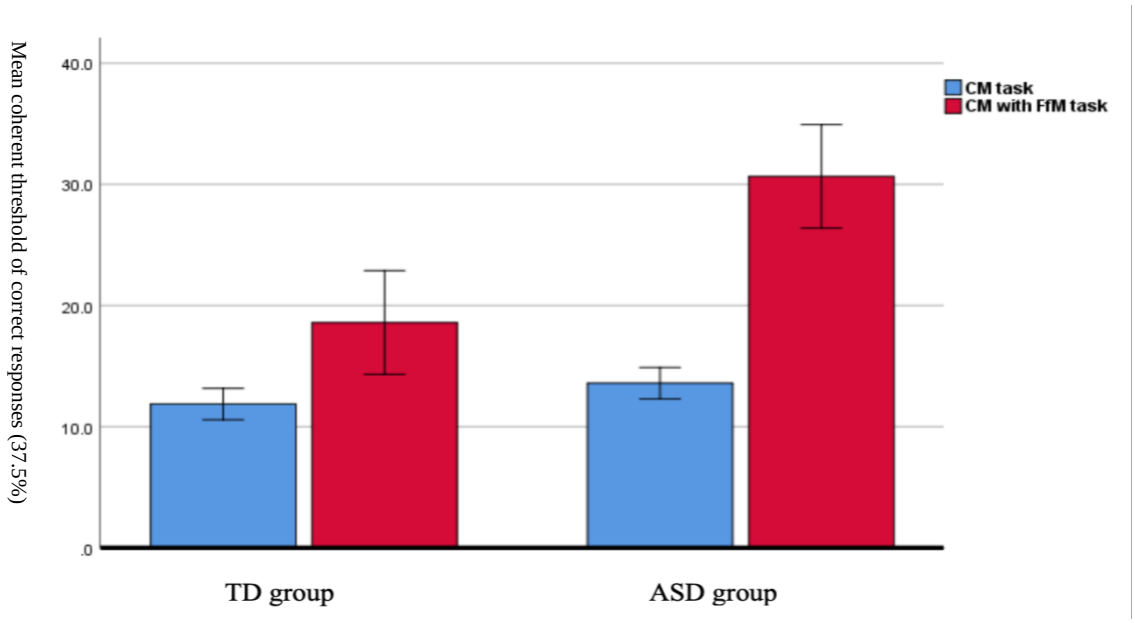

Figure 3-3 Compression of overall coherence threshold in CM and CM-FfM tasks between both groups. Error bars: SEM

The Proportion of correct responses to the shape also was significantly different between groups: individuals with ASD showed higher percentage of hit responses (mean=94%) compared to control group (mean=79%) (Fig. 3.4). A chi-square test found a significant difference between the two groups and the frequency of correct response to the shape, X^2 (1, N = 200) = 9.634, *p* =.002).

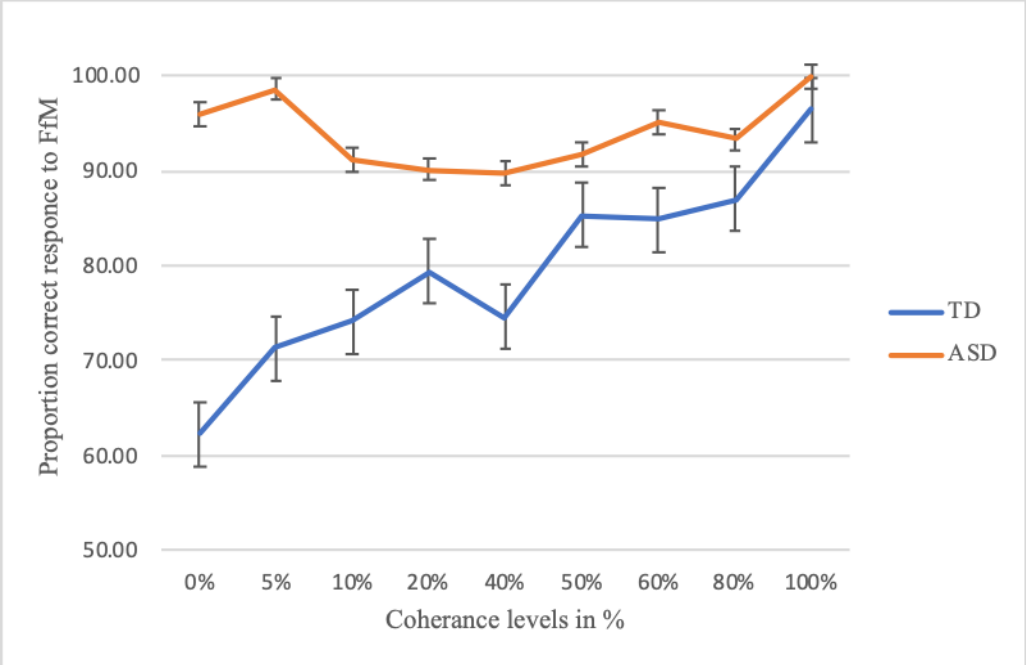

Figure 3-4 Average group accuracy respond to shapes at different coherence levels preformed in the CM-FfM task. Error bars: SD

We also characterized performance of correct responses to shape in each group at different coherence levels (Figure 3-4). This analysis allowed us to explore each individual's average performance of integration of the FfM information, which implicitly contributes to determining individual global motion processing. This analysis will define: an individual's performance at each level of coherence, maximum and minimum accuracy percentage in global and local information detection, and remove any constraints imposed by the overall average of correct response for the group. Towards this end, an ANOVA was computed on the raw data (across coherence levels and between groups). This analysis indicated that the group difference found in the overall frequencies of percentage of correct responses was due to differences in the integration of FfM information in parallel to the global information. Specifically, shape identification accuracy in the ASD group was between 90 and 100% correct at all nine levels of coherence (including the 0%: see Figure 3-4) accuracy in the control group increased

approximately linearly with coherence. The ANOVA results revealed statistically significant main effect of coherence ($F(8,208) = 11.929$, $p = 0.0005$).

Finally, in each group, high performance was presented when coherence level reached 100%. At that level of coherence, a t-test failed to find a significant difference between accuracy in the two groups ($t(26) = 0.823$, $p = 0.419$). This failure to find a significant group difference at high levels

of coherence indicates that both groups were able to perform better at a high level information and zero level noise in the back ground (100% coherence level) and there were no differences between both groups ($t(26) = 0.823$, $p = 0.419$) in the ability to maintain attentional engagement with the task (Figure 3-5).

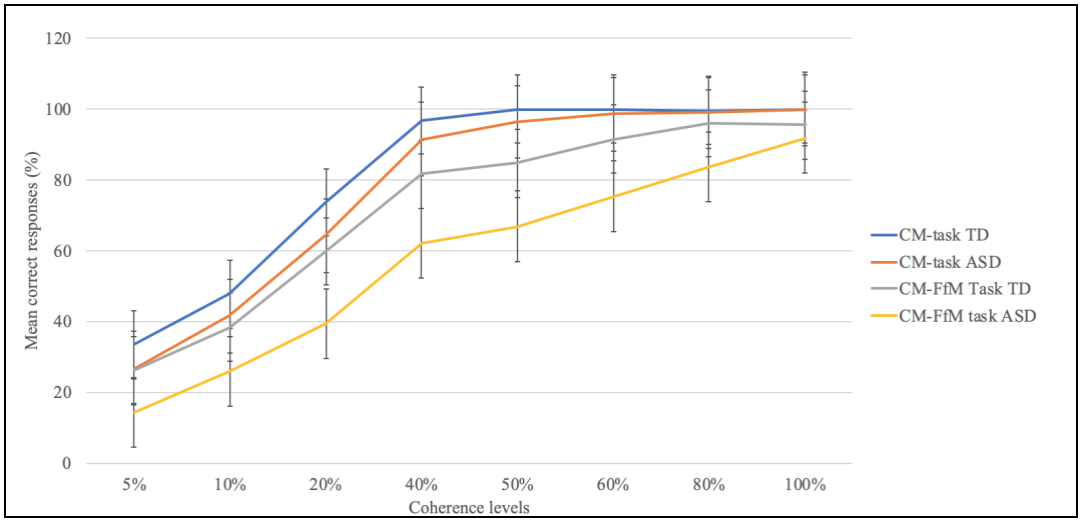

Figure 3-5 Mean threshold levels at each coherence levels. Error bars SEM

3.4.2 ASD Observers Require More Time to Respond:

To investigate the effect of tasks type on behavioral performance in ASD, we measured the response time of each participant at each coherence level and then compared average response

time between both groups. ANOVA showed no main effect of groups was observed [$F(1,26) = 2.352$, $p = 0.137$], indicating that the two groups showed comparable overall performance. However, a significant interaction of task type [$F(1,26) = 20.440$, $p < 0.05$] was observed, reflecting an overall increase in response time in both ASD and controls when FfM shape was embedded in the global motion task (Figure 3-5).

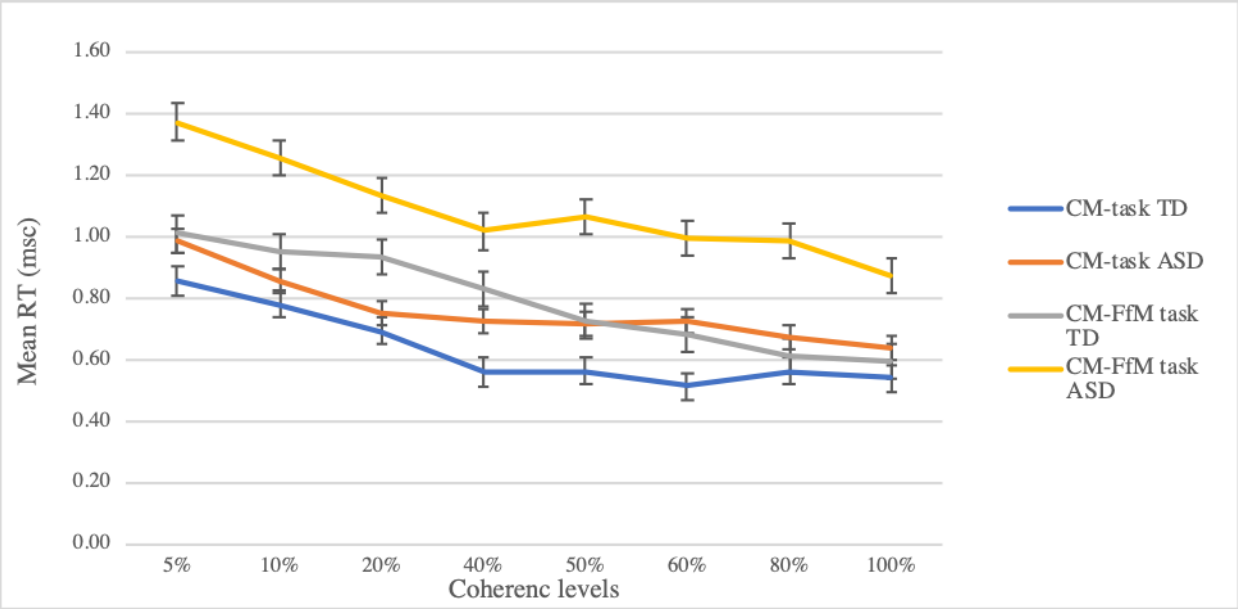

Figure 3-6 Average response time to global direction at each coherence level for both tasks CM and CM- FfM and for both groups ASD,TD. Error bars: SEM

Critically, this effect was exaggerated for individuals with ASD [$F(1,26) = 15.048$, $p < 0.001$]. A pairwise test indicated significant high response time for ASD group at the CM-FfM task (mean= 1.1, STD= 0.37) and no main difference in the CM task (mean= 0.76, STD= 0.33) compared to control group for the same tests respectively (mean= 0.79, STD= 0.26) , (mean = 0.63, STD = 0.13). T-test results for both tasks was: CM:[t (16.913) = -1.349, p = 0.195], CM-FfM:[t (26) = -2.411, p = 0.023].

3.5 Discussion

Our findings suggest that individuals with ASD tend to process coherent global motion similarly to control group. However, when FfM information was embedded in the task, compared to the control group the ASD group higher shape in dentification accuracy but lower sensitivity to coherent global motion. These results demonstrate for the first time that global/local motion perception is not generally atypical in autism,[185] however, it is more biased toward local information. Thus, the mechanism of processing form from motion presumably differ from the mechanisms that process more elementary CM data. Interestingly, the integration in the ASD of both the coherent global motion task and the identification of a familiar shape in the CM-FfM task reached as same as control group specially when noise level was zero. However, and before we discuss what could be behind the biased local/ global motion perception found in ASD, it is worth mentioning that this extraordinary performance of the group of ASD was highly notable. For a naïve participant in our tasks, it was very difficult to determine the shape initially, but defining the global direction of the coherent was easier. In the control group, for instance, the difficulty to perceive the shape was obvious – and expected - so they required several training trials with the aid of a pointer to spot the shape. However, participants with autism were able to spot the shape correctly even at the initial presentation during the training trial (note: both groups had the same number of training sessions to prevent perceptual learning effect). In light of these observations and the statistical findings we can address the following explanation of atypical global/local motion perception found in autism. Our results for the CM-FfM condition are consistent with previous results from the study of Jones et al.[203] showing no evidence of fundamental difficulties with the perception of CM and FfM in their high IQ autism group. However, in Jones's study the CM and the FfM tasks were measured separately, though using

noise elements adjusted by the same staircase method in the background for both tasks. Moreover, our findings of normal processing to global coherent direction concur with other studies in adults with autism,[160,194] contrary to related studies where global motion deficit has been found in autism using psychophysical tasks[95,158,166,185,191,195,202] and neuroimaging techniques.[192,193] Certainly we can argue that these studies used different stimuli methods and various parameters which make it difficult to compare. Therefore, in our task, our findings imply same task methods of processing local FfM and global CM when both types of information are processed simultaneously. Based on fMRI studies that have investigated neural activation of processing CM and FfM information at the same time,[265] results suggested that the FfM information has a distinct processing mechanism than CM information. For example, FfM information might only be processed at the ventral occipito-temporal cortex (VOT), whereas combined information of FfM and CM perception might be processed in the area of MT+/V5 or an area including lateral occipital cortex (LOC) based on lesion evidence. This suggests the existence of at least three functionally and anatomically distinct regions in human visual cortex that process FfM signals and may be independent from static form perception.[266] Related studies using VEPs,[194] however, have found that the LOC and the VOT areas, which are mostly activated in processing FfM information, could be typical in individuals with ASD, while, dorsal stream deficiency has been detected in autism group despite comparable behavioral performance with control group.[191,267] Such findings suggested that visual cognitive areas that process visual inputs of FfM and coherent global information concurrently could be highly activated for object motion direction recognition and less activated to global motion in autism. Related asymmetries of local/ global visual processing have been found in autism using fMRI and static hierarchical

shape recognition task.[268] However, to understand the neural abnormalities behind this biased function, more imaging studies should be employed.

