Visual Perception in Autism Spectrum Disorders

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Abstract (300 words)

Individuals with Autism Spectrum Disorders (ASD) are known to exhibit atypical visual perception. Consequently, there is fervent research interest in vision in ASD, for advancing scientific understanding of the experiences of individuals with ASD, and because neurobiological models of visual perception exist, for facilitating the search for a neurobiological explanation for ASD.

This thesis presents research conducted at the cognitive level, the neuro-physiological level and the psycho-physical level, for examining vision in ASD. The psycho-physical findings suggest that atypical visual perception in ASD is unlikely to have a sub-cortical origin as sub-cortical magnocellular and parvocellular pathway functioning, and low/high spatial frequency detection in adolescents with ASD were found to be no different from typically-developing controls. There was, however, evidence indicating local motion direction perception deficits in the same adolescents with ASD suggesting that atypical motion perception in ASD may have a cortical origin. Electrophysiological investigation of low level visual perception in ASD revealed findings concurring with this latter interpretation. More specifically, whereas visual evoked potentials demonstrated visuo-integrative processes associated with perception of second order and hyperbolic gratings were not atypical in children with ASD, there was increased activity of the visual cortical region. A further gamma power analysis then demonstrated that there may be increased neuro-connectivity within primary visual area V1 in the children with ASD. Atypical low level visual cortical processes may result in locally-biased perceptual style previously observed in individuals with ASD. However, a cross-cultural comparison of perceptual style in children with ASD and TD children from Singapore and England, found evidence suggesting that locally-biased perceptual style in ASD may not be culturally universal. In sum, lower level visual cortical processes may be atypical in ASD, and whether these atypicalities manifest at the higher perceptual level can be determined by cultural variability in attention and response processes.

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1 Chapter One – Introduction

1.1 What are Autism Spectrum Disorders?

Autism Spectrum Disorders (ASD) encompass a group of developmental conditions characterized by qualitative impairments in communication, qualitative impairments in social interaction, and presentation of restricted, stereotypic or repetitive interests, behaviours or activities (APA, 2004; WHO, 1992). The prevalence of ASD is estimated to be up to 1 in 100 of the population (Baird, et al., 2006). ASD includes sub-categories such as Autistic Disorder, Asperger's Syndrome, and Pervasive Developmental Disorder Not-otherwise specified (PDD-NOS). A diagnosis of Autistic Disorder requires deficits in communication, social interaction and presentation of restricted, stereotypic or repetitive interests, behaviours or activities to be displayed prior to three years of age. Asperger's syndrome is associated with difficulties in social interaction and restricted, stereotypic or repetitive interests, but not language delay. A diagnosis of PDD-NOS is used when a child shows ASD symptoms, but do not fit into the other sub-groups due to a late on-set of the condition, atypical or mild expressions of those behavioural traits.

ASD is a heterogeneous condition. With respect to the behavioural aspect of ASD, no two individuals with ASD have exactly the same behavioural profile, even if they have the same diagnosis of an ASD sub-category. For example, an individual identified with a qualitative impairment in social interaction as manifested by a marked impairment in the use of multiple nonverbal behaviours (APA, 2004), could be recognized with the atypical behaviour because he/she only directs facial expressions of extreme intensity to other people, or because he/she has unusual facial expressions (Lord, et al., 2000). Furthermore, the cognitive abilities of individuals with ASD are wide-ranging, with a substantial percentage i.e. 25% to 64% of the ASD population identified with intellectual disabilities (M. Dawson, Soulières, Gernsbacher, & Mottron, 2007). Research on the neurobiology of ASD has revealed some consistencies in neuro-anatomical or neuro-functional differences between individuals with ASD and TD individuals (DiCicco-Bloom, et al., 2006), and a number of genetic atypicalities in ASD have been documented (Muhle, Trentacoste, & Rapin, 2004). Even so, the exact aetiology of ASD still eludes current knowledge. Understanding heterogeneity in the behavioural and cognitive profile of ASD may reveal sub-types of the condition with differing underlying aetiology, which could hold the key to

advancing research into the neurobiology and genetics of ASD. Searching for meaningful sub-types within the autism spectrum is one of the recommended strategies within the Autism Speaks USA Strategic Plan for Science (G. Dawson, et al., 2009), whose ultimate objective is to develop effective personalized medical and psychological interventions for individuals with ASD.

ASD is a disabling condition that has a negative impact not only on the well-being and development of the individual, but also on the well-being of parents (Allik, Larsson, & Smedje, 2006; Gray, 2002) and the economy (Järbrink, Fombonne, & Knapp, 2003; Jarbrink & Knapp, 2001). Despite ASD's negative impact on the individual's level of social functioning, savant skills have been observed to be of a higher proportion in the autistic population than in the general population (Heaton & Wallace, 2004). These 'talents' could come in the form of extraordinary abilities such as naming the day of the week for any random date, or of more simple day to day tasks such as noticing small changes in the room (Jarrett & Sutton, 2008). Individuals with ASD may also display 'islets' of abilities whereby they show superior performance on a sub-set of cognitive tasks, relative to their performance on other tasks (Happé, 1999). These abilities need as much explanation as do the disabilities associated with ASD. Recognizing the cognitive processes that underlie both the disabilities and abilities of ASD may eventually contribute to programs that would aid individuals with ASD in developing to their fullest potential and enable them to make positive contributions to society.

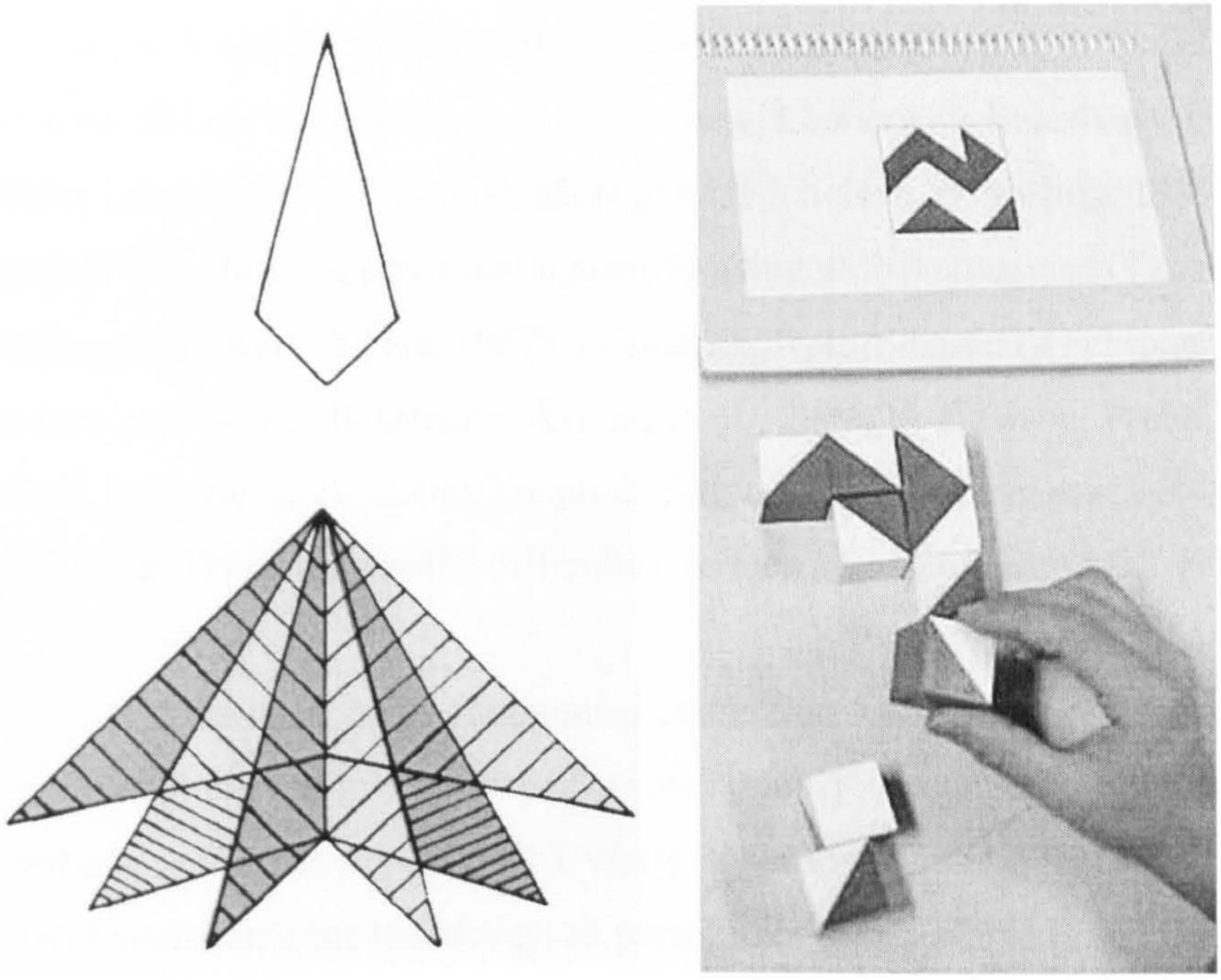
1.2 Psychological Research on ASD

There are currently two main areas of research in ASD. There is a branch of research that focuses on the core social deficits of ASD, and another branch of research that investigates the non-social behavioural aspects of the disorder. Research on the core social deficits of ASD progressed rapidly with the conception of the 'Mind-Blindness' theory of autism (Baron-Cohen, Leslie, & Frith, 1985). This theory suggests that individuals with ASD lack a 'Theory of Mind' (ToM), which is defined as the ability to attribute mental states to the self and others in order to predict and explain the behaviours of self and others (Baron-Cohen, et al., 1985). The 'Mind-Blindness' theory of autism has evolved into the empathizing theory of ASD (Baron-Cohen, 2005, Baron-Cohen & Belmonte, 2005). Empathy is a broader concept than ToM, and is defined as the ability to identify and

respond appropriately to the emotions and thoughts of another person. There is a large pool of research investigating components of the empathizing system in ASD, from the more basic processes such as eye gaze detection and joint attention (e.g. Pelphrey, Morris, & McCarthy, 2005), to the more complex processes such as emotion recognition (e.g. Dapretto, et al., 2006) and ToM (e.g. Castelli, Frith, Happe, & Frith, 2002). This branch of research is however unable to account for the non-social behavioural aspects of ASD.

This thesis operates under the branch of research that investigates the non-social behavioural aspects of ASD. The non-social ASD traits include the presentation of restricted, stereotypic or repetitive interests, behaviours or activities, and also a number of superior abilities such as rote memory (from anecdotal reports in Frith, 1989) and attention to visual detail (Happé & Frith, 2006). The latter ASD trait is exemplified by superior detection of target shapes from more complex figures i.e. the Embedded Figures Test (EFT) (Jarrold, Gilchrist, & Bender, 2005; Jolliffe & Baron-Cohen, 1997; Pellicano, Gibson, Mayberry, Durkin, & Badcock, 2005; Ropar & Mitchell, 2001; Sang, Ren, & Deng, 2006; Shah & Frith, 1983, for negative findings see Brian & Bryson, 1996; Burnette, et al., 2005; Ozonoff, Pennington, & Rogers, 1991) and by superior reproduction of test designs from a set of blocks i.e. the Block Design Task (BDT) of the Wechsler Scale of Intelligence (Caron, Mottron, Berthiaume, & Dawson, 2006; Ehlers, et al., 1997; Ropar & Mitchell, 2001; Sang, et al., 2006; Shah & Frith, 1993; Siegel, Minshew, & Goldstein, 1996, for negative findings see Burnette, et al., 2005; Ozonoff, et al., 1991). Please see Figure 1.1 (pg 4) for an example of the EFT (left panel) and the BDT (right panel). This branch of research that investigates the non-social behavioural aspects of ASD attempts to account for both the disabilities and the abilities of individuals with ASD.

Figure 1.1 The EFT and the BDT.



The left panel shows an example of a test figure (bottom) and a target shape (top) to be located in the test stimulus, from the EFT (Witkin, Oltman, Raskin, & Karp, 1971). The right panel shows the BDT of the Wechsler Scale of Intelligence.

1.3 The Weak Central Coherence account of ASD

The dominant cognitive account that attempted to explain the non-social behavioural traits of ASD is the "Weak Central Coherence" (WCC) theory of ASD (Frith, 1989; Happé & Frith, 2006). The WCC account is a broader theory compared to the ToM account, and was initially proposed to explain both the non-social and the social behavioural traits of ASD. The original conception of WCC postulates that whereas neuro-typical individuals have a drive for meaning and context in information processing i.e. central coherence, individuals with ASD have difficulties drawing different pieces of information together and processing information as a coherent whole (Frith, 1989). WCC suggests that superiority in local i.e. detail-oriented information processing in individuals with ASD is a result of the deficit in global information processing.

WCC predicts individuals with ASD to have difficulties understanding social interactions which are very often context-dependent. WCC can also explain why individuals with ASD have shown deficits in the perception of social stimuli such as faces

(Boucher & Lewis, 1992; Davies, Bishop, Manstead, & Tantam, 1994; de Gelder, Vroomen, & van der Heide, 1991; Deruelle, Rondan, Gepner, & Tardif, 2004; Hobson, Ouston, & Lee, 1988; Humphreys, Minshew, Leonard, & Behrmann, 2007; Klin, et al., 1999; Langdell, 1978; Tantam, Monaghan, Nicholson, & Stirling, 1989). Faces are visual stimuli thought to be processed optimally using global strategies (Tanaka & Farah, 1993; Young, Hellawell, & Hay, 1987). A local i.e. feature-based rather than a global approach, to face processing (Behrmann, Avidan, et al., 2006; G. Dawson, Webb, & McPartland, 2005; Deruelle, et al., 2004; Joseph & Tanaka, 2003; Lahaie, et al., 2006; Teunisse & de Gelder, 2003) would predict difficulties in face perception in ASD.

On the other hand, fragmented perception would be beneficial for encoding details, thus explaining instances of superior rote memory. Fragmented perception may also facilitate performance on the EFT where dis-embedding abilities are required, and the BDT where visualizing the test-design as parts rather than a whole is an effective strategy. Furthermore, this piece-meal processing style may lead to interest only on a particular feature of an object, or a particular aspect of a more general topic, which explains the perseverance on certain aspects of activities and restricted interests, sometimes observed in ASD. In light of WCC potentially underlying a number of ASD-related behaviours, the WCC account has formed the basis of a substantial area of ASD research investigating visual perception (for a review see Dakin & Frith, 2005), and also auditory perception (Alcántara, Weisblatt, Moore, & Bolton, 2004; Bonnel, et al., 2003; Groen, et al., 2009; Heaton, 2003; Samson, Mottron, Jemel, Belin, & Ciocca, 2006; Teder-Sälejärvi, Pierce, Courchesne, & Hillyard, 2005) in individuals with ASD.