3.5.1 Neural Related Findings:

To our knowledge, there are no studies that have used functional imaging methods to investigate simultaneous local/ global motion information processing in autism. However, increased activity in visual areas in autism in response to random motion compared to coherent motion have been reported in several imaging studies.[193,269] Brieber et al[193] suggested that there are differences in neural activation between controls and participants with ASD at different processing stages of the dorsal pathway, including increased neural activity in the primary visual cortex, and unmodulated activation in the motion-sensitive area V5, combined with no differences in the response performance between the ASD and TD group. This finding might explain our results for the normal performance between groups on CM task without shape. However, an explanation to the deficit in global motion perception specific to integration of the FfM information at the same time could theoretically arise from one of two scenarios: a diffuse, non-specific neural dysfunction in the early visual area, or a cortical underconnectivity to complex stimuli. A diffuse, non-specific neural dysfunction related to debilitate of neural activity in V1 leading to impairment in the dorsal stream has been proposed based on fMRI findings in autism.[193,210] Indeed, these studies used coherent motion as the main task. However, the complexity in our task would suggest that the task requirement would involve more integration of neural areas. Thus, there would be involvement of more cortical areas that are mainly beyond the V1. Besides, if this hypothesis is valid, a deficit in perception to FfM information should also be implied, since FfM information may require inputs from both early and higher visual cortex.[214,219] Therefore, a

cortical underconnectivity theory, which posits that interregional (systems-level) connectivity circuit in the brain are disrupted in autism, might better explain our results.[270,271] Indeed, in the autism group, elevated CM thresholds when FfM was included resulted in a shallower psychometric functions. As evidence, the aggregation signals from FfM task may increase significantly compared to CM task alone, affecting their relative performance particularly when the level of coherence decreases in the display while the integration of FfM information remain comparably high. Alternatively, we find a general offset in the psychometric function across all coherence levels in the CM-FfM condition, but no difference in the slope of this function in the CM task alone, suggesting that evidence of accumulation in the autistic perceptual system approaches a similar decision-threshold as in controls, but in the embedded task more variability was found in autism. An increase in signal variability would predict both higher thresholds and lower accuracy across coherence levels due to more contribution from neurons tuned to FfM detection during the formation of the global motion decision-variable in the ASD group. The post hoc t-tests on our parameter estimates revealed that the difference between response performance to FfM shape was more significant for the ASD group, whereas in the control group it increased in parallel with the increase in the global coherence level. Our assumption of disturbed dorsal stream activity in area V5 might be more profound when integrated with other cortical areas, hence this disturbed activation might be reserved if the stimuli complexity is reduced. Earlier, Koldewyn et al[191] found no support of a general dorsal stream deficit in ASD. Instead, they speculated that differences in dynamic or 'spatiotemporal' attention lead to the visual motion impairments in ASD. Relatively, our autism group was able to perform the coherent task as well as typical participants, which may demonstrate that deficits seen on the CM-FfM task cannot be the result of differences between groups in general attentiveness, and

task understanding or motivation, which couldn't support this hypothesis. Moreover, related results showed that attentional processes could potentially confound performance on tasks assessing global motion in autism. For example, using prolonged RDK stimuli may result in feature tracking method to define motion direction.[191] We only presented our stimuli for a short duration (i.e. 500 ms) to measure motion perception, in order to prevent the use of serial search strategies and therefore, attention could not account for the results in the present study.

3.5.2 Neural Noise Theory

Interestingly, ASD performance to global information was reserved at full coherence (100%) in combination with FfM information. Results of symptoms where individuals with autism often report both hyper- and hypo sensitivities within the same sense modality have been found in related studies.[68,272] These findings are supported by studies of increased internal noise being associated with decreased visual perception or decreased coherence in natural neural oscillation mechanisms involved in autism.[237] Park et al[226] found that increased internal noise and worse external noise filtering influence perception in children and adolescences with ASD. They found that estimated internal noise was correlated with ASD symptom severity, suggesting that individual variability in internal noise may be related to ASD symptomatology, a result that is correlated with previous findings.[237] Related finding of increased neural variability in first-degree relatives of ASD individuals suggests a genetic influence of an ASD genotype on the level of internal noise in the brain.[273] This theory of defects in internal noise in autism could explain to a great extent the increased performance at 100% coherence level (zero noise) in the autism group in this study. However, it is very difficult to speculate on our findings as being solely due to decrease internal noise in ASD.

3.5.3 Longer Time to Response

Our response time results, which were consistent with previous findings, [128,185] suggested that the autism group needs more time to respond to both tasks despite the comparable performance in CM task. Van der Hallen et al[152] explained that declined performance in individuals with autism was due to short time of task exposure, as well as task complexity, which makes autism performance worse. Hadad et al,[196] also suggested that people with developmental disorders may require longer time to process motion information due to long range deprivation at early childhood that may extend the period of processing visual inputs at adult stage.[162]

3.6 Conclusion

The data presented here contributes to the characterization of global/ local motion perception within the greater autism spectrum. However, limitations in our study, such as, small sample size in the ASD group may affect the possibility of normal disruption in threshold level. The results showed that all our participants with autism have the same impairment on the coherence task with embedded FfM shape points to a new model of biased motion perception in autism. Moreover, we have to mention that we measured other stimulus paradigms using drifting grating stimuli, speed factor, and optic flow, all in the same sample of subjects and our initial results indicate that related factors might explain local/ global motion abnormalities in adults with ASD. Taken together, the data suggests that the impairment of motion processing in individuals with ASD may not necessarily arise solely from one abnormal mechanism, or a broad impairment in ASD in spatiotemporal integration, but rather a complex factors may contribute to decreased sensitivity to motion perception at different areas of the cortical visual areas and may be influenced by internal/external noise.

3.7 Acknowledgements

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Chapter 4: Selective Impairment of Direction of Heading Judgment Measured Using Optic Flow Stimuli in Autism Spectrum Disorders

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Bakroon	Y	Y	Y	Y
Roy	Y			
Lakshminarayanan	Y			Y

4.1 Overview

4.1.1 Background

Previous studies of optic flow (OF) in individuals with Autism Spectrum Disorder (ASD) showed a selective impairment compared to normal control group in detecting direction of radial motion. Altered function of medial superior temporal area (MST) related to processing of OF motion was suggested. This study investigated whether this deficit in OF perception in autism is related to biased local/ global motion perception, or to disturbed connectivity of functional brain networks at the same area.

4.1.2 Methods

We measured psychophysical detection thresholds for radial OF stimuli in 13 ASD and 14 typical developmental (TD) adults. We measured threshold in two tasks : eccentricity of heading direction task, and contrast sensitivity task to OF motion. In both tasks we randomized the density (15, 80 dots) and speed (4, 10 deg/sec) of the moving stimulus dots.

4.1.3 Results

The eccentricity of heading direction task results showed no significant group differences were found for low dot density (15 dots), while high dot (80 dots) density showed low sensitivity to OF motion in the ASD group compared to the TD. In the contrast sensitivity task, however, we found high thresholds in the ASD group for detecting OF motion when dot density was low (15 dots), but not when dot density was higher (80 dots). In both tasks, there were no group differences in the effect of dot speed nor in response time.

4.1.4 Conclusion

Our results suggest that selective ASD-related impairments in OF processing might be related to altered connectivity among visual cortical areas.

4.1.5 Keywords

Optic flow, motion perception, ASD, dots density, speed parameter, contrast sensitivity.

4.2 Introduction

Previous research on visual perception in autism spectrum disorders (ASD) suggests that ASD is associated with enhanced processing of small details and impaired perception of global motion.[191,193,205] Recent investigations hypothesize that visual deficits in ASD may arise from abnormal functional and structural connectivity of complex cortical neural networks that are activated during motion processing.[163,230,274,275]

Optic flow (OF) motion is an important source of information for navigating through the environment,[276] but few studies have investigated OF processing in observers with ASD. Imaging studies show that OF stimuli are processed in the dorsal portion of the medial superior temporal cortex (MSTd) of macaque monkeys.[277] In humans, however, fMRI evidence has shown that OF patterns activate a network of areas including visual area V5/MT, and area MST, with strong direction-selective response to radial and circular motion in human hMT+,[278] and the lateral occipital channels,[279] while translational and radial motion are activated mainly in the MT/V5 area.[280,281] Neuroimaging studies that studies activation at the MT/V5 and the MST area related to motion perception in ASD suggest that functional connectivity comprising of long-

range connections in the brain may be diminished; this is accompanied by greater localized connectivity.[282] However, the mechanism(s) underlying such defects in ASD is still unknown.

According to the dual pathway model,[188] two streams are generated from the dorsal pathway and its recipient parietal areas, the dorso-dorsal (d-d) and ventro-dorsal (v-d) stream.[283] Optic flow information is processed through the v-d pathway.[284] Several studies suggest that the ventral stream alone found intact in ASD observers most of the time,[156,211] while dorsal stream vulnerability was reported as the main theory of declined global motion perception in autism.[151,250] Few studies, however, studied the v- d integration in autism in relation to OF motion perception. Recently, Bakroon et al[275] suggested that the decline of motion perception found in autism might be related to the complexity of the stimulus, and/or that ASD individuals have increased internal noise that affect the processing of both local/global information simultaneously. Hence, we proposed that integration of global motion was processed through the "d-stream", while form-from-motion was processed separately through the "v- stream". Based on event-related potentials (ERPs) data[282] detection of direction of heading of OF integrated through v-d stream. Hence measuring direction detection in ASD using OF motion may add more evidence to the theory of complexity- specific impairments. For example, Yamasaki et al[204] compared the perception of global coherent motion and optic flow motion in adults with autism and a control group. The results showed no group differences in detecting direction of heading in both, though Event-Related Potentials (ERPs) data showed a prolonged P200 latency for OF responses in ASD group compared with control group, and no performance differences in the coherent motion task. Their results, however, suggest that impaired OF perception in autism might be related to dysfunction of the v-d (inferior parietal lobule) stream. Yamasaki used low speed random dots in their stimuli, which might prolong the integration of OF motion in

autism.[162] Earlier studies, showed that observers can make more accurate judgment of direction of heading in a straight pathway when the speed of elements (moving dots) increased.[285] In autism, the relationship between motion sensitivity and speed discrimination is controversial. For example, Manning et al[286] suggested a deficit in children with ASD for discriminating slow speed, yet at higher speed levels they showed same sensitivity as the control group. On the other hand, Chen et al[205] found that autism participants have enhanced speed discrimination in a coherent motion task when visual comparisons were made over a prolonged temporal distribution period. Unfortunately, we cannot compare between the two findings because Manning et al used slow motion (1.5, 6 deg/s) whereas Chen et al used faster motion (5.25 – 9.45 deg/s). Furthermore, developmental studies suggest that infants developed sensitivity to fast speed, while adults largely respond to slow speed OF pattern.[279] A late delay in the developmental trajectory in autism[162] could explain the differences in speed sensitivity, but one cannot generalize these findings to cover all types of motion (e.g. OF motion).

Optic flow and motion contrast have often been studied separately in autism, and yet they share important commonalities. Findings of contrast sensitivity in motion perception in autism are controversial. Some studies found that there is intact luminance contrast sensitivity in the ASD group, [94,95,98,287,288] while others found deficits.[46,62,92] Indeed the different methods and the wide range of parameters used in these studies make it difficult to determine a firm finding of motion contrast perception in autism. Results show that OF motion and motion contrast both depend upon the aggregation of local motion signals in the brain, either for global integration or regional segmentation.[289,290] Related studies have also found that motion contrast activation varies with speed.[291] Therefore, comparing OF related contrast and speed modulation responses in adults with autism may shed light on the extent to which cortical mechanisms for the

processing to these two types of complex motion are distinct in this group. The data may also provide benchmarks for future studies of the motion processing in autism in the visual domain network.

Here we report self-heading of direction discrimination using an optic flow task that varied dot density, speed, and contrast parameters to answer the following questions:

(1) Does sensitivity of self- heading of direction detection impaired in autism?

(2) Does speed or density affect their performance in detecting direction of heading?

(3) Does luminance variation of local elements (dots) decrease contrast sensitivity to OF motion in autism and/ or would decrease discrimination of heading direction?

4.3 Methods

4.3.1 Participants

We recruited 15 adolescents and adults (age range 16-40 years) with ASD, and 14 Typical Developmental (TD) control participants that were matched in age, gender, and approximate academic level. All ASD participants were adults who had previously been diagnosed with ASD based on childhood medical reports assessed by an experienced clinicians, and there were no updated reports subsequently. In addition to these childhood medical reports, ASD participants completed the Autism Quotient Test of Baron-Cohen et al,[259] a 50-item self-administered questionnaire targeting sub-clinical autism-like traits. The AQ test was completed online, and mean score was 27, +/- 2.7. One participant from the autism group who scored 35+, and who also was found to have a sibling with severe autism was excluded from the study. Another ASD participant failed to complete the tasks and therefor was removed from the data analysis. Hence

only 13 ASD participants were included in the final sample. All participants had their vision checked and no significant differences were found between both groups (Table 4-1).[275]

	Control (SD)*	ASD (SD)*	Group comparison
Age range (16-40 years)	25.92 (6.45)	26.75 (6.74)	p = .79
Visual Acuity (log Mar)	-0.13 (0.11)	-0.16 (0.09)	p = .44
Contrast test (log Mar)	1.93 (0.18)	1.82 (0.12)	p = .06
Stereo-acuity (second of arc)	20.71 (1.81)	21.35 (7.53)	p = .11

Table 4-1 Data on selected visual functions of experiment participants.