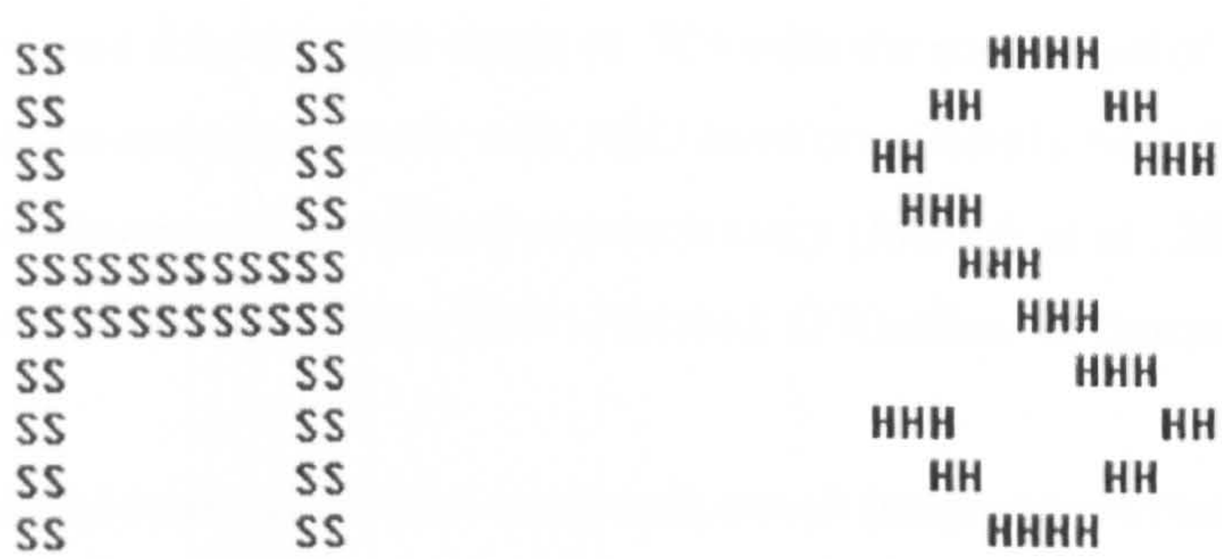
The WCC account has evolved since its original conception, taking into consideration new empirical findings. WCC is now thought to occur alongside social deficits in ASD rather than explain it, because there is a lack of evidence for correlations between superior performance on EFT and BDT and level of social functioning in individuals with ASD (Burnette, et al., 2005; Happé, 1999; Happé & Frith, 2006; Sang, et al., 2006). It has also been re-conceptualized as a local bias in perceptual style rather than a deficit in drawing pieces of information together. This was in view of subsequent research on WCC in visual perception in ASD, which found children and adolescents with ASD to have intact global perception of hierarchical figures i.e. large letters made up of smaller

letters (Ozonoff, Strayer, McMahon, & Filloux, 1994; Plaisted, Swettenham, & Rees, 1999; Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000).

Hierarchical Figures Tasks

Hierarchical figures tasks require participants to identify or indicate the presence of a letter that could appear at the global level of the hierarchical figure i.e. the large letter or at the local level of the hierarchical figure i.e. the small letters. Please see Figure 1.2 for examples of hierarchical figures. There are two variants to hierarchical figures tasks, a divided attention task and a selective attention task. In a divided attention task, participants are not told whether the target letter would appear at the global or the local level and they are to attend to both levels of the stimuli, to identify or detect the target letter. In a selective attention task, participants are told that the target letter would appear either at the global or the local level, so they only need to attend to one level of the stimuli, to identify or detect the target letter.

Figure 1.2 Examples of Hierarchical Figures (from Plaisted, et al., 1999)



Participants with ASD have been found to perform no differently from TD participants in detecting/discriminating letters at the global level when asked to do so i.e. in selective attention tasks (Ozonoff, et al., 1994; Plaisted, et al., 1999; Rinehart, et al., 2000). These results suggest that individuals with ASD are as capable of global perception as TD individuals when directed to do so. Therefore, WCC in ASD was suggested to be more of a local bias in perceptual style, rather than a deficit in global processing.

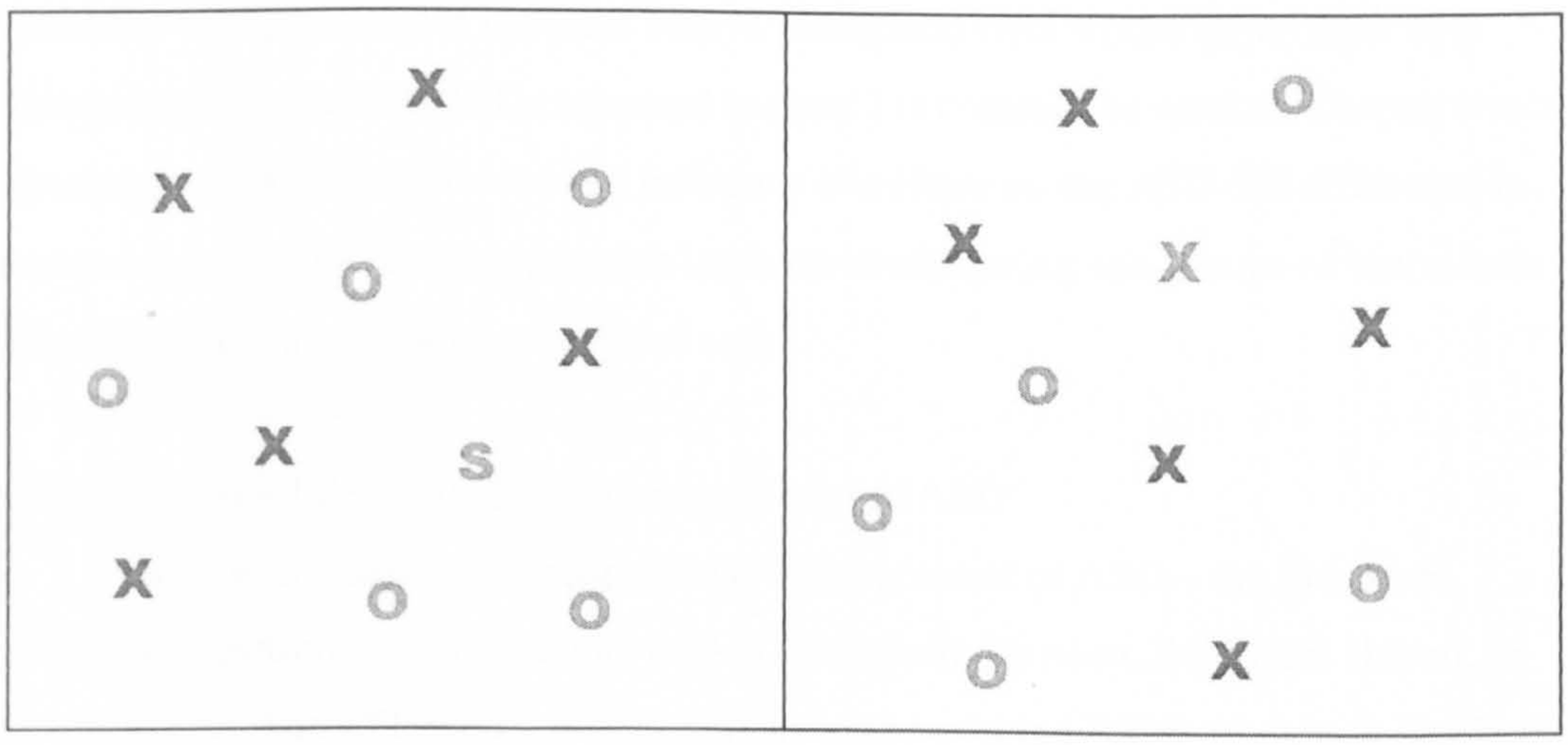
Even so, data from hierarchical figures tasks only revealed some evidence supporting superior processing of local details in ASD. Participants with ASD performed

better at detecting a letter at the local level than TD participants in divided attention tasks (Plaisted, et al., 1999; Wang, Mottron, Peng, Berthiaume, & Dawson, 2007), and showed a greater local to global interference in a selective attention hierarchical figures task (Wang, et al., 2007). However, two other studies that employed divided attention tasks found no evidence for better performance at the local level in participants with ASD (Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Mottron, Burack, Stauder, & Robaey, 1999).

Visual Search Tasks

There is further evidence of superior processing of local details in ASD on visual search tasks. Visual search tasks require participants to find a target element amongst an array of distracters, in which better performance is associated with increased perception of local details. In a feature search task, as shown in the left panel in Figure 1.3, a target is identified by a single feature i.e. the target letter 'S' only shares a feature (the colour green) with one set of distracters (the green 'O's). In a conjunctive search task, as shown in the right panel in Figure 1.3, a target is identified by a combination of at least two features i.e. the target green 'X' shares a feature (the colour green) with one set of distracters (the green 'O's), and a feature (the shape of 'X') with the second set of distracters (the red 'X's). Children and adolescents with ASD have consistently been found to perform better on visual feature and conjunctive search tasks (Jarrold, et al., 2005; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998).

Figure 1.3 Examples of visual search task stimuli (adapted from Plaisted, et al., 1998).



1.4 The reliability of WCC for explaining ASD

The mixed findings of superior processing of local details in ASD invoke the possibility that only sub-groups of individuals with ASD show a local bias in visual perceptual style, and that this is not a universal feature of ASD. As already indicated in the second paragraph of section 1.2, WCC in ASD was also not consistently replicated with the EFT (Brian & Bryson, 1996; Burnette, et al., 2005; Ozonoff, et al., 1991) nor the BDT (Burnette, et al., 2005; Ozonoff, et al., 1991). It is therefore important to examine further this atypical visuo-perceptual behaviour in ASD, which may help reveal how sub-types with varying visuo-perceptual style in ASD arise.

Therefore, the local bias in perceptual style in ASD is re-explored in Chapter two, as part of a cross-cultural study on atypical perceptual style in ASD. This is also in view of current evidence suggesting that there is a cultural influence on visuo-perceptual style in neuro-typical individuals (Nisbett & Miyamoto, 2005). A local bias in perceptual style has been observed in individuals with ASD from both Western and Asian nations, albeit the majority of the studies were conducted in the Western nations. All forty-three experimental studies cited in a review article by Happé & Frith (2006) were conducted with individuals with ASD and without ASD from the United States, United Kingdom, Western Europe, Australia or Canada (Happé & Frith, 2006). There are at least two studies that have been conducted in China which have replicated the observation of a local bias in perceptual style in Chinese individuals with ASD (Sang, et al., 2006; Wang, et al., 2007). However, no cross-cultural study of field-dependence in children with ASD has been conducted. It remains to be established if the local bias in perceptual style would be stronger with Chinese individuals with ASD compared to their TD controls, or weaker. Chapter two's objective is to examine if there is an influence of culture on the ASD-TD difference in perceptual style, so as to provide some leads on investigating sub-groups of individuals with ASD who have varying perceptual styles.

1.5 The Enhanced Perceptual Functioning model of ASD

There is an alternative theory to the WCC account of ASD – the Enhanced Perceptual Functioning (EPF) model of ASD (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). The EPF model is very similar to the evolved WCC account in that both do not assume that individuals with ASD show deficits in global perception i.e. drawing pieces

of information together. The EPF model and the WCC account are different in that the EPF suggests an involuntary dominance of lower level perceptual processes in comparison to higher level cognitive functioning in ASD, resulting in an imbalanced relationship between the lower level detail-oriented processes and the higher level integrative operations. Perceptual processes may be more dominant in individuals with ASD than higher level operations, while the higher level operations may be more dominant in TD individuals than the perceptual processes. In tasks such as face perception where global strategies are thought to be optimal, superior perceptual processes may be disruptive for the higher level integrative processes to occur. On the contrary, in tasks such as the EFT, the BDT and visual search, where perception of local details is associated with better performance, superior perceptual processes in individuals with ASD may be advantageous.

This thesis regards the EPF model and the WCC account as complementary theories rather than competing theories. WCC suggests that there is a local bias acting on the higher level perceptual processes in ASD, but does not indicate how the local bias arises. It may be argued that a dominance of lower level perceptual processes in ASD, as suggested by the EPF model, may result in a local bias in perceptual style, as described within the WCC account.

1.6 Low level visual perception in ASD

The EPF model predicts atypicalities in low level visual perception in ASD. Here the term "low level" visual perception refers to the initial stages of translating sensory information received into neural signals, and may involve processing basic features of visual images i.e. form, colour, motion, and depth separately. It is possible that it is the visual processes operating at the lower perceptual level that is universally atypical in ASD (Milne, et al., 2002; Plaisted, et al., 1999), and whether these atypical low level visual processes manifest at the higher perceptual level in visual cognitive tasks such as the EFT and the BDT is determined by individual variability in attention and response processes. Investigations of low level visual perception in ASD can determine whether atypical visuo-perceptual behaviour in ASD is associated with differences at the higher perceptual level of information processing, or is rooted in basic perceptual abnormalities. Moreover, there is sufficient information about the neurobiology of low level vision, which has enabled deductions about the physiological underpinnings of the atypical visuo-perceptual

behaviour in ASD to be made. There is a substantial amount of on-going research on low level visual mechanisms in ASD, and neurobiological accounts have been postulated. The subsequent sections will review the literature on motion and form perception, which form a large proportion of the research on low level visual perception in ASD. Please also see the Appendix for Table 8.1 (pg 156), which summarizes group experimental studies in which low level *motion* perception in ASD have been addressed, and Table 8.2 (pg 160) which summarizes group experimental studies in which low level *form* perception in ASD have been addressed.

1.6.1 Motion perception

Visual motion perception has been investigated in individuals with ASD with the use of random dot kinematograms (RDK) (Davis, Bockbrader, Murphy, Hetrick, & O'Donnell, 2006; de Jonge, et al., 2007; Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006; Milne, et al., 2002; Milne, et al., 2006; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000), "motion" Glass patterns (Spencer & O'Brien, 2006), plaid stimuli (Vandenbroucke, Steven Scholte, van Engeland, Lamme, & Kemner, 2008), and first and second order sinusoidal gratings (Bertone, Mottron, Jelenic, & Faubert, 2003). These studies have revealed some evidence for impaired visual motion perception in individuals with ASD.

Random Dot Kinematograms

RDK consist of test fields of moving dots, in which a percentage of the dots are moving coherently in the same direction i.e. signal dots, and the remaining dots are moving in random directions i.e. noise dots. RDK assess global motion perception as the movement of the individual signal dots i.e. local motion signals have to be perceived and integrated, for the overall direction-of-motion of the dot display to be perceived (Smith, Snowden, & Milne, 1994). Children and adolescents with ASD have been found to have elevated motion coherence thresholds i.e. percentage of signal dots required to perceive overall motion of the display, compared to TD controls (Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000). It was therefore suggested that individuals with ASD may have deficits in global motion perception. However, a number of subsequent studies which also used RDK as test stimuli, did not find evidence for impaired global motion perception in ASD (de Jonge, et al., 2007; Del Viva, et al., 2006; Milne, et al., 2006; Takarae, Luna, Minshew, & Sweeney, 2008). The choice of task i.e. detection of

motion instead of discrimination of direction-of-motion, and the use of shorter stimulus durations may explain the null findings.