** indicates standard deviation. Note: visual acuity and contrast sensitivity were evaluated using the Freiburg test, and Stereo-fly test were used for depth perception.*

Written consent was obtained from all participants and/or their parent/guardian, in accordance with the protocol approved by the University of Waterloo Research Ethics Committee and the Research Ethics Board at Wilfrid Laurier University.

4.3.2 Stimulus

Stimuli were computer generated using the psykinematix software (http://www.psykinematix.com/index.html), and displayed on a gamma corrected MacBook Pro-laptop (15.4-inch, 2880 x 1800 pixels, 60 Hz refresh rate). Optic flow was presented with a random dot kinematogram (RDK) stimulus. Perceived motion was measured in two experiments:

(1) Eccentricity discrimination task: dot contrast was held constant at 100% and eccentricity angle was varied. OF direction randomized in two directions (right, left) of a fixation line, to measure the minimum eccentricity angle.

(2) Contrast sensitivity task: The Michelson contrast of the dots were varied to home in on threshold. and OF angle was fixed above threshold.

In both tasks, sensitivity (i.e, the inverse of threshold) for direction detection was measured as a function of stimulus speed (4, 10 deg/s) and the number of dots (15, 80 dots). The four combinations of stimulus speed and dot number were all randomized throughout the task. (Figure 4-1).

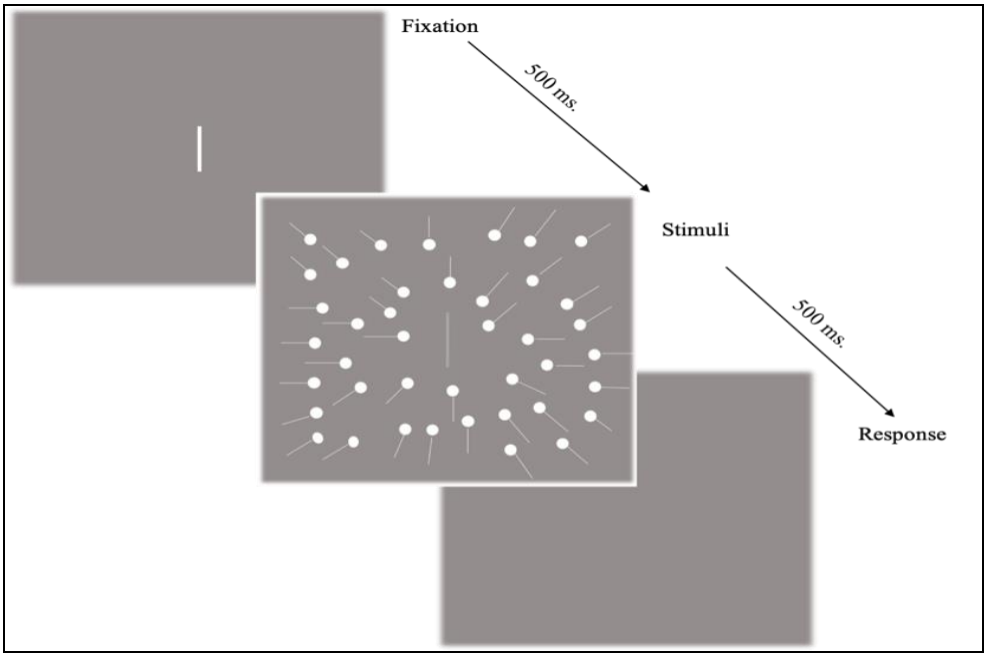

Figure 4-1 Optic flow motion used in both tasks.

Eccentricity & contrast. The stimuli were presented within a borderless gray square window (19º × 19º) at the center of the display. The dots were white and subtended (0.118°) with limited lifetime (200 ms) and updated after 18 frames. The OF motion moved inward to the right or to the left of a center line. The fixation line appeared before the presentation of the stimuli and disappeared during the optic flow motion allowing the perception of heading of direction of the dots only by processing the global motion. The stimulus was presented for (500 ms) followed by an interstimulus interval time of 500 ms.

Participants sat on a chair and were aligned with a monitor using a head and chin rest from a viewing distance of 56.5 cm. A visual tunnel was attached to the screen and the head rest. Participants had to look binocularly through this tunnel (Figure 4-2). We used the visual tunnel to create the illusion of environment motion as participant moved toward a central point of the horizon, and also to eliminate any visual field distraction.

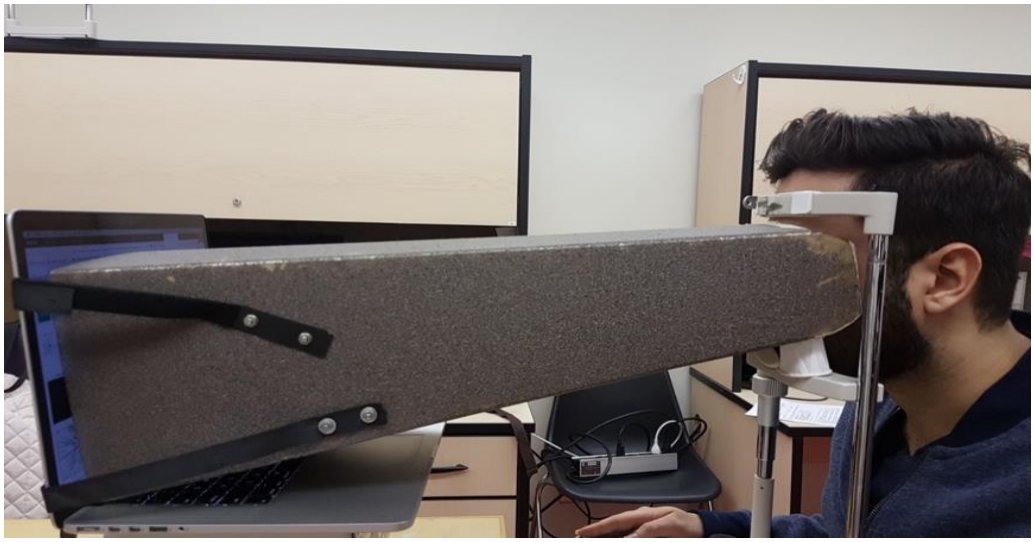

Figure 4-2 Visual tunnel was used during the experiment, allowing a 56.5 cm viewing distance.

The luminance in this case was only received from the laptop screen during the experiment. In both conditions, participants indicated whether the direction of optic flow motion was heading towered the right or the left of the center line, using right & left arrow keypad, and using their dominant hand. Participants were instructed to respond as soon as the stimuli disappear, and they could take a break when needed by pressing keyboard space bar at any time. The main experimenter was present throughout the experiment. Audio feedback using different beep sounds after each hit or miss response was used to encourage participants to maintain high performance. "The actor has given written informed consent based on the UW consent form, to publish of his photograph"

4.4 Psychophysical Testing

4.4.1 Eccentricity Discrimination Task

In this task, threshold was defined as the minimum eccentricity angle that a participant could reliably discriminate. The eccentricity of the direction of heading was positioned randomly to the left or right of the center line, and the magnitude of the angle of eccentricity was varied across trials using a staircase method. The observer's task was to determine whether the target was heading to the left or to the right of the center line. All participants had to complete two blocks with two speeds and two dot densities, each of the parameter was randomized at 50% of the trials. Thus, each subject viewed a total of four conditions repeated in 2 blocks. The adaptive staircase varied the degree of eccentricity present in each trial based on the observer's recent response history, in order to converge on (track) the 79% correct performance level. At the beginning of each trial, the staircase began at a supra-threshold eccentricity (0.75°), then decreased 50% after three consecutive hit responses. However, eccentricity was varied with a 2-down/ 1-up staircase that used 10% step size after two consecutive correct responses, and a 15% step size after one incorrect response. The staircase terminated after six reversals and threshold was taken as the mean of the last four reversals. All participants had to complete 10 practice trials as before the beginning the test trials, and all questions were answered clearly. Participants were instructed to respond immediately after the stimulus disappeared.

4.4.2 Contrast sensitivity task

The stimulus in this task had the same parameters, dots number and speed, as the RDK used in the eccentricity experiment. The contrast modulation (visibility) of the contrast task could be varied in an analogous manner according to the equation:

Dot contrast modulation

= (DC mean – BC mean)/(DC mean + BC mean)

where DC is the mean luminance of the dots and BC is the mean luminance of the background However, in this task the angle of eccentricity from the fixation line was fixed at a supra-threshold level (0.75°)[147,292] and motion discrimination thresholds were estimated by varying dot contrast using an adaptive staircase method. Each staircase started with a dot contrast of 75%, and contrast was decreased by 50% after three consecutive correct responses. After this, the contrast was decreased by 2.5% after 3 consecutive correct responses, and increased by 5% after 1 incorrect response. A staircase was terminated after four reversals. These step-sizes measurements were calculated based on a prior pilot study in order to: (1) decrease number of trials; (2) minimize noise at the end of the trial that might be caused by long task duration; (3) prevent boredom and/ or fatigue.[275] The assigned threshold here was to define the minimum contrast, at which each participant could reliably judge the direction of heading of the OF motion.

4.5 Data analysis

Although stimulus presentation was controlled by an adaptive staircase, examination of the data suggested that a better estimate of threshold would be obtained by fitting a psychometric function to all of the responses (rather than using the average of the last several reversals). This was done (a) to eliminate the possibility of biased threshold estimation in these types of adaptive techniques from erroneous responses in ASD and (b) to allow statistical analyses that require independent estimates of data points. Psychometric functions (response accuracy vs. stimulus level) were estimated by fitting a Weibull function to each participant's data. The chance level

was assigned at 50% and threshold collected at above chance level, 79% correct. The Weibull function (with a slope and threshold as free parameters) was used to measure the threshold (t) and slope (s) at 79% probability level at each dot and speed level tested within each of the two conditions with the function given by:

$$F(x, \alpha, \beta) = 1 - \exp(-[x/\alpha^{\beta}])$$

Where x is the stimulus parameter, and α and β are the sensitivity parameters that control the shape of the function. However, in the Weibull function, α and β are analogous (but not similar!) to the threshold and slope respectively. The threshold (t) and slope (s) for a specified probability level (*p*) (threshold criterion) at a constant assumed value (c) of the psychometric functions is defined as:

$$t = pc^{-1}(p) \quad \text{and} \quad s = \frac{\partial pc}{\partial x\,(x=t}$$

Response time (RT) was collected throughout the experiment as the time taken by the subject to respond to stimulus. Subjects were instructed to respond as soon as the stimulus disappeared. RT less than 0.1s and greater than 0.75s were classified as anticipatory and late responses, respectively, and were not included in the analysis. RT outliers were all points more than 100 ms above average RT to each parameter were removed and considered as rest time as long as it did not occur more than four times per task; otherwise, the test was repeated in a subsequent visit to the lab. Collecting RT was considered for the following reasons: (1) comparing subject performance between parameters levels/tasks: (2) showing that participants were responding during the time interval most of the time: and (3) comparing results with related findings, which show that the ASD group has prolonged RT when compared with TD group.[144,275] Following these criteria, only a few trials were discarded from the RT-analyses:

eccentricity task (4.31%), and contrast task (3.49%) from both groups, and no participant required for a full repetition of a task.

All data were analyzed using SPSS software. Differences in performance (threshold, RT) for (eccentricity, contrast) were analyzed between groups (TD and ASD) for each task separately.

4.6 Results

4.6.1 Complex Processing of Optic-Flow Eccentricity in Autism

Eccentricity threshold is the minimum eccentricity angle from the central heading line that the participant was able to identify accurately. A higher threshold means low sensitivity (Table 4-2). The threshold was measured as a dependent value for each participant at each parametric value. A 2(group) x 2 (dot number) x 2 (speed dot) ANOVA found no significant interaction of speed , dot and groups ($F(1, 25) = 1.396$, $P = 0.249$. However, increasing number of dots and speed level improved the performance of both groups and decreased the threshold level. Dots and group interaction was significant ($F(1, 25) = 6.105$, $P = 0.021$) compared with no significant effect between speed and group ($F(1, 25) = 1.061$, $P = 0.313$) (figure 3).

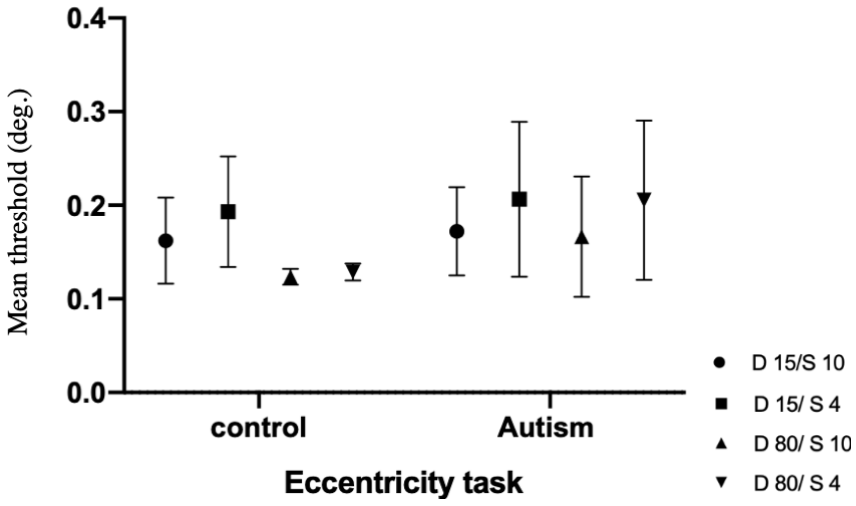

Figure 4-3 Threshold levels of eccentricity tasks at all parameters and between groups. Error bars SDM

Post-hoc pairwise comparisons found that threshold was higher in ASD compared to TD when number of dots was high (80 dots) at speeds of 4, 10 deg/s [t (12.248) = -3.228, p = 0.007)] and 10 deg/s [t (12.387)= -2.388, p= 0.034)].