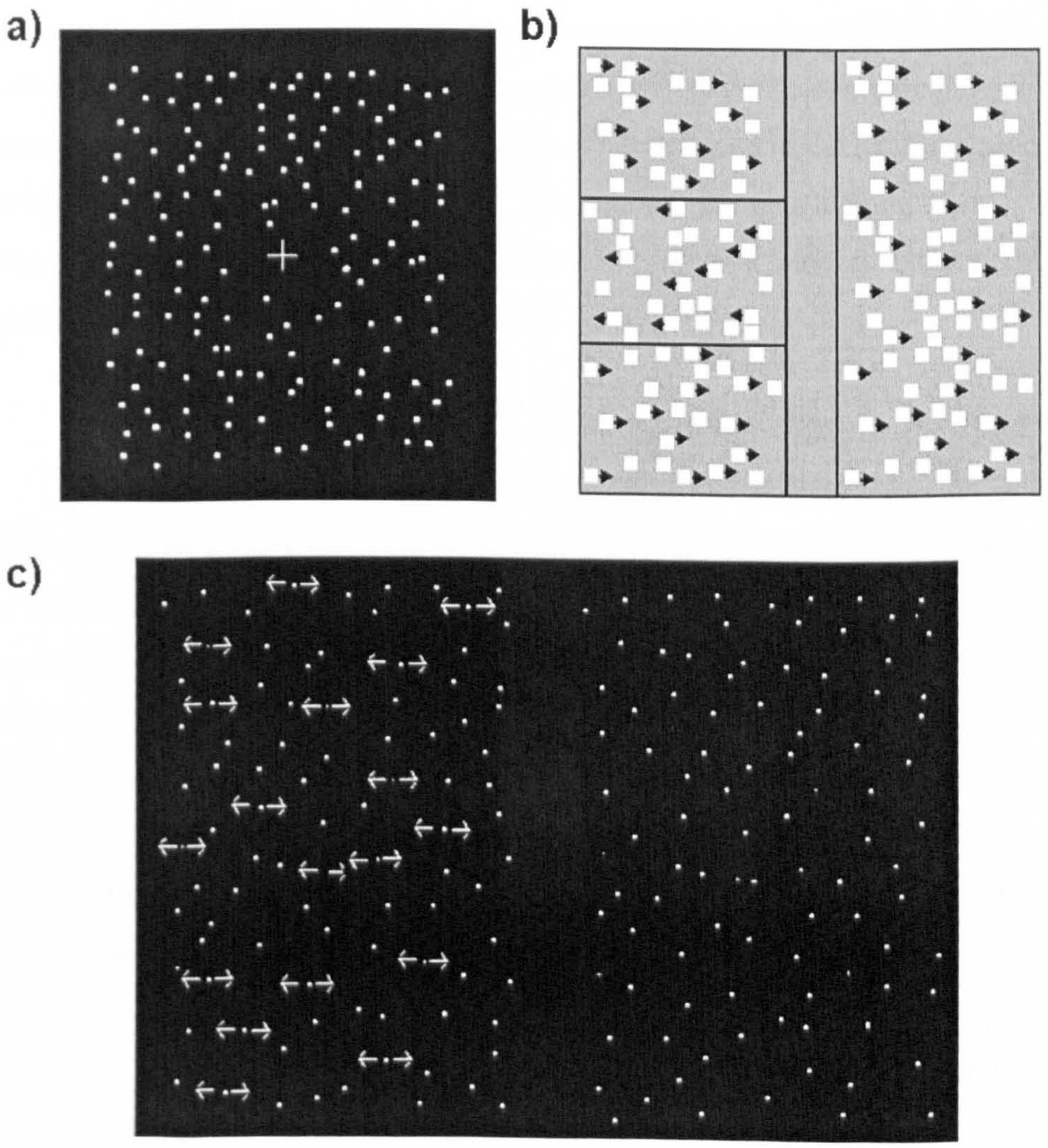
The use of a detection of motion task rather than a discrimination of direction-of-motion task may explain null findings of impaired global motion perception in two studies (de Jonge, et al., 2007; Milne, et al., 2006). These two studies only required participants to detect the presence of global motion in one of two test panels, where only one panel contained coherently moving dots. This is in contrast to the four studies which required participants to discriminate direction-of-motion of RDK and found evidence for impaired global motion perception impairment in ASD (Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000). Davis et al (2006), Milne et al (2002), and Pellicano et al (2005) asked participants to indicate the direction-of-motion of the coherently moving dots, while Spencer et al (2000) asked participants to locate a patch of dots whose coherent motion was opposite in direction to the coherent motion of the remaining dots in the test field. Please see Figure 1.4 (pg 12) for a) example RDK used in Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005, b) example RDK used in Spencer, et al., 2000, and c) example RDK used in Milne, et al., 2006. Detection of global motion is likely to be an easier task than discriminating direction of global motion. The global motion perception detection tasks with RDK (de Jonge, et al., 2007; Milne, et al., 2006) may therefore not have been sufficiently sensitive to detect significant group differences in task performance between the participants with ASD and the TD participants[1].

Differences in stimulus duration may also explain null findings in two other studies (Del Viva, et al., 2006; Takarae, et al., 2008). In these studies, a discrimination of direction-of-motion task was used, but with stimulus durations of 160ms (Del Viva, et al., 2006), and 300ms (Takarae, et al., 2008). No group differences on global motion perception were observed (Del Viva, et al., 2006; Takarae, et al., 2008), although there was a trend for impaired global motion perception in adolescents with autism and language delay in one

[1] This suggestion is further supported by data from Davis et al, 2006, who found no impairments in performance on a two temporal interval matching task with RDK stimuli, where participants were to indicate whether the coherent motion presented in the first time interval is same or different from the coherent motion presented in the second time interval, but impaired global motion perception on the task requiring discrimination of direction-of-motion of RDK, in the same group of participants with ASD.

study (Takarae, et al., 2008). The other studies which employed a discrimination of direction-of-motion task and used a stimulus duration of 600ms (Pellicano, Gibson, et al., 2005), 1000ms (Davis, et al., 2006; Milne, et al., 2002) or until a response was made (Spencer, et al., 2000) found evidence for impaired global motion perception in ASD. Davis et al (2006) did find evidence for impaired global motion perception in ASD for the condition in which stimulus duration was 1000ms, but not for the condition in which stimulus duration was 220ms. It is possible that stimulus durations of less than 600ms make the global motion perception tasks as difficult for the TD participants, as it is for the participants with ASD, making group differences (if any) in task performance less significant.

Figure 1.4 Examples of RDK stimuli (a) from Milne, et al., 2002, b) from Spencer, et al., 2000, and c) from Milne, Swettenham, & Campbell, 2005).



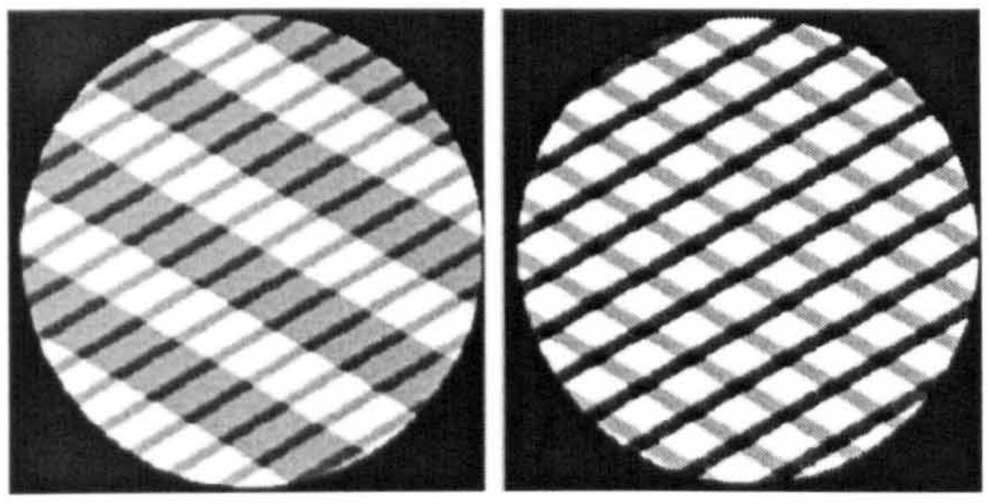
"Motion" Glass Patterns

Children with Autistic disorder, but not Asperger's syndrome, were found to be impaired at detecting global motion within "motion" Glass patterns (Spencer & O'Brien, 2006). Glass patterns are static visual stimuli created by the super-imposition of one or more copies of a pattern of random dots, where one copy is a geometric transformation of the original (Glass, 1969). The Glass patterns used in Spencer & O'Brien (2006) were formed from three super-imposed patterns of random dots, and can be observed as a field of dot-triplets, of which a proportion was positioned as a circular patch, and the remaining was randomly aligned. The "motion" Glass patterns consisted of similar displays but limited life-time dots moved from the position of the first dot to the position of the last dot in the dot-triplets. Participants were asked to locate the circular patch i.e. the global movement pattern composed of the dot-triplets i.e. the local motion signals. The task was a detection task and not a discrimination of direction-of-motion task. However, the detection of circular motion with "motion" Glass patterns may be as complex as discrimination of direction-of-motion task of RDK, as the local motion signals that had to be integrated in the "motion" Glass patterns moved in different directions, whereas those in the RDK tasks described previously moved only in one direction. This subtle difference in complexity of the visual integration process may have made the detection task with "motion" Glass patterns sensitive enough to elicit a group difference.

Plaid Stimuli

Further controversial findings with regards to global motion perception abilities in ASD come from a study that used plaid stimuli (Vandenbroucke, et al., 2008). Plaid stimuli are composed of two superimposed gratings with different orientations, and which are moving orthogonally to their orientations. As shown in Figure 1.5 (pg 14) the plaid stimuli used in Vandenbroucke et al (2008)'s study were formed with square-wave gratings. The resultant perception of these plaid stimuli could be of the component motion i.e. two transparent gratings moving in different directions, or be of the global motion i.e. a coherent plaid pattern moving in one direction. There were no significant differences between the adolescent and adults with ASD and TD controls on the predominance of the global motion percept over the component motion percept, and the number of times per second that the resultant percept switches between the two. The results therefore contradict previous findings of impaired global motion perception in ASD.

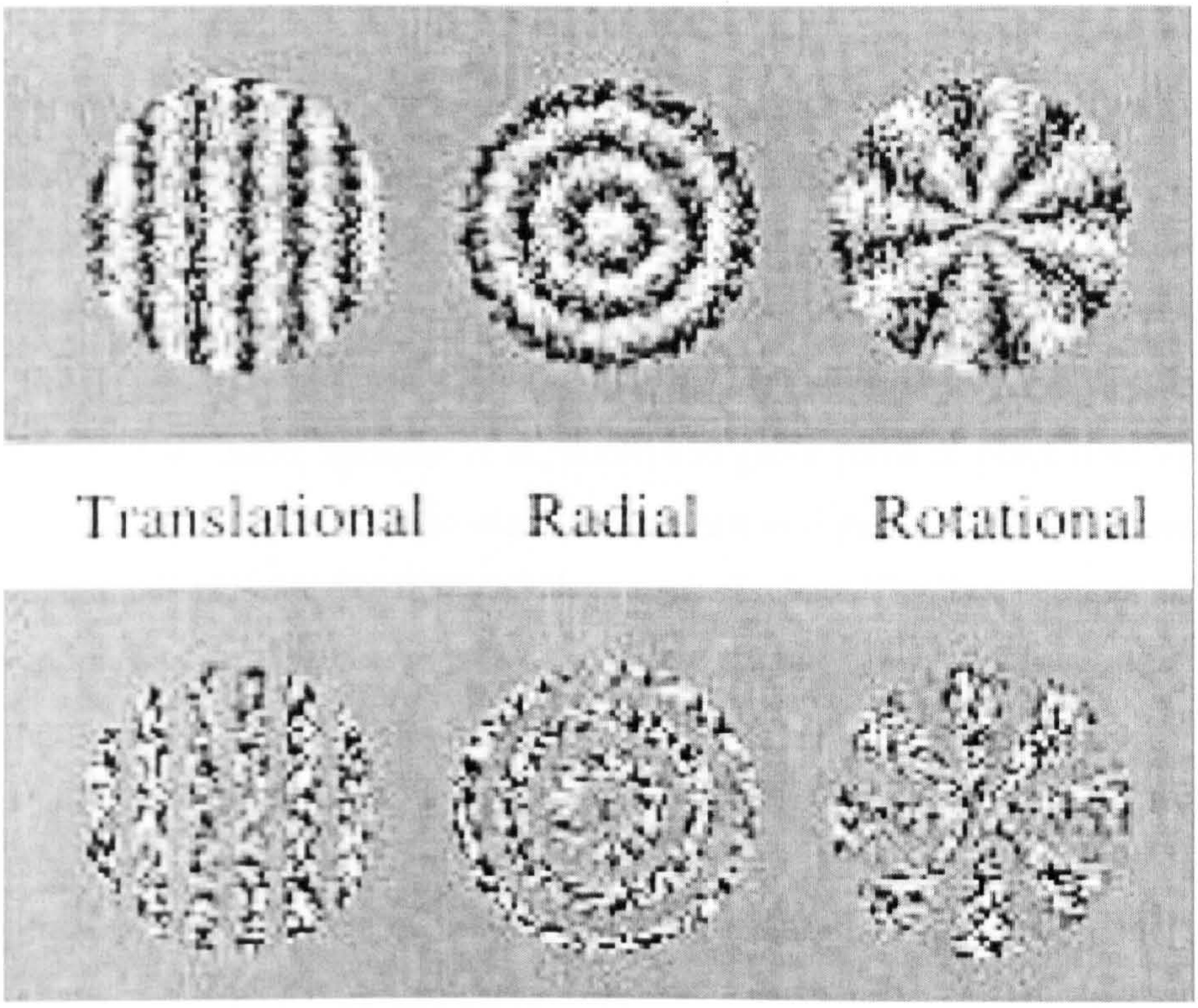
Figure 1.5 Examples of Plaid stimuli (from Vandenbroucke et al., 2008).



First and second order sinusoidal gratings

Children and adolescents with ASD have been compared with TD controls on discriminating direction-of-motion of parallel, concentric, and radial first and second order sinusoidal gratings (Bertone, et al., 2003). Please see Figure 1.6 (pg 15) for examples of the first and second order sinusoidal gratings. Sinusoidal gratings are theoretically suitable for assessing low level visual perception as they are thought to be elementary components of natural visual scenes (Campbell & Robson, 1968; Graham, 1992). Sinusoidal gratings are also functionally suitable for assessing low level visual perception as they can be easily manipulated to represent different basic features of visual images. First order sinusoidal gratings are defined by luminance; whereas second order sinusoidal gratings are defined by contrast i.e. changes in changes in luminance. Perception of direction-of-motion of first order gratings require detection of changes in luminance i.e. contrast. On the other hand, second order gratings require further integration of local contrast signals, for the detection of grating regions containing different contrast, to enable the percept of the direction-of-motion to be observed (Larsson, Landy, & Heeger, 2006). The participants in Bertone et al (2003) were found to have intact direction-of-motion discrimination for first order gratings, but impaired direction-of-motion discrimination for second order gratings. Based on this finding, Bertone et al (2003) suggested that previous observations of impairments in visual motion perception in ASD may be attributed to difficulties in integrating visual signals, rather than a motion perception deficit per se. These two accounts can be dis-entangled if similar patterns of deficits can be observed for static stimuli requiring different levels of visual integration in individuals with ASD. Thus, the following section describes the research on form perception abilities in ASD.

Figure 1.6 Examples of first and second order sinusoidal gratings (from Bertone, et al., 2003).



The top panel displays first order gratings, and the bottom panel displays second order gratings.

A recent study (Takarae, et al., 2008) also found intact discrimination of direction-of-motion of first order gratings in adolescents with autism and no language delay, but demonstrated poorer discrimination of direction-of-motion of first order gratings in the adolescents with autism *and language delay*. There is no data on the early language development of participants with ASD in Bertone et al (2003), but Takarae et al (2008)'s finding suggests that individuals with ASD with different histories of language development may have different visual abilities. This issue of sub-groups will be returned to in chapter five and seven.

1.6.2 Form Perception

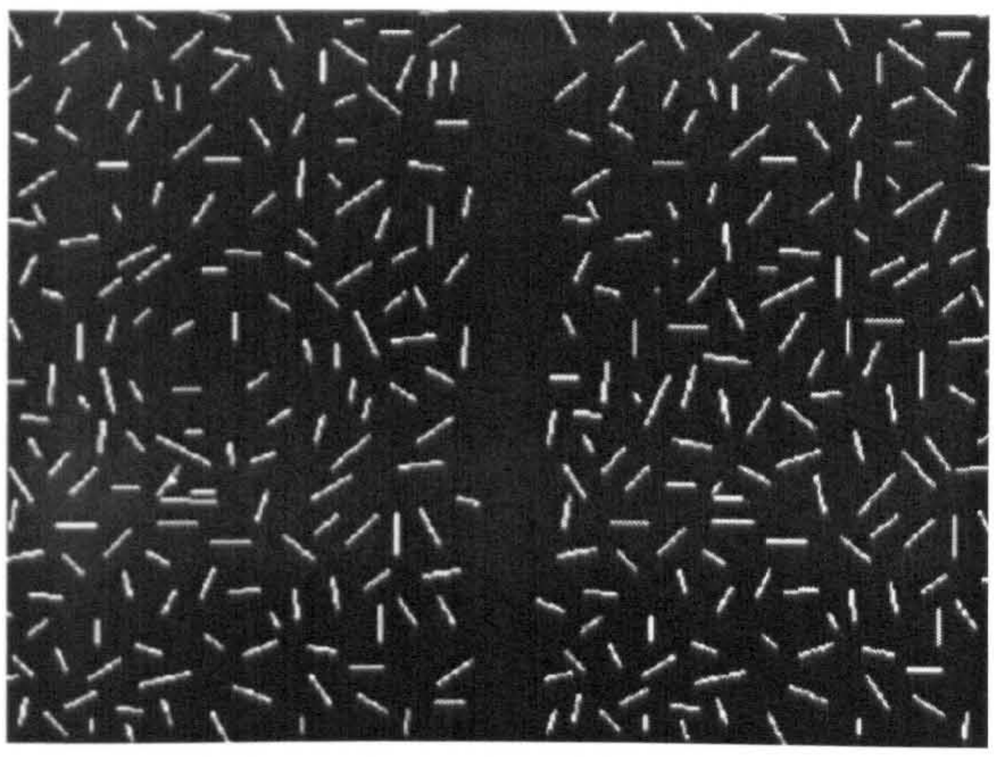
Several studies have shown that global form perception is not impaired in individuals with ASD (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Davis, et al., 2006; Del Viva, et al., 2006; Kemner, Lamme, Kovacs, & van Engeland, 2007; Milne, et al., 2006; Spencer, et al., 2000), with the exception of one study (Spencer & O'Brien, 2006). The studies which found no group differences in global form perception presented participants with ASD and TD participants with line segment displays (Blake, et al., 2003; Milne, et al., 2006; Spencer, et al., 2000) and gabor patch displays (Del Viva, et al., 2006; Kemner, et al., 2007). These stimuli are shown in Figure 1.7 (pg 17), where a) depicts line segment displays and b) depicts gabor patch displays. The line segment displays consist of randomly aligned line segments i.e. noise segments, of which a proportion was positioned around a circular region i.e. signal segments. The gabor patch displays consist of randomly aligned gabor patchs i.e. noise elements, of which a proportion i.e. signal elements were oriented to form a circular pattern. The signal elements in both types of displays need to be integrated for the global percept of the circular form to be observed.