Task	Eccentricity				Contrast			
Parameters	80 d./ 10deg.sc	80 d./ 4deg.sc	15 d./ 10deg.sc	15 d./ 4deg.sc	80 d./ 10deg.sc	80 d./ 4deg.sc	15 d./ 10deg.sc	**15 d./ 4deg.sc**
ASD	0.1666 ± 0.064	0.2055 ± 0.085	0.1723 ± 0.047	0.2065 ± 0.082	2.3654 ± 0.49	2.3592 ± 0.57	3.7046 ± 0.79	**3.8015 ± 1.1**
TD group	0.1236 ± 0.084	0.1289 ± 0.009	0.1623 ± 0.045	0.1932 ± 0.059	2.2829 ± 0.25	2.1243 ± 0.18	3.0471 ± 0.79	**2.8071 ± 0.69**

Table 4-2 Threshold levels for OF motion tasks in ASD and control. Data presents mean and SD

However, when small number of dots (15 dots) ran at different speeds, thresholds did not differ significant differences between both groups (p > 0.05). The trends below (Figure 4-4) showed

that at high dots density (80 dots), TD group maintained high performance at both speed levels. However, ASD group showed higher threshold (lower sensitivity) at both speeds. 15 dots perimeter, showed no significant differences at both speed and between groups.

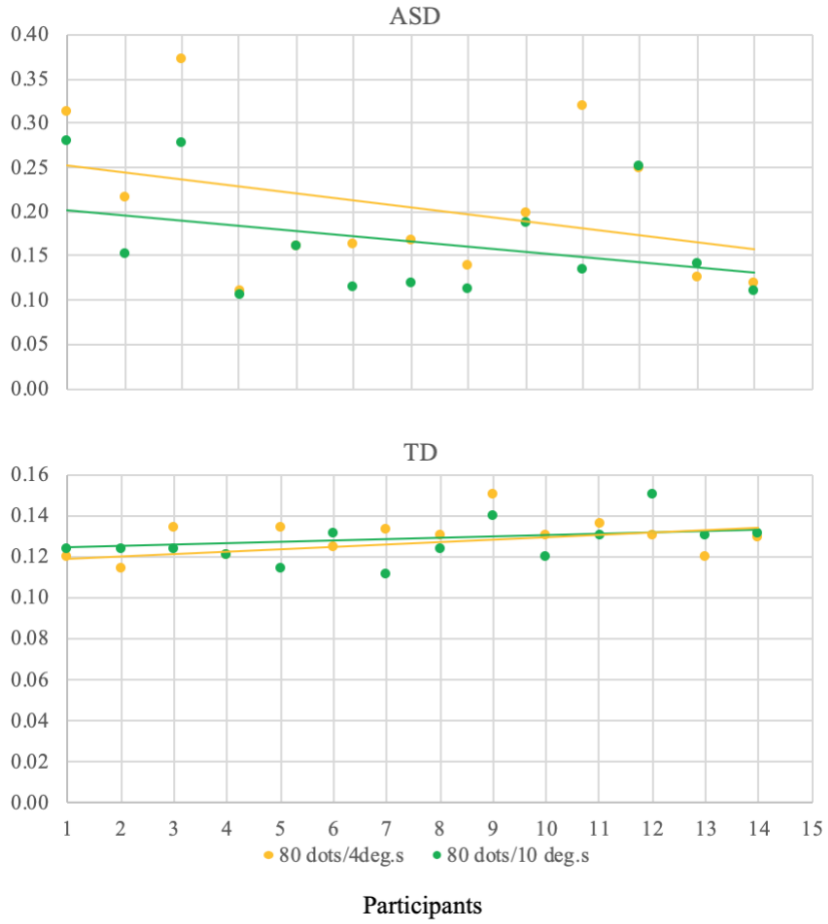

Figure 4-4 Eccentricity task results show mean average trends of threshold levels at high dot density for two speed levels (fast, slow) in both groups.

4.6.2 Contrast Sensitivity of Optic-Flow in Autism

The minimum contrast needed to discriminate optic-flow was measured as a function of dot speed and number in both groups. Contrast thresholds were analyzed with a 2 (Group) x 2 (Speed) x 2 (Number) mixed ANOVA which found a significant main effect of dot number (F(1,

25) = 75.68, P = 0.005). This main effect of dot speed was not significant (F(1, 25) = 1.03, P = 0.320).

The two-way interaction between group and dot number was significant (F(1, 25) = 8.408, P = 0.008), while interaction between group and dot speed was not significant (F(1, 25) = 1.416, P = 0.245). Finally the three-way interaction between dot number, speed, and groups was not significant (F(1, 25) = 1.41, P = 0.245) (Figure 5).

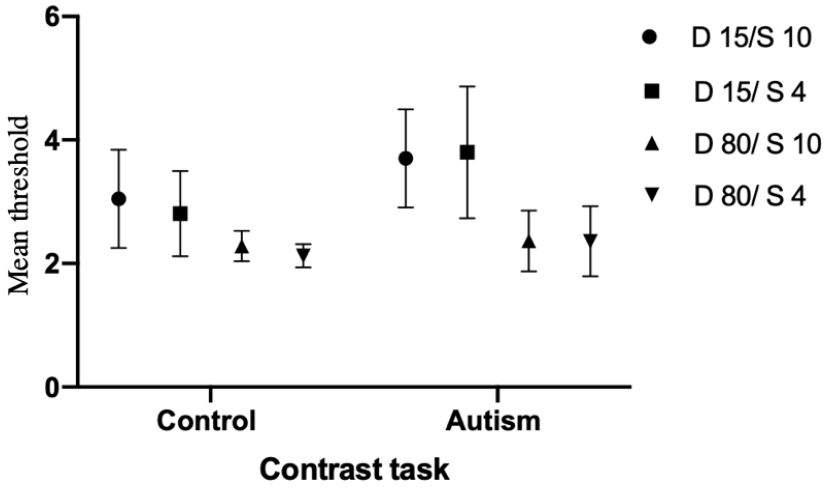

Figure 4-5 Threshold levels of contrast tasks at all parameters and between groups. Error bars: SDM

Post-hoc analyses found that thresholds in the ASD group was significantly lower than thresholds in the TD group when the number of dots was low (15 dots) at both the slow [t (25)= -2.896, p= 0.008)] and fast speeds [t (25)= -2.144, p= 0.042)]. Also, the standard deviation in the ASD group was larger than in the TD group, even when their performance enhanced when the number of dots and speed level increased. This finding, however, might be explained by two reasons: (1) the sample size of our ASD group is small[293] and/ or: (2) an abnormal neural mechanism of altered perception of OF motion may occur at all conditions even if the performance (based on the mean threshold) is comparable between the groups.[204] The trend of

individuals' contrast threshold fixed at density and compared between both speed levels show that at high density levels both groups maintain high performance (low threshold) and no significant differences between both groups were observed (Figure 4-6).

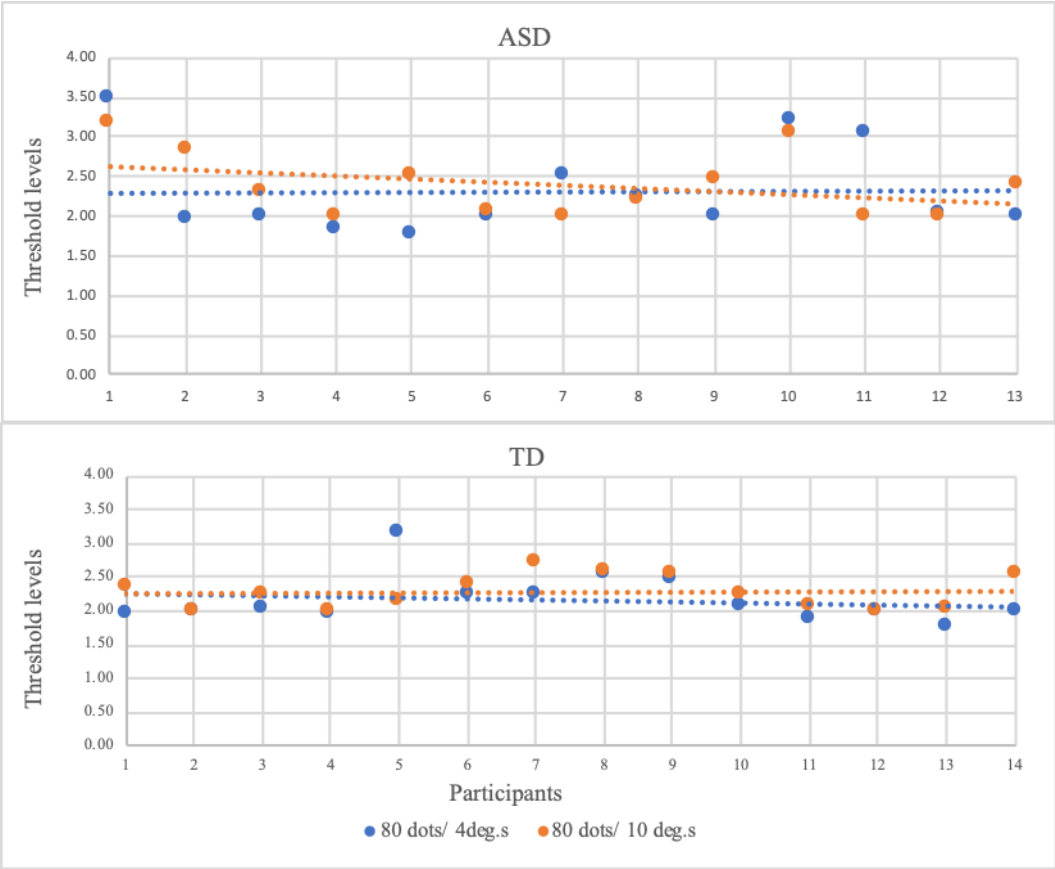

Figure 4-6 Contrast task shows trends of mean average threshold of each participant in both groups at high dot densities ran at two speed levels (fast, slow)

However, at low density, TD group showed increased performance when speed of the dots was faster, while in autism group their performance was poor at both speeds, which result in significantly higher threshold than TD group (Figure 4-7)

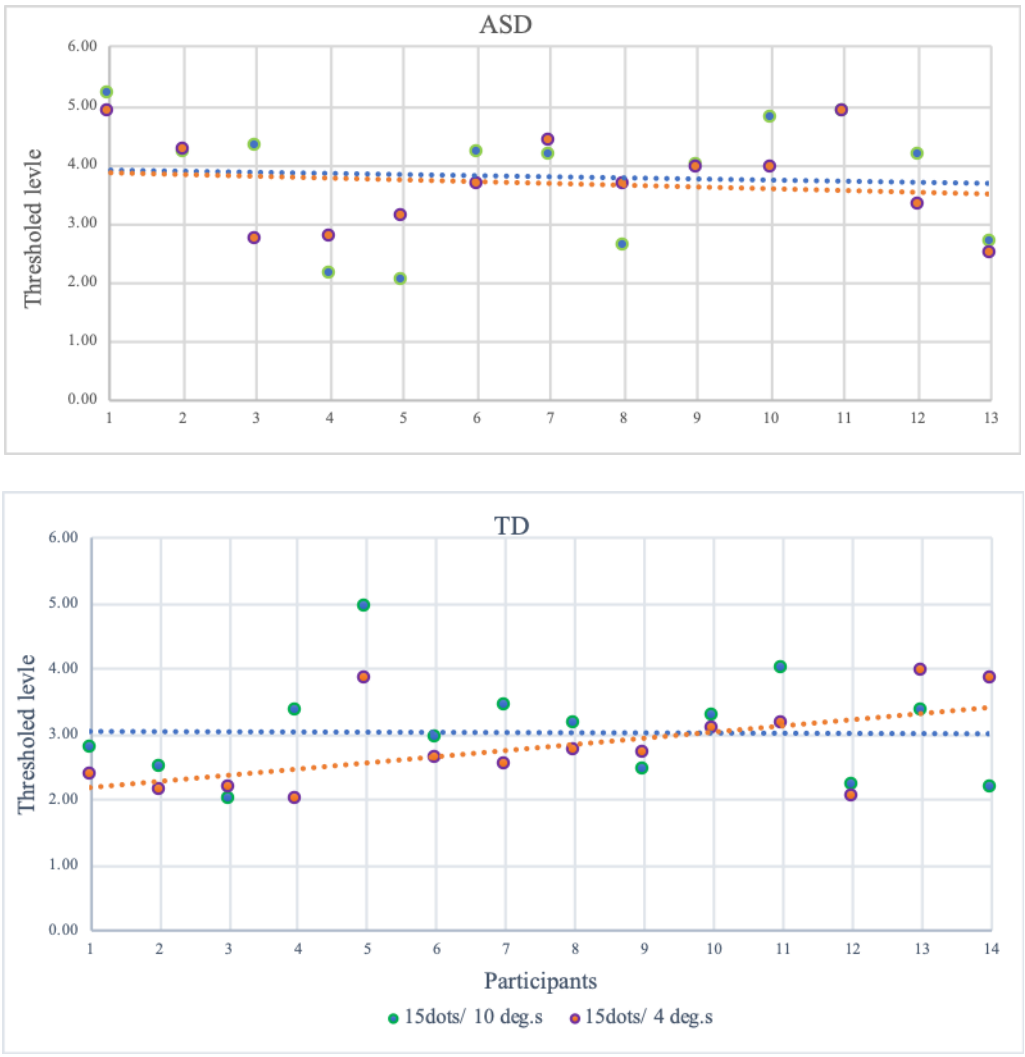

Figure 4-7 Contrast task shows trends of mean average threshold level of each participant at high dot densities ran at two speed levels (fast , slow)

4.6.3 Response time:

Results from our experiment revealed no group differences in response time when compared to control group in eccentricity task (F (1,25)= 0.375, p=0.546). However, the general decrease in response time was found with increasing dot number (F (1,25)= 4.948, p=0.035), with no group difference (F (1,25)= 0.665, p=0.423). Speed levels also showed no effect in RT (F (1,25)= 0.318, p=0.578), or a main group difference (F (1,25)= 1.871, p=0.184) (Figure 4-8).