Glass Patterns

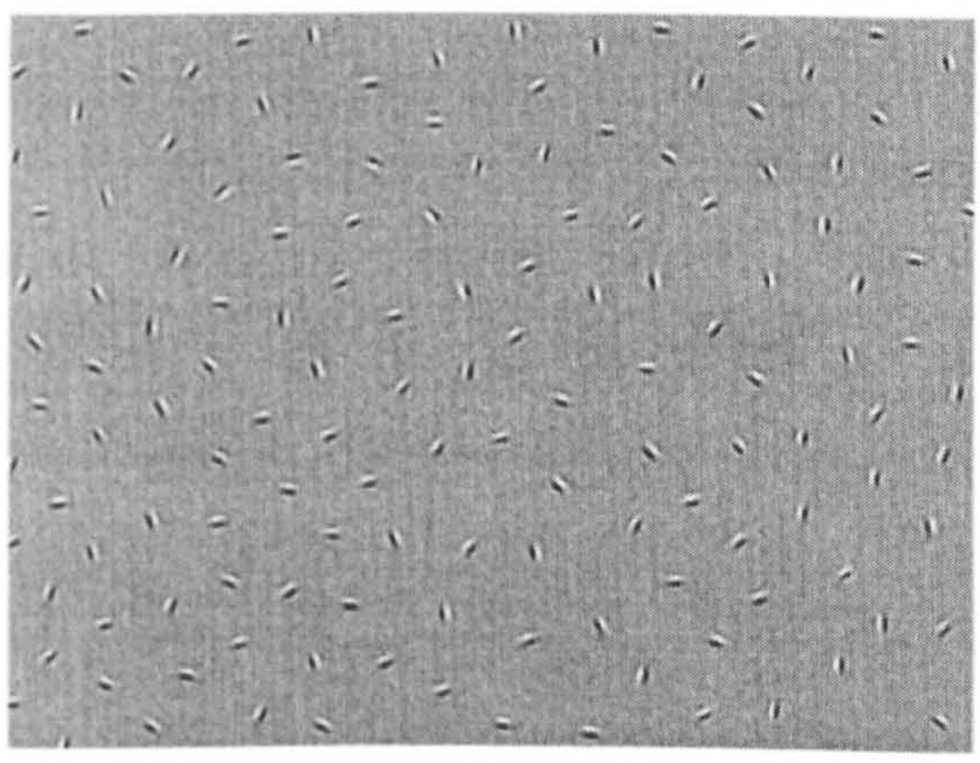
Children with Autistic disorder, but not Asperger's syndrome, were found to be impaired at detecting global form perception with static Glass patterns (Spencer & O'Brien, 2006). As described in the first paragraph on page 13, and as shown in c) of Figure 1.7 (pg 17), the Glass patterns used in the study consist of a field of dot-triplets, of which a proportion was positioned as a circular patch, and the remaining was randomly aligned. Participants were asked to locate the circular patch within the stimuli. The Glass patterns may require an additional level of integration than line segment displays and gabor patch displays. The luminance signals of the dots within the dot triplets in the Glass pattern have to be integrated across space before the orientation of the dot triplets can be established, whereas orientation information is intrinsic in the local signals within the line segment displays and the gabor patch displays. It is possible that children with Autistic disorder show more difficulties perceiving global form in Glass patterns than in line segment or gabor patch displays, because the Glass patterns require both local and global integration of the dots for the global form to be perceived, whereas the line segment displays and gabor patch displays only require global integration of the local signals.

Figure 1.7 Examples of global form perception stimuli (a) a line segment display from Milne, et al., 2005, b) a gabor patch display from Del Viva, et al., 2006, c) a Glass pattern from Spencer & O'Brien, 2006).

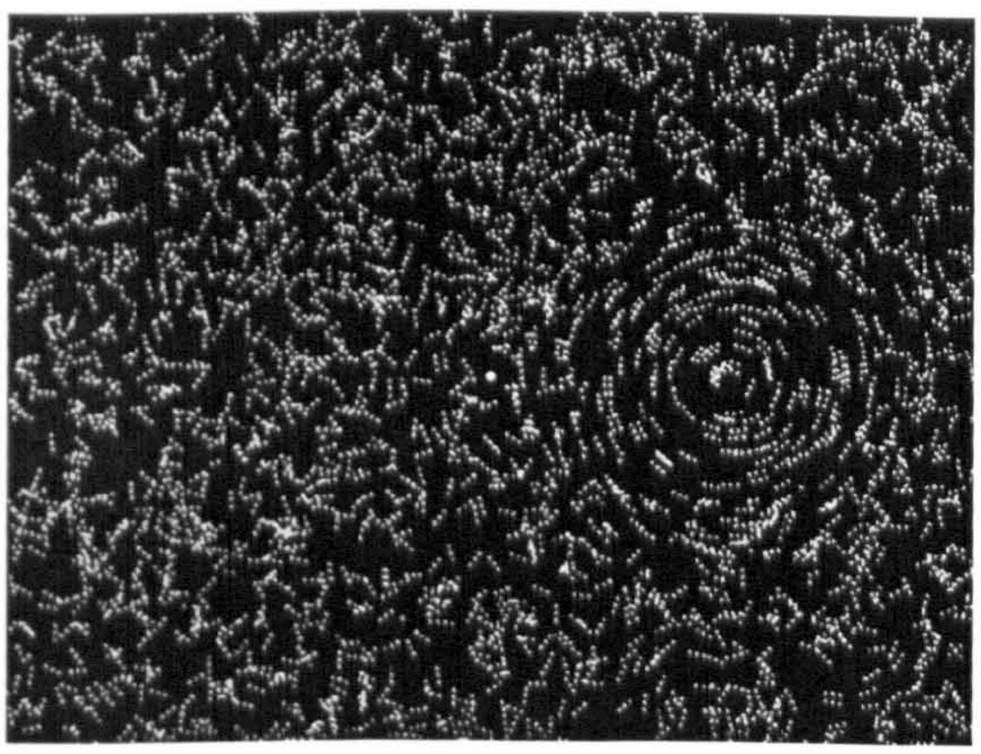
a)



b)



c)



On a different note, Glass patterns are similar to RDK (and also "motion" Glass patterns) in that they require local integration of dots within the test stimuli, albeit Glass patterns require local integration across space, while RDK require local integration across time, for perception of local visual signals and subsequent detection of the global form/motion. Atypical local integration of visual signals may therefore underlie deficits in global motion and form perception observed in ASD. As the next paragraph describes, evidence from studies employing first and second order gratings also suggest that individuals with ASD may have difficulties with integrating visual signals, and not with perceiving motion stimuli per se.