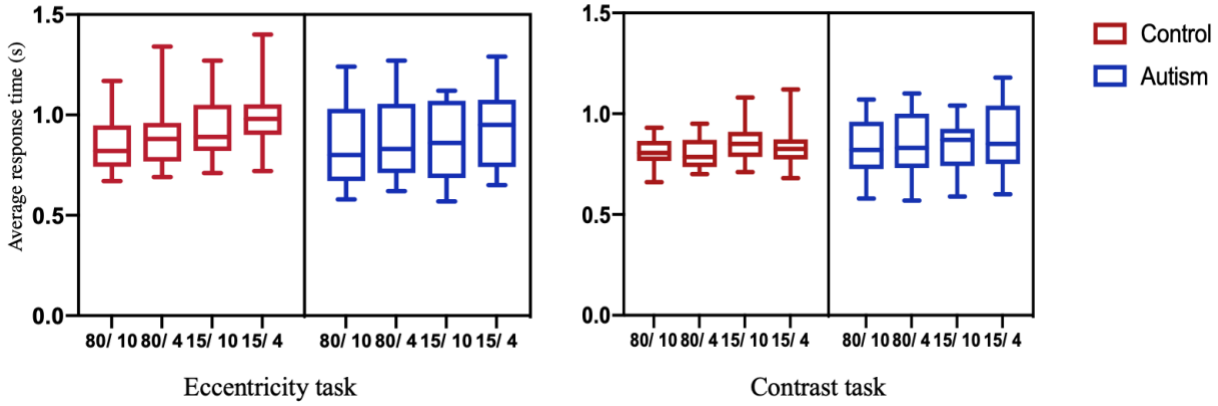

Figure 4-8 Average response time for both groups for both tasks and for all parameters

In the contrast task, the results also showed a significant effect of increasing number of dots on decreasing the time taken to response (F (1,25)= 5.067, p = 0.033). However, no interaction between the groups was found (F (1,25)= 0.211, p=0.650) (Figure 4-8).

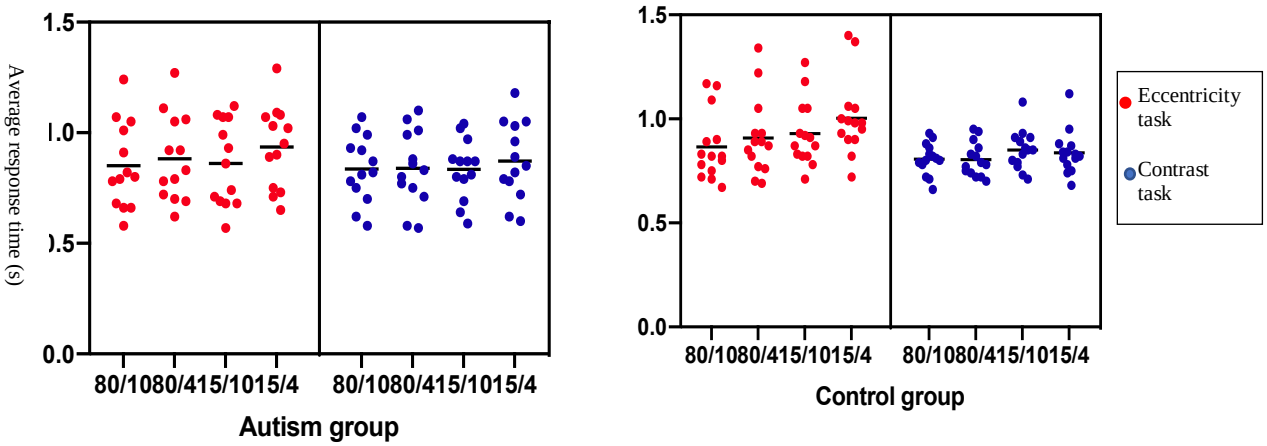

Figure 4-9 Comparing average response time for each parameter and for each task separately for both TD and ASD groups.

We compared the RT for each group and between both tasks (eccentricity, contrast) separately. From Figure (4-9), we can see that control group showed shorter response times in the contrast task compared to the eccentricity task in all conditions (Mean RT eccentricity= 927 ms, Mean

RT contrast=824 ms). The ASD group also had shorter RTs in the contrast task compared to eccentricity task in all conditions (MRT eccentricity= 886 ms , MRT contrast=846 ms). What is more interesting is that RT of ASD group was shorter than TD group in the eccentricity task, but not the contrast task, which might suggest that ASD- related variability seen in the eccentricity performance may due to speed/accuracy trade-off.

4.7 Discussion

4.7.1 Sensitivity to Optic Flow Motion Discrimination in Autism

In this study we investigated self-heading direction discrimination using OF stimuli in ASD and TD adults. Direction discrimination thresholds were measured with OF stimuli that varied in dot speed and density. We found that thresholds in both groups were affected significantly by dot density but not dot speed, which agrees with previous findings.[147,205,291] However, we found specific patterns of abnormality related to individuals with autism which are summarized as follows:

1- In the eccentricity task, the autism group showed similar performance to the control group. However, their sensitivity was lower when the number of dots was high, while the speed parameter had no significant effect.

2- In the contrast sensitivity task autism participants showed decreased contrast sensitivity only when the number of dots was low; thresholds in both groups were similar in the high dot density condition. Finally in both groups the effect of dot speed on threshold was not significant.

3- In both tasks, response times on correct trials did not differ significantly between groups.

These results provide new evidence of selective impairments to OF motion perception in autism that might be related to ASD-related changes in area visual MST, which has been suggested to be a selective response to the complex patterns of OF.[280,294] Receptive fields in of V5/MT cells may relatively be small to cover the gamut of OF motion parameters (patterns, speeds, and directions, which can extend up to 360°). However, MST neurons were found to be directionally selective with receptive fields that cover large parts of the visual field.[295,296] Consequently, our results here show that performance impairments to radial motion may require strong pattern activation in the MST area in the autism group.[291] This ASD-related impairments depends, however, on dot density, more than dot speed, which agrees with previous findings related to OF motion.[297,298] Our results are the first to show that dot density affects OF motion in autism, particularly for high dot density. High dot density should evoke strong activation at the MST area.[296] This strong activation would correspond to the integration between V5/MT area that is directionally selective to local motion information, and MST area that processes global heading direction.[280]

We hypothesize that reduced functional and structural connectivity between and within distributed cortical networks of MT and MST might be the underlying cause of reduce sensitivity to OF responses in adults with ASD.

Indeed, studies utilizing visual evoked potentials (VEPs), event-related potentials (ERPs), and diffusion tensor imaging (DTI) in autism show that neuro-integrative processing at higher cortical levels in both the ventral and dorsal pathways might be impaired in ASD,[282] while lower-level processing is spared when both levels are activated at the same time. Interestingly, our findings show that performance at low dot density was intact in autism, which may be related to intact MT in autism, particularly when the dots move in a coherent direction (zero noise

level).[232,237,275] Altered connectivity within V1 in autism, as posited by the underconnectivity theory,[298] also appears to the perception of self-direction of heading.[204] Yamasaki et al[282] suggested that deficits in the P-pathway (with intact M-pathway) in V1 might underlie perceptual impairment found in ASD. However, our results show that sensitivity of individuals with ASD declined only when number of dots was high. Neurons in V1 responds better to high spatial frequency, slow speed, and contrast variation which suggest that our stimuli would evoke stronger activation in areas beyond V1. Moreover, comparing perceptual thresholds in our data across dot density conditions for individuals with ASD and TD show reciprocal changes of speed trends with large dot density, and low sensitivity at both speeds for ASD when compared to TD which might result due to reduction in processing complex information related to deficit in the connectivity in the hMT+ area.[301] Recently, Zeng et al[302] proposed that the whole brain functional connectivity in children with autism is characterized by significantly reduced network activation that may affect multiple cognitive domains and brain systems in ASD.

Our findings lead to a new insight into the neural circuit mechanism underlying the deficits to local /global perception in ASD. These deficits might be result from rather complex functional alterations in visual networks rather than enhanced processing of local details and reduced processing of global structure.

The speed parameter provides a different criteria in defining OF motion.[296] Our results show that heading direction was strongly affected by dot density varied but not dot speed. Hence, it is possible that the connectivity between MST and occipital channels would be closely coupled to neural dysfunctional activity in ASD. This is based on the assumption that OF motion processing of high spatio-temporal frequencies requires integration of neurons in the v-d (IPL) stream beyond V5/MT. Therefore, impaired OF perception found in our study in ASD adults

may result from the dysfunctional integration of the higher level(s) of MST area rather than V5/ MT area. Of course, these ideas are speculative? because very little is known about how self-motion perception in autism is affected by dot speed and density. Hence, we consider this a novel finding and further neuroimaging, electrophysiological, and psychophysical studies are required to verify this hypothesis.

4.7.2 Optic Flow Contrast Sensitivity is Biased in Autism

We found that contrast thresholds in our OF discrimination task were affected by dot density but not dot speed. At high dot density (80 dots) the autism group showed comparable contrast sensitivity to the TD group when dots were moving at fast and slow speeds. However, at low density (15 dots), contrast sensitivity was lower in the ASD group compared to the TD group at in both fast and slow dot speeds. These results suggest for the first time that adults with autism might have defects in contrast-dependent responses related to OF motion. Studies in contrast modulation related to motion perception suggest two cortical response sources: early visual medial occipital cortex at V1 that show high sensitivity to motion contrast magnitude, and lateral segregation at a higher level of V5/MT.[303–305] However, it is important to note that most of these results were generated from transitional motion perception. Earlier, we indicated that OF may activate cortical area in MST to the most dominant flow pattern of forward self-motion in depth. Fesi et al,[291,304] for example, used steady-state visual evoked potential (SSVEP) to study contrast modulation responses to motion across different direction and coherence levels. Their results showed that, across all patterns, the responses were activated among dorsomedial occipital channel and peeked at 4 deg/s (slow speed), and then plateaued at 16deg/s (fast speed). However, tuning for different types of motion-defined forms suggests specific interaction among local motion/luminance dynamic and those associated with global edge/shape/form processing. This

corresponds to both onset and offset of the motion-defined figure. Taking these findings into account, our results of defective contrast sensitivity for low density motion patterns could be either due to: disturbed connectivity between specific direction contrast cells at V1 and higher area of V5/MT; or motion contrast defects specific to OF in an early V1 area. Hence, based on the proposition of feed-forward and feed-backward connectivity between primary extrastriate area V1 and V5/MT+ as important for initial contour segregation, the first scenario suggests that our results would reflect increased threshold for both conditions of dot densities. However, this was not the case.[304] In fact, related studies show that areas in the hMT+ complex have demonstrated different activation properties across varied values for stimulus parameters, such as dot density.[305] Moreover, responses at hMT+ may be more categorical to object recognition that is specified by changes in the state of segmentation.[306,307] Our second scenario is that the autism group may have distributed response at V1 corresponding to sensitivity to motion contrast magnitude, and subsequently affecting the early processing necessary for figural segmentation specific to OF motion. This finding, however, is relatively consistent with recent results that indicate increased receptive field size in the extrastrite visual area including the MT, which might be the underlying mechanism of reduced motion perception in autism group.[195,244] Schauder et al[195] results show that reduce neural responses to stimuli significantly smaller than the receptive field size at V1 would decrease contrast sensitivity for this stimuli. Earlier Foss-Feig et al[46] found enhanced sensitivity to high contrast stimuli but not to low contrast, suggesting impairment in response gain in autism. Thus, if this is the case, then we assume the deficit seen in our autism group at low density would reflect low sensitivity in processing of egomotion information at early visual receptive field per se, as a factor in the depth structure of an OF scene. However, an argument can be raised that this might affect the OF motion at fast speed,

rather than both speeds at the same time (4, 10 deg/s). Fesi et al[291] and Hou et al[308] discovered that tuning across speeds would reflect activation of population of neurons in MT -which it is different for speed contrast- and will reflect stronger activation of early inputs neurons at V1 particularly when the number of spatial inputs is low.[309] It is possible that high spatial inputs may recruit a different population of cells of higher order areas of MT. Intact MT area response, particularly when the motion pattern ran at 100% coherence level was reported in autism,[228,275] and this may explain our result under high dot density condition.

Our results indicate that cortical processing of OF motion engage a more widespread network with more complex space and pattern tuning properties than had previously been assumed.

This further underscores the choice of experimental parameters used in OF motion perception studies. Further studies involving neuroimaging and OF stimuli are necessary to determine the differences in cortical processing and sensitivity in ASD at different cortical areas.

4.7.3 Response Time

In order to explain the results of response time related to OF tasks in autism, it is important to emphasize the mechanism of "bottom-up" sensory processing and "top-down" modulation. Bottom-up is the mechanism through which the brain uses external inputs on the retina at a given time. This process is fast and involves involuntary attention that rely only on parallel, feedforward processing. On the other hand, top-down is the constructing process of sensory information and previous knowledge, guided by attentional selection that is based on exogenous inputs.[310] Although we describe both mechanisms as being separate, in fact, they occur almost at the same time and activate same brain areas using similar neural mechanisms.[311] Recent experimental finding and modeling studies suggest that bottom-up attention relies on feedback

from top-down signals (for more information see Khorsand et al).[311] Related studies of top-down and bottom-up processing in autism suggest a delay in visual signals that subsequently affect visual perception. For example, Maekawa et al[175] recorded Event-Related Potentials (ERPs) to study selective attention to top-down and bottom-up sensory information in ASD. These investigators used black–white windmill patterns combined with a vestibular attention task. The results showed that behavioral performance of ASD group was comparable with the TD group. However, ERP data showed both groups elicited the same P1 (lower level information) and P300 (top-down attention) waveforms. The ASD group had a significant P300 latency when compared to TD. Similar results were also found by Yamasaki et al[204] using OF motion stimuli. Here, the ASD group showed latency in P200, which is elicited by the central parietal regions. Prolonged RT was also reported in the autism group in response to different types of motion.[312,313] Our autism group have also conducted a series of coherent motion direction discrimination task using RDK. Prolonged RT was found in ASD particularly when motion discrimination involved high level of noise.[275] By comparing the two studies together (coherent motion and OF), we suggest that there may be different levels of motion perception processing. This would involves two types of top-down feedback projections (due to horizontal connections within a cortical neural level as well as links between different levels of different areas).[314] For instance, motion processing that involves interactions between V1 and cortical area V5/MT (Figure 4-10), would predict prolonged RT as a result of conveying signals between and from higher processing stage(s). These signals will also be involved in shaping sensory processing in V1 and hence, might explain the findings in the coherent motion task.

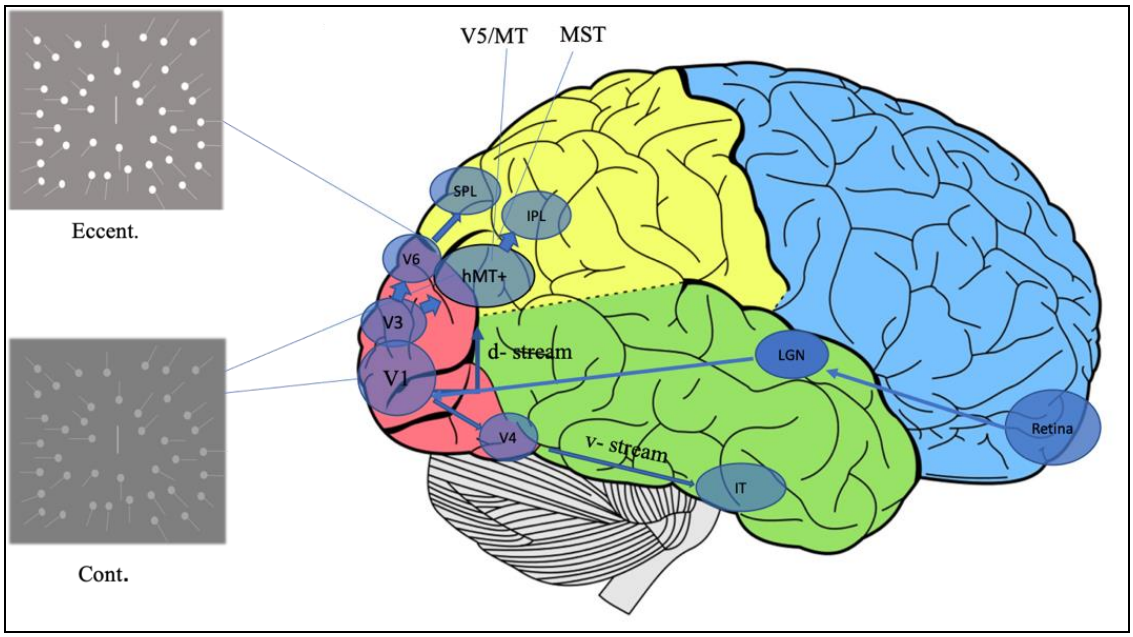

Figure 4-10 The main neural visual areas that activated mainly by the two types of OF tasks in our study, which involved both the v-d pathways in the visual system.

However, studies of Perception processing involving modulation between V5/MT and MST area within hMT+, e.g OF motion, would show that performance may not involve prolonged RT in autism. In fact it might show shorter RT in ASD group than control group. Recent findings[302] show that MST containing a set of shortest paths between and within related areas involved in processing motion information beyond the primary areas could reflect faster attentional feedback integration in autism. It can be argued that in the context of a broader view where there are dichotomies, such as feedforward/feedback and local/global tasks, designing experiments to understand vision might not be useful.[315] Therefore, we can't generalize our finding, but we consider that these findings and others would raise an important conceptual issue by measuring RT performance in autism in relation to task requirements as well as task activation in related neural areas.

4.8 Conclusion

The current study shows that OF motion processing is selectively impaired in ASD. Previous studies used only one pattern to assess OF sensitivity in autism, yet these results indicate that separate mechanisms are differently recruited depending on experimental parameters, namely, pattern and speed. At high density, increased threshold level in ASD group may reflect abnormal neural connectivity in processing information at higher order cortical area, particularly hMT+. Contrast modulation findings, however, suggest main defects that might occur at local cortical area V1, which correspond to the spatial integration of the dots rather than temporal modulation. The current findings of RT to OF motion in autism could also support the idea of significant reduced functional networks in adults with autism. These experiments also show that, the mechanism of changing visual processing to OF per se is likely elicited by neural events that are specific to different visual events that may alter neural connectivity in different areas of the brain in ASD

4.9 Acknowledgment

We thank Dr. Benjamin Thompson for advice on optic flow experimental parameters as well as his advice in stimulus generation.

Chapter 5: Motion Processing in Adults With Autism Spectrum Disorder Using A Speed Discrimination Task.

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Bakroon	Y	Y	Y	Y
Roy	Y			
Lakshminarayanan	Y			Y

5.1 Overview

5.1.1 Background

Speed discrimination relies on direction-selective neurons that are tuned to local spatial and temporal frequencies. Previous studies on speed processing in adults with Autism Spectrum disorders (ASD) have focused upon temporal discrimination and the results are controversial. In this psychophysical study we varied both spatial and temporal information to study speed discrimination in adults with autism.

5.1.2 Methods

We compared two groups of ASD adults and adolescents (ages 16-40 years: n=14) of ASD individuals (n=14) and healthy controls (n=14). We used a forced-choice psychophysical procedure to measure speed discrimination thresholds with drifting sine wave gratings that varied in duration (250 & 500 ms) and speed (2 & 6 deg/sec.).

5.1.3 Results

We found no significant group differences in speed discrimination thresholds. Response times also were comparable between groups, suggesting normal neural decision-making capability in determining speed modulation in autism.

5.1.4 Conclusion

Our findings suggested a normal speed processing in ASD. However, this might depends upon the task requirements used in this study. Increasing the task complexity might revealed more about the motion perception in ASD.

5.1.5 Key words

Speed-discrimination, autism spectrum disorders (ASD), visual psychophysics, drifting gratings, response time, task duration.

5.2 Introduction

Autism Spectrum Disorder (ASD) often is associated with enhanced perceptual processing of local visual features and degraded processing of global features.[144] However, in perceiving motion, there seem to be deficits in integration of local and global information, which could be due to selective brain areas activated by certain stimulus methods, more than general deficits in the global perception.[282] Impaired long range brain connectivity has been reported in ASD.[302] On the other hand, the short range brain connectivity has been reported to be preserved and sometimes even enhanced in autism.[316] The variability in experimental methods and stimuli used in the different perceptual studies makes it difficult to draw firm conclusions regarding the mechanisms underlying such visual abnormalities in ASD. Some studies have found that sensitivity to global motion in adults depends on stimulus speed.[317] Impaired sensitivity to coherent motion in ASD could be attributable to variation of speed parameter.[205,286] For example, Chen et al[205] reported enhanced performance in ASD group in speed discrimination task when the temporal range increased compared to control. This finding, however, can be explained as

being due to working memory[121] rather than impaired visual motion processing. Other studies have measured motion perception in children with ASD.[162,286] It is worth mentioning that developmental studies report a delay in speed processing particularly for slow speeds in children.[318] This delay might be prolonged in children with autism due to atypical the development of the ability to detect changes in the spatial parameters of moving objects, which therefore might cause them to require longer presentation times to perceive slow motion. In this study, we report results from an experiment that examined speed discrimination of drifting sine wave gratings in adults with ASD that employed two different temporal conditions two different spatial frequencies and two stimulus duration times (short, long). This stimulus has previously been used to show that investigate speed discrimination differs in younger and older adults particularly at short stimulus durations.[317] Our previous results on autism suggest that speed integration might be preserved in ASD[319], yet they might need longer time to respond to stimuli.

5.3 Methods

5.3.1 Participants

We tested 14 adults with ASD and 14 typical developmental (TD) participants with matched age and gender. The ages ranged from 16-40 years (mean = 25.7), and there were 5 females and 9 males in each group. There were no significant differences in basic visual functions such as visual acuity (Table 1). Exclusion criteria for the autism group included family history of ASD or related developmental disorder, any known comorbid medical conditions, and/or under any psychiatric medications in the previous six months before the start of the study.

	Control (SD)*	ASD (SD)*	Group comparison
Age range (16-40 years)	25.92 (6.45)	26.75 (6.74)	p = .79
Visual Acuity (log Mar)	-0.13 (0.11)	-0.16 (0.09)	p = .44
Contrast test (log Mar)	1.93 (0.18)	1.82 (0.12)	p = .06
Stereo-acuity (second of arc)	**20.71 (1.81)**	**21.35 (7.53)**	**p = .11**

Table 5-1 Data on selected visual functions of experiment participants.

**indicates standard deviation. Note: visual acuity and contrast sensitivity were evaluated using the Freiburg test,16 and Stereo-fly test were used for depth perception*

Controls were excluded from participation if they had ever received mental health treatment, taken psychiatric medications, been diagnosed with a genetic or neurological disorder, had brain trauma/ injury, or had a sibling with autism. Participants with ASD completed the Autism Quotient test (AQ) of Baron-Cohen et al,[259] a 50-item self-administered questionnaire targeting sub-clinical autism-like traits. The AQ test was completed online, and the mean score was 27, +/- 2.7. Accordingly, one participant from the autism group who scored 35+ was excluded from the study, who also had a sibling with severe autism.

5.3.2 Stimuli

The stimuli were computer generated using the Psykinematix software (http://www.psykinematix.com/index.html), and displayed on a gamma corrected MacBook Pro-laptop (15.4-inch, 2880 x 1800 pixels, 60 Hz refresh rate). The stimuli consisted of a pair of gratings with a spatial frequency 2 cycle/degree, oriented vertically and drifting perpendicular to

the direction of orientation (Figure 1). Stimulus contrast was 100%. The gratings were presented within two circular windows. We used the same technique as Foss-Feig et al[46] to generate the drifting grating. The temporal envelop was a hybrid- Gaussian which Foss-Feig described as an envelope where the edges " are half-Gaussians and the central portion is set to maximum contrast. Fine temporal precision was obtained by adjusting the SD of half-Gaussian edges, and transferring "excess" contrast to the flat central portion. This hybrid envelope allowed fine temporal precision of brief stimuli and avoided protracted fade-in/fade-out periods associated with prolonged temporal Gaussians. Gaussian flanks allow for subframe sampling (a temporal equivalent of subpixel sampling), permitting accurate presentation particularly for brief stimuli by using only a few monitor frames". Each circle circular window had a radius of 0.5° radius at the viewing distance of 1 meter and were centered on points that were centered on points 1.25Åã to the left and right of a small central fixation cross.

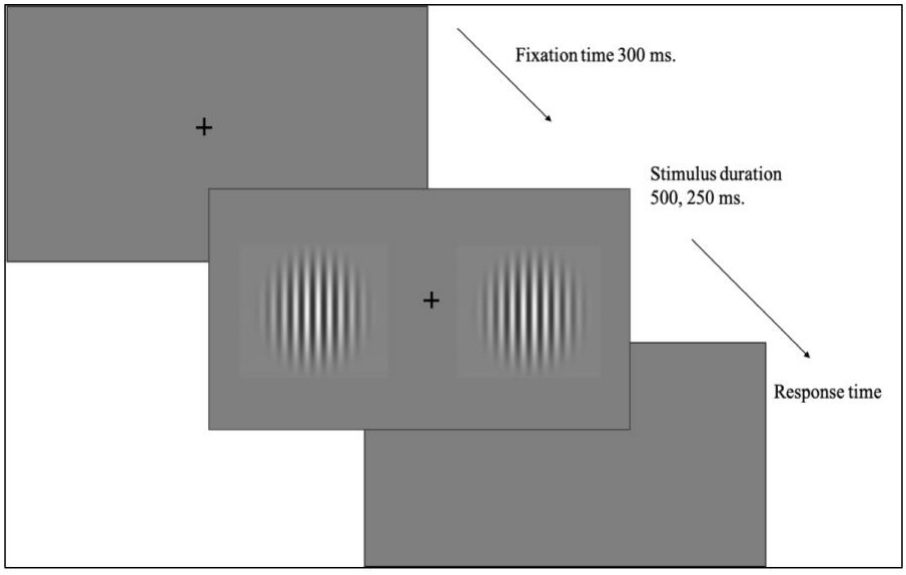

Figure 5-1 Speed-discrimination stimulus.

The stimulus occupied 4.08 deg of visual angle at a viewing distance of 1m. Participants keep fixating at the cross mark during the stimulus presentation, then it disappeared to prevent image after-effect.

The subject had to fixate binocularly on the fixation cross. Two reference speeds were used: 2 and 6 deg/sec, which corresponded to temporal frequencies (i.e., spatial frequency times speed) of 4 Hz and 12Hz, respectively. Two drifting grating were presented simultaneously for either 500 ms or 250 ms. The inter-stimulus interval between trials was set to 500 ms, during which time participants had to respond. The task was conducted in a dark room, with only a side light (room luminance ~ 0.56 cd/m^2).

5.3.3 Task

The observer's task was to indicate which of the two moving gratings drifted faster. Participants were instructed to fixate on the central cross at all times. Based on a prior pilot study, the size of the two circles and the working distances were both chosen carefully so that: (1) both circles fell within the 5º of visual fixation center; (2) observers did not alternate fixation between the two grating, and (3) the speed differences would be discriminable only obtained if the observer processed motion information of the two targets at the same time. Participants used the left and right arrow keys on the key pad to respond using their dominant hand. Participants were instructed to respond as soon as the stimuli disappeared. They could take a break when needed by pressing the keyboard space bar at any time. The experimenter was present throughout the trials. Audio feedback using different beep sounds after each response was used to encourage participants to maintain high accuracy to inform them that their answers were recorded, and to indicate the next trial onset. All participants had 10 practice trials, and all questions were answered before the start of the task.

5.3.4 Psychophysical Method

One of the drifting gratings circle was defined as the "standard" and moved at the reference speed of 2 deg/sec or 6 deg/sec. The other grating was defined as the "test" and drifted at speeds that were varied across trials by an adaptive staircase method. The left/right positions of the standard and the test gratings were randomized throughout the task. A 3-down /1-up staircase controlled the speed increment that was added to the test grating. At the beginning of each staircase the test grating speed was 75% faster than the standard grating. The test speed was then decreased by 25% after three consecutive correct responses. However, around threshold the staircase decreased the speed increment by 10% after 3 consecutive correct responses and increased the speed increment by 5% after 1 incorrect response. Eight reversals were collected before the staircase terminated and threshold was defined as the mean of the last six reversals. During each staircase the stimulus duration and the reference speed was fixed. Conditions were not interleaved, which may increase the uncertainty of the response. Therefore, each reference speed (2 and 6 deg/sec) was tested for two stimulus durations (500 and 250 ms.) with an inter-stimulus interval of 500ms. Each condition ran for 4 trials in 3 blocks giving a total of 12 trials for each condition, and all 4 conditions were randomized throughout the task. All speed discrimination thresholds were converted to a Weber fraction ($\Delta V/V$) for comparison across the different reference speeds where ΔV is the difference between the mean estimated speed threshold and the standard speed V.