First and second order sinusoidal gratings

Children and adolescents with ASD were found to have deficits in perceiving direction-of-motion of second order gratings, but not first order gratings (Bertone, et al., 2003). There is further evidence for a deficit in integrating visual signals for static stimuli from a study that compared individuals with ASD on orientation discrimination of static parallel first and second order gratings (Bertone, Mottron, Jelenic, & Faubert, 2005). As described previously, first order gratings are defined by luminance, whereas second order gratings are defined by contrast i.e. changes in changes in luminance, which require further integration of the local contrast signals for perception of the overall pattern (Larsson, Landy, & Heeger, 2006). Participants with ASD were found to have impaired orientation discrimination of second order gratings, but showed enhanced orientation discrimination of first order gratings, compared to TD controls (Bertone, et al., 2005). This finding provides further evidence that individuals with ASD do not have an isolated motion perception deficit, but have general difficulties with "complex" stimuli i.e. stimuli which require visuo-integrative processes. This "complexity" hypothesis is able to account for the observed deficits in perception of orientation and direction-of-motion of second order gratings (Bertone, et al., 2003, 2005), global motion perception (Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000; Spencer & O'Brien, 2006) and global form perception (Spencer & O'Brien, 2006) in individuals with ASD. Perception of orientation and direction-of-motion of first order gratings are not dependent on visuo-integrative processes, so may be spared in ASD (Bertone, et al., 2003). The "complexity" hypothesis is however unable to provide an explanation for *superior* orientation discrimination of first order gratings in ASD (Bertone, et al., 2005).

1.7 Neural Correlates of low level visual perception in ASD

A neuro-physiological account that is based on the "complexity" hypothesis has been put forward to explain the deficits in perception of "complex" stimuli and also superior perception of first order gratings specific to orientation and not direction-of–motion, in ASD. The account suggests that there may be atypicalities in neuro-connectivity within the visual cortical region i.e. reduced transmission of neural information between functional visual cortical regions, but increased lateral connectivity within primary visual area V1 in ASD (Bertone, et al., 2005; Mottron, et al., 2006). This atypical neuronal structure is a suspected mechanism underlying the EPF model (Mottron, et al., 2006). Visual information from the retina is transmitted by the sub-cortical visual pathways to the primary visual area V1 (Merigan, Freeman, & Meyers, 1997; Merigan & Maunsell, 1993). The primary visual area V1 relays the neural visual information it receives to V2 and the extra-striate visual areas for further neural processing (Bullier, 2001). Neural processes associated with perception of first order gratings have been thought to occur within primary visual area V1 (Dumoulin, Baker, Hess, & Evans, 2003; Smith, Greenlee, Singh, Kraemer, & Hennig, 1998), whereas neural integration processes involved in perception of second order gratings are thought to occur in V2 and extra-striate visual area V3 (Dumoulin, et al., 2003; Smith, et al., 1998). Global motion perception has been associated with fMRI activation in extra-striate visual areas V5 and V3a, the ventral occipital surface, the intra-parietal sulcus and temporal structures, while global form perception has been associated with fMRI activations in the middle occipital gyrus, the ventral occipital surface, the intra-parietal sulcus, and the temporal lobe (Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000). The perception of second order gratings, global form and motion stimuli may engage not only primary visual area V1, but also V2 and the extra-striate visual areas, and would be more dependent on transmission of neural information between the functional visual cortical regions than perception of first order gratings would be. As suggested by Bertone et al (2005), individuals with ASD may have reduced transmission of neural information between these functional visual cortical regions which manifest as difficulties with visual stimuli requiring visuo-integrative processes (Bertone, et al., 2005).

On the other hand, increased lateral connectivity within primary visual area V1 in ASD may promote processing of orientation, though not so much direction-of-motion, of first order gratings. Lateral connections between V1 neurons have been proposed to shape

orientation selectivity in V1 neurons (Andrews, 1965; McLaughlin, Shapley, Shelley, & Wielaard, 2000; Shapley, Hawken, & Ringach, 2003). Computational model simulations of visual processing in V1 have demonstrated that increased neural connectivity within V1 i.e. between V1 neurons, may promote more efficient processing of orientation information of visual stimuli (Gustafsson, 1997). Direction-selective V1 neurons are not known to be as effective at discriminating direction-of-motion, as orientation-selective V1 neurons are at discriminating orientation of form stimuli (Albright, 1984; Pack & Born, 2001; Pack, Livingstone, Duffy, & Born, 2003; Wuerger, Shapley, & Rubin, 1996). Therefore, increased neural connectivity within the primary visual area V1 may result in enhanced orientation perception but not have an influence on motion perception of first order gratings.

There is no known *direct* evidence linking atypical neuro-connectivity with atypical visual perception of stimuli requiring different levels of engagement of the primary visual area V1, V2 and the extra-striate visual areas in ASD. Such direct evidence can be obtained using non-invasive neuro-imaging techniques such as EEG which measure scalp electrical activity produced by neural responses. Therefore, the neuro-physiological correlates of low level visual perception of stimuli requiring different levels of engagement of the different visual functional cortical regions, in children with ASD and TD children, are explored in chapters three and four. Chapter three investigated visual evoked potentials in children with ASD with the objective of determining if their deficits in perception of "complex" stimuli may be a result of atypicalities in the additional visuo-integrative processes required. Chapter four is a follow up on the data analysis conducted in chapter three and uses gamma power as a measure of local neuro-synchrony (von Stein & Sarnthein, 2000), to determine if children with ASD may show atypical neuro-connectivity within the visual cortical region.

1.8 Sub-cortical processes relating to low level visual perception in ASD

Sub-cortical visual pathways transmit visual information from the retina to primary visual area V1 (Merigan, et al., 1997; Merigan & Maunsell, 1993). There has been suggestion that the functioning of the sub-cortical magnocellular (M) and parvocellular (P) pathways may be compromised in ASD and consequently contribute to impaired global motion perception in ASD (Milne, et al., 2002). However, psychophysical studies that

measure M and P pathway functioning in individuals with ASD and TD controls reveal no evidence that individuals with ASD show atypical M pathway functioning (Bertone, et al., 2005; Davis, et al., 2006; Pellicano, Gibson, et al., 2005), and some evidence that they may have impaired P pathway functioning (Davis, et al., 2006, for negative findings see Bertone, et al., 2005). Chapter five re-visits the hypothesis that M and P pathway functioning may be atypical in ASD, using different test stimuli characteristics to tease apart the M and P pathway functioning from previous research. It also introduces a number of new psycho-physical measures for examining M and P pathway functioning, such as the balance of M and P pathway functioning, and the veracity of M and P pathways' contribution to the cortical visual motion areas, in order to conduct a thorough examination of M and P pathway functioning in ASD.

Finally, chapter six addresses a speculation that the local bias in visual perception in ASD may have a basis in atypical low and/or high spatial frequency visual mechanisms (Behrmann, Avidan, et al., 2006; Kemner & van Engeland, 2006; Milne, et al., 2002; Plaisted, et al., 1999), specifically that perception of low spatial frequencies may be impaired (Milne et al., 2002, Behrmann, Thomas et al., 2006) and that perception of high spatial frequencies may be enhanced (Boeschoten et al., 2007). Several studies have examined low and high spatial frequency mechanisms in ASD using psycho-physical techniques and clinical screening tools, but this may be the first study to map the entire spatial frequency contrast sensitivity function in individuals with ASD using a rigorous approach.

1.9 The scope of the thesis

In sum, chapters two to six in this thesis comprises a series of studies that examined vision in individuals with ASD at the cognitive level, the neuro-physiological level and the psycho-physical level. The data will enable issues relating to cultural modulation of ASD-related visuo-perceptual behaviours, the electrophysiological correlates of visual perception in ASD, M and P pathway functioning in relation to motion direction perception in ASD, and the functioning of low and high spatial frequency detectors in ASD, to be addressed.

2 Chapter Two –

The influence of culture on perceptual style in children with ASD and typically-developing children from Singapore and England

2.1 Introduction

As described in chapter one, individuals with ASD have shown weak central coherence (WCC) in visuo-spatial tasks such as the Embedded Figures Test (EFT) (Jarrold, et al., 2005; Jolliffe & Baron-Cohen, 1997; Pellicano, Gibson, et al., 2005; Ropar & Mitchell, 2001; Sang, et al., 2006; Shah & Frith, 1983), and the Block Design Task