Response time (RT) was collected throughout the experiment as the time taken by the subject to respond to the stimulus. Response times below (0.1 s) (anticipatory responses) and above (0.75s) (late responses) were filtered out. RT outliers were all points more than 100 ms above average RT to each parameter were removed and considered as rest time as long as it did not occur more

than four times per task; otherwise, the test was repeated in a subsequent visit to the lab. Following these criteria, only a few trials were discarded from the RT-analyses for all parameters, (ASD group 5.23%, and TD group 3.30%), and no participant required for a full repetition of a task. Repeated measures ANOVA analyses were conducted with group (ASD, TD) as in between-subjects variable and 'test' and "RT" as the repeated-measures variables, each was conducted separately.

5.4 Results

5.4.1 Normal Speed Processing in Autism

A 2 (group) x 2 (duration) x 2 (speed) ANOVA results found significant group and stimulus duration interaction ($F(1,26) = 5.06$, $p = 0.033$), while speed and group interaction was not significant ($F(1,26) = 1.587$, $p = 0.219$). Also, three interaction between group , speed , and duration was not significant ($F(1,26) = .179$, $p = 0.676$). Overall mean threshold presented in Figure 5-2 showed that ASD had similar performance to control in speed discrimination task and there was no statistical differences at all parameters. Interestingly, speed discrimination thresholds in ASD observers were lower than thresholds in TD observers in the slow speed, long stimulus duration condition, (ASD mean = 0.38, TD mean = 0.509), yet these results were not statistically significant(Figure 5-3).

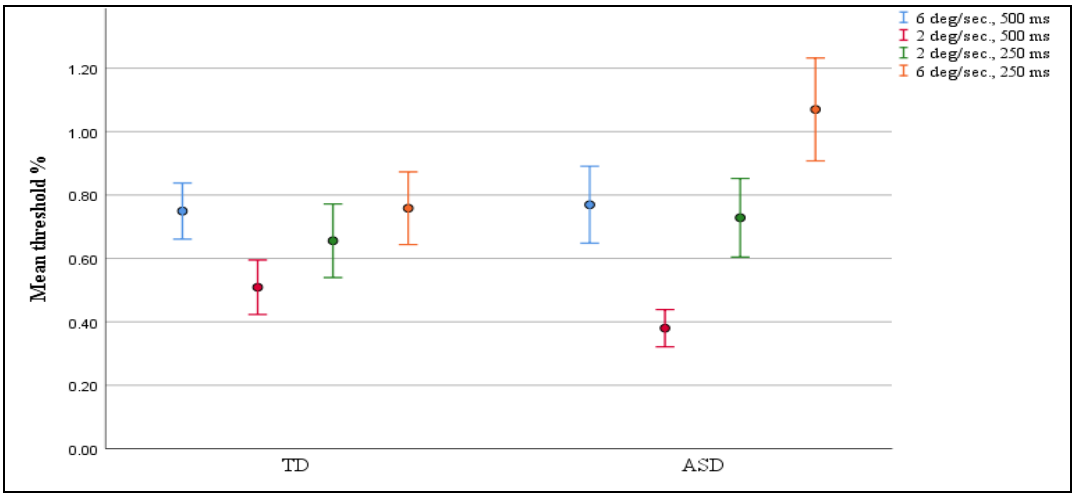

Figure 5-2 compared mean thresholds of speed discrimination between both groups and across all parameters. Error bars present SEM

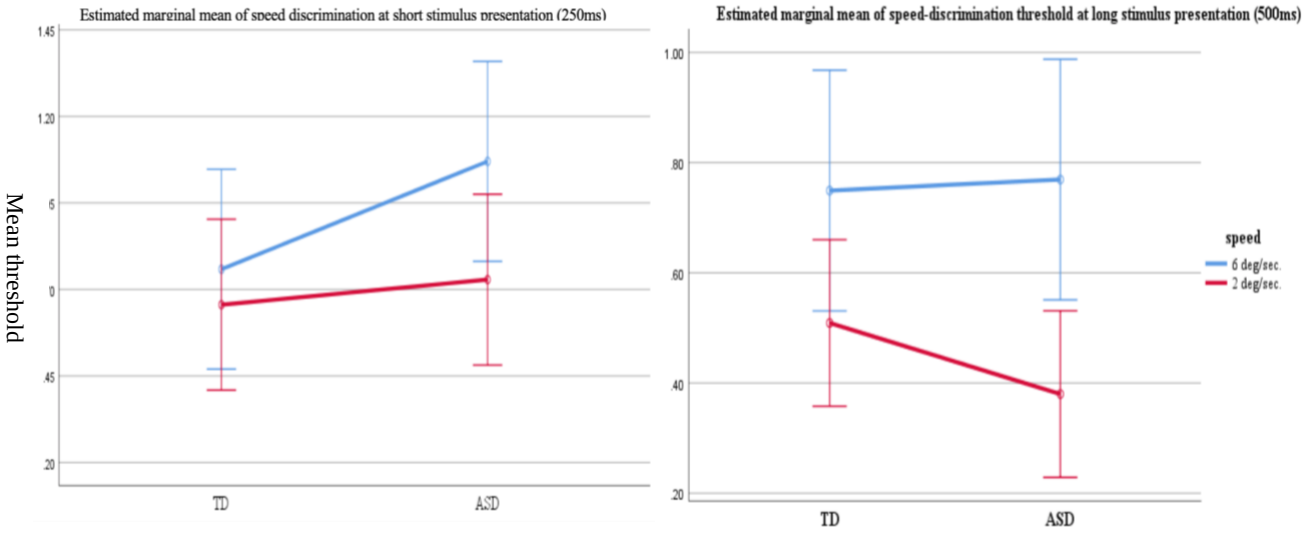

Figure 5-3 Speed-discrimination threshold based on stimulus duration varying at two speeds. ***(left)*** *shows comparison of threshold of discrimination fast and slow speeds at short stimuli duration* ***(right)*** *shows threshold of discrimination fast and slow speeds at long stimuli duration. Results revealed comparable performance of both groups with no statistical significant difference. Error bars presents SEM*

5.4.2 Response time

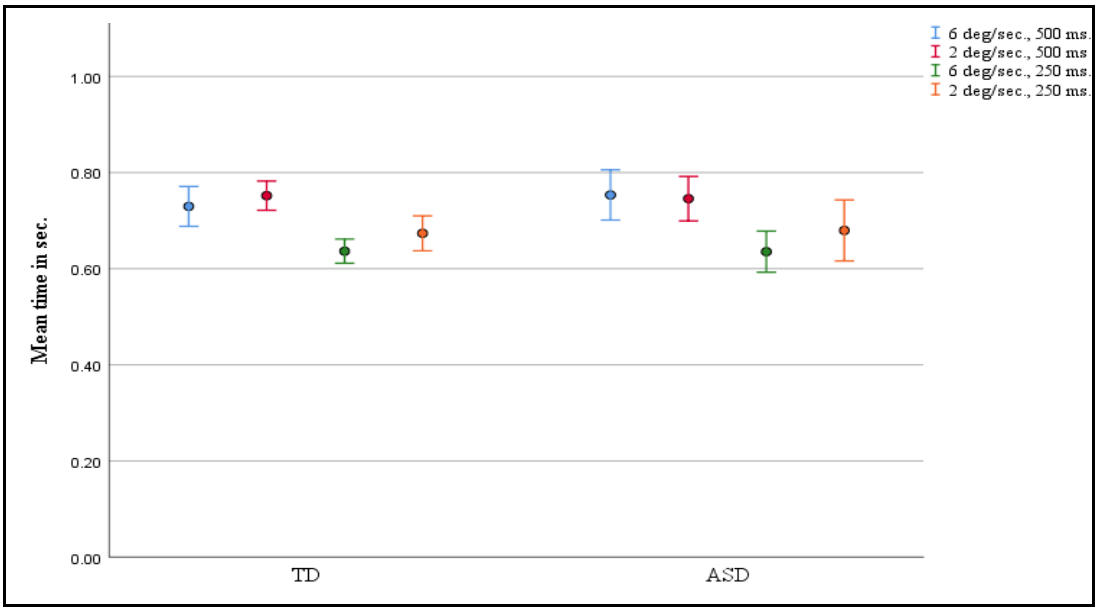

Figure 5-4 Mean response time between both groups at all tasks parameter, showing no significant differences in performance between groups. error bars present SEM

Average response time did not vary between the ASD and the TD group based on speed parameter ($F(1,26) = 0.81$, $p = 0.778$) (Figure 5-4). However, groups performance did vary based on stimulus durations ($F(1, 26) = 27.166$, $p < 0.05$). At short stimuli presentation, both groups took longer time to respond to slow speed (2 deg/sec) (Mean RT: ASD = 0.679 ms, TD = 0.673ms), compared to fast speed (6deg/sec) presented for the same duration (Mean RT: ASD = 0.635 ms, TD = 0.636ms) (Figure 5-5 (A)). At longer stimulus duration, the mean RT increases for both groups and at both speed parameters compared to short stimuli presentation, yet no statistical significant was observed between groups ($F(1, 26) = 0.034$, $p = 0.855$), (Figure 5-5).

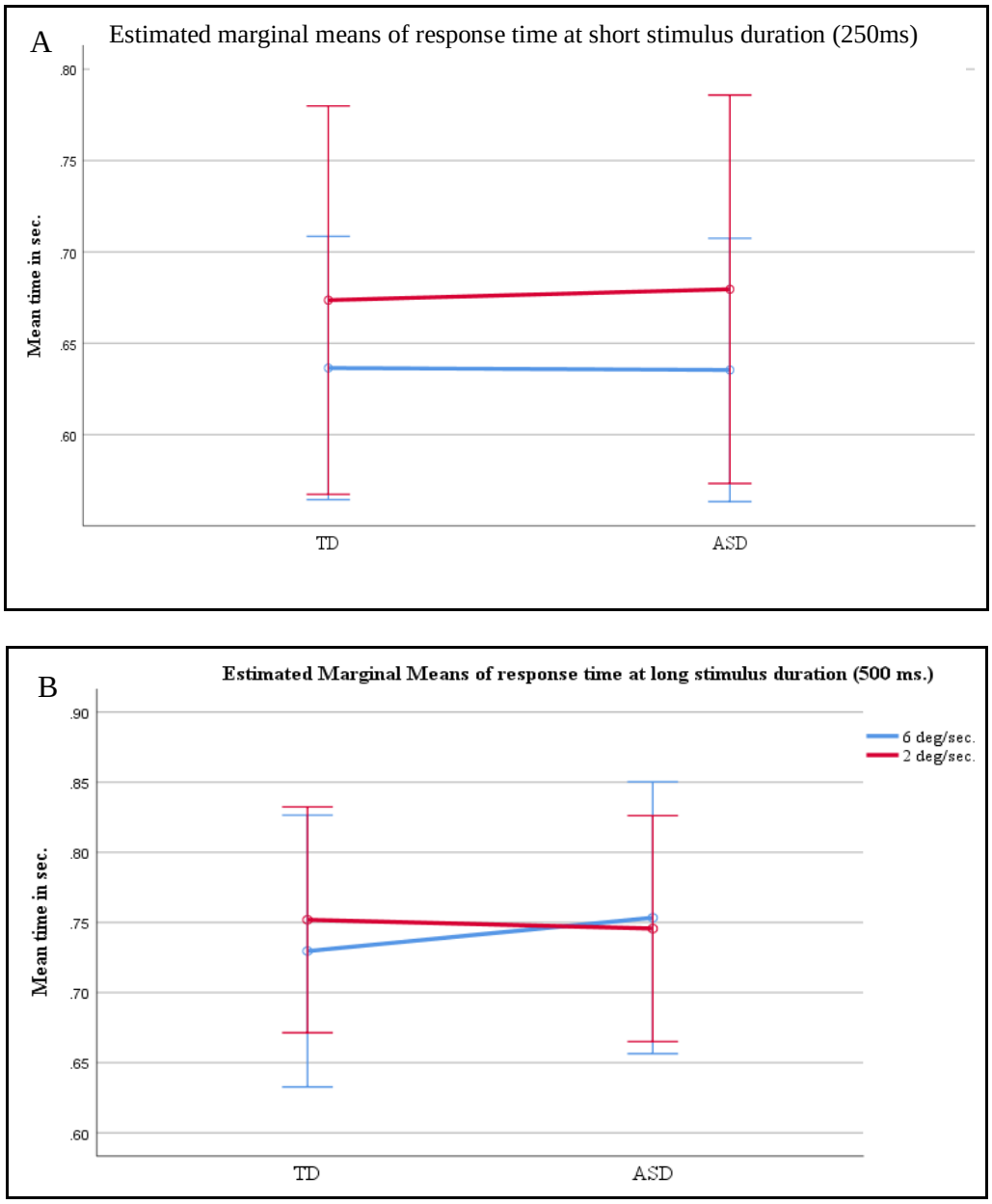

Figure 5-5 Average response time collected immediately after stimulus end.

(A) *showing mean RT of both groups to fast and slow speeds at short stimulus duration.* ***(B)*** *showing mean RT of both groups to fast and slow speed at long stimulus duration. . Error bars present SEM*

Change in speed, however, did not show within- subjects performance differences ($F(1, 26) = 1.417$, $p = 0.245$), neither speed/ group interaction ($F(1, 26) = 0.081$, $p = 0.778$).

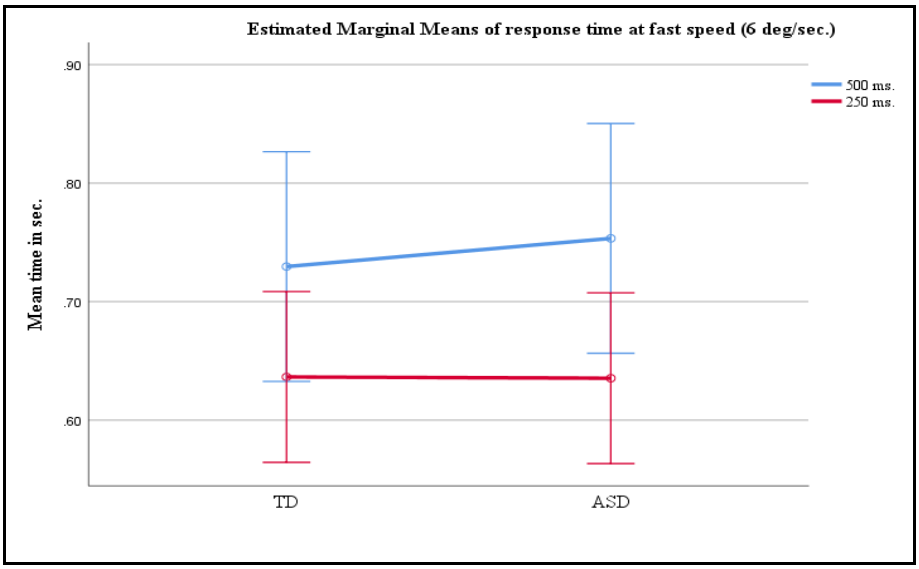

Figure 5-6 Mean RT based on fast speed parameter varied at both stimuli duration (250, 500 ms) in both groups. Error bars presents SEM

Both groups showed comparable performance when stimuli ran at both slow, and fast speed and for both short and long stimuli duration (Mean RT: ASD = 0.6796 ms, TD = 0.6736 ms) (Figures 5- 6 & 5-7).

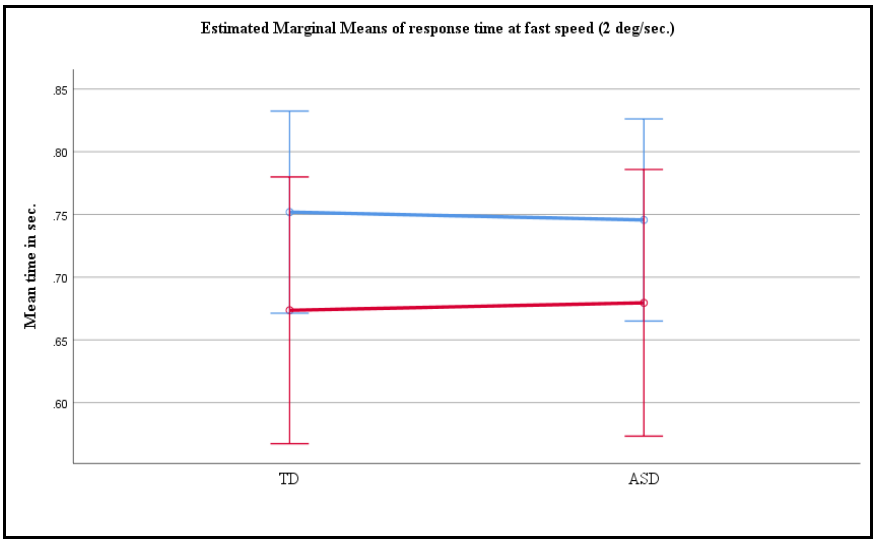

Figure 5-7 Mean RT based on fast speed parameter varied at both stimuli duration (250, 500 ms) in both groups. Error bars represents SEM.

5.5 Discussion and Conclusion

In this study we found that individuals with ASD had normal speed discrimination performance similar to healthy controls. Both groups showed similar effect to change in duration of stimuli more than the speed variation. When drifting grating stimuli moved at fast speed for short duration, ASD group showed an elevation in speed-discrimination threshold similar to the TD group. On the response time comparison, both groups responded similarly to the increase/ decrease of stimuli duration, particularly at long duration, more than the speed parameter. An overall average RT shows no statistical differences in the group performance for any of the stimulus parameter.

5.5.1 Speed discrimination in ASD

Speed processing requires integration of spatial and temporal information processing between early visual cortex area V1 up to higher order visual areas, such as MT/V5. However, this could vary based upon the method and selective stimuli parameters used in a speed experiment. Speed discrimination have been reported normal in autism group at slow and fast parameters.[144] The main differences however was found when stimuli methods vary by other factors, for example, noise level,[237] temporal modulation[152] and/ or visual search.[316] For example, Chen et al[205] used coherent RDK stimuli to assess speed discrimination. Their results showed findings similar to our study of normal speed processing in ASD. However, in Chen's study, ASD individuals exhibited enhanced performance at longer stimulus durations compared to the TD group. However, failed to find significant group differences in speed discrimination even at long stimulus durations. These differences between the results obtained in the two studies might be

explained by the different stimuli used in the two experiments. The RDK stimuli used by Chen et al may require enhanced processing of coherent motion preformed in higher order cortical areas, whereas the drifting gratings used in our experiment may be processed in lower visual areas. A study by Manning et al.[286] that used RDK to study fast and slow motion perception in children with ASD, obtained results that were comparable to our findings, although they found higher thresholds in the ASD observers for slow stimulus speeds. Based on the findings from age differences in response to speed tasks, children tend to show less sensitivity to slow speed compared to adults.[318] Hence, children with autism might be more affected by disrupted brain networks at early development stages.[302] These findings suggest that motion perception might be disturbed in autism particularly for complex stimuli that require more integration between visual cortical areas.[95]

A question could be raised as to whether the methods used in the above mentioned studies actually reflect the normal speed processing advantage in ASD? If so, is this advantage limited to early cortical processing (e.g., within V1) and does it decrease at higher order areas such as MT? Or can we attribute the speed processing advantage in autism to other factors?.[205]

We provided the example above that show ASD participants decreased performance in detecting speed parameter using RDK stimuli, yet drifting grating stimuli show normal response to speed same as control. Bertone et al,[64] for example, used two static orientation-discrimination tasks with first-order drifting grating, and second-order texture-defined stimuli in adults with ASD compared to TD group. Their results suggest that ASD-related visual impairments depends on stimulus complexity irrespective of static or dynamic stimulus characteristics. However, we cannot completely agree that the stimuli used by Bertone et al were ideal for assessing the function of higher order visual areas, which been found to be activated more by dynamic stimuli

than static stimuli. The drifting gratings in the Bertone et al. study involved perceptual processing at early levels of V1,[320] and hence their results might agree with our results. Drifting grating stimuli may only reflect the enhanced local processing advantage found in ASD, but not the altered function at higher-order areas.[135] However, we agree with the idea that stimuli complexity may disturb motion processing in ASD particularly the global motion more than local motion.[275]

Previously[275] we measured coherent motion discrimination thresholds using RDKs in the same experimental cohort reported here. We found that direction discrimination thresholds were similar in ASD and TD observers. However, we also found that combining the coherent motion discrimination task with a second simultaneous, form-from motion shape identification task resulted in significantly greater dual-task costs on the coherent motion task in ASD participants. This result suggests that ASD deficits in global motion processing may increase with increased stimuli complexity. Studying speed discrimination using different stimuli type and methods can revealed so much about motion perception-related to speed. Cliffored et al.[321], for example, studied speed discrimination using RDK stimuli presented in optic flow patterns and rotational stimuli. They found that participants reported radial motion appeared to move faster than rotational motion. However, when speed parameter was compared using same type of stimulus participants showed no differences between the two targets running at the same speed. Cliffored et al. argued that their results were consistent with the idea that perceived speed is based upon the pooled responses of elementary motion detectors, but that speed processing may manifest upon constrains on motion-in-depth and object rigidity.[321] In ASD, there are no research that studied such differences in speed discrimination using deferent methods. In general, ASD show

intact primary visual area,[9] hence this may explain the normal speed discrimination found in this study.

Finally, the findings in this study suggest normal speed processing in autism. It may not be the whole story, and it would not explain the distinct mechanisms mediating different domains of visual information processing. Further elucidation requires additional experiments and imaging studies in this group.

Chapter 6

Conclusion and future outlook

Many theories have been proposed to understand the underlying mechanisms of motion information processing in ASD. No firm conclusion can be drawn as to where exactly deficits exist in the neural visual areas in autism. For a long time, the theory of enhanced local perception and diminished global perception was the dominant theory to explain the biased performance in extracting small details that were found in tasks that used so-called Navon stimuli.[322] Introducing new methods to assess motion perception in autism have implicated other factors, such as altered connectivity across visual networks, that may start at birth.[49] Disturbed cortical connectivity may also affect the basic function of primary cortices and/or increase neural variability in autism. However, these suggestions attempt to reconsider the idea of impaired global (or rather, biased) processing between local/global information to be either intact or even enhanced on tasks necessitating static spatial information processing and poor performance with dynamic information.[46,86,160,163] Therefore, the impairments of motion processing in individuals with ASD does not necessarily arise solely from one abnormal mechanism or even a broad impairment of spatiotemporal integration, but rather from complex factors that contribute to decreased sensitivity to motion perception based on activated different areas of visual cortex. These areas may also be influenced by related mechanisms, for example, the internal/external deficits in visual noise filtering in autism.[237,275] Herein, we suggest some general neural factors that

contribute to ASD-related changes in motion processing that are based on the findings from our experiments and related research in this field:

- Visual task involves activation of the primary area at V1, based on the feedforward/ feedback connection,[320] ASD will be associated with enhanced local perception.[236] This finding may be demonstrated by using tasks such as drifting grating and 100% coherent RDK stimuli. However, when the task involved changes in contrast, for example, ASD participants exhibited an enhancement in detecting high contrast with large target sizes, which may suggest abnormal weakening of response gain control.[46] In contrast, autism group presented deficits in detecting low contrast modulation, which could be due to signal/noise ratio weak response,[62] or to large receptive fields that may decrease response gain control in zero noise level task.[195,319]
- When the tasks require processing on high-order cortical areas (e.g., MT/V5 and MST), ASD-related deficits will be observed when stimulus complexity is high, signal/ noise ratio is low,[226] and the task required abnormal integration of information within and between higher-orders visual areas[323] Otherwise, normal performance might be obtained in ASD observers if these "stimuli triggers" mentioned above are controlled.[98,158,193]
- Response time in the ASD observers to dynamic visual stimulus[316] suggests that enhanced local processing found in autism may not be caused by long stimulus presentations or by advanced search ability. In fact, RT may be affected by stimuli task requirements more than actual enhancement/deficit located at the visual processing area. For example, increased RT in autism was observed when stimulus complexity increased.

However, increasing the time of presentation can overcome this deficit, and ASD participants may tend to respond in a similar way to control group.[185,275]

Other factors that influence visual processing found in autism include:

- **The diagnostic criteria**: In the past few years, the diagnostic criteria have varied in terms of inclusion and exclusion measurements. Although, the recent DSM-V widened the inclusion criteria to include all previous categories under one umbrella[153] the assessment procedure is still based on either the direct or indirect observations of individual behaviors. These "tests" consider two categories of symptoms: 1) Persistent deficits in social communication/interaction and 2) Restricted, repetitive behavior patterns. Severity level assessment (1 less sever – 3 extremely severe) is based on level of support needed for daily functions. However, information can still be obtained through observation by a third party (parents, school teacher) or by self-report questionnaires such as the Autism Spectrum Quotient.[259] Yet, these type of assessments still lack the cognitive measures that can truly differentiate autism groups. Furthermore, these assessments do not include any sensory evaluation, such as visual processing. The lack of sensory evaluation may contribute to the variability that is typically seen in data collected within and between putatively homogeneous groups of ASD individuals. In our review, we showed an example taken from same "high-level IQ" autism group, which include high-functioning" autism (HFA), and Asperger Syndrome (AS).[144] In these two groups researchers still find statistically different observations in motion

perception.[151,199] Curunt diagnostic criteria make it difficult to create ASD groups that are truly matched and, consequently, to observe ASD-related changes in behaviour that are consistent across experiments

- **The autism group sample**: The majority of studies that have investigated motion perception in autism were either examined children with autism *or* adolescent and adults, with autism. As far as we are aware, no study has examined both age groups. Hadad et al[162] reviewed the significant differences in motion perception, particularly global motion perception, that exist between children and adults. Results in this field show that sensitivity to different types of motion information develop at rates.[209] Other studies suggest that sensitivity to differences speed and the minimum displacement of motion that defined form, may not fully mature up to 11 years old.[318,324] It is possible that these immaturities are prolonged in individuals with autism, perhaps reflecting abnormal development of brain network connectivity. Most Studies have reported that children with autism exhibit enhanced local motion processing with a diminished global motion perception [e.g., Ronconi et al][140]. On the other hand, studies on adults with autism have yielded contradictory findings[e.g., bakroon et al.] [275]. Hence, studies that tested children and adult with ASD using the same stimuli and methods could provide important data about the development of motion perception in autism. Also, it could draw "clear" understanding of the underlying abnormalities in visual processing and whether perceptual learning would overcome such abnormalities over time.

- **Methods used in studying motion perception in autism**: previously we reported[144] that using different methods makes it difficult to compare findings from different studies. Therefore, we suggested that tasks of same methods should be used and should vary one or two parameters. This method will insure activation of the same levels of neural processing and connectivity. Also, it will mediate other factors such as, bottom-up and top-down feedback projections.[314]

The results presented in this thesis have provided new information on how motion perception is processed in autism. It is worth emphasizing that the results from our experiments have been reported from the same experimental cohort of the autism and the control group with the following general conclusions:

- Normal global perception was found in individuals with autism when responding to global direction task.
- In a global/local task, locally-oriented information, such as form-motion perception in autism, was intact, while global motion declined. However, this biased processing may decrease with the increasing task complexity.
- Higher-order processing may be altered by internal/external visual noise filtering in autism.
- Long stimulus durations may enhance perceptual performance in ASD.
- Speed perception is normal in autism.

To support these hypotheses, further research is needed to clarify the actual neural functional and anatomical activation in autism in response to specific visual stimuli, such as neuroimaging techniques.

A farther challenge will be determining if these findings support the social orientation and/or the bottom-up theories of ASD.[93] In other words, does the information obtained from these studies support the idea of existing developmental neural abnormalities which later affect information input and manifest themselves as ASD? Or is the social brain characterized by the autism syndrome corrupted, thus, receiving and processing input information at different visual areas result in abnormal visual function?

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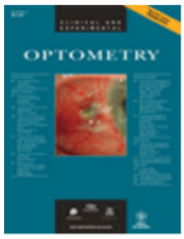

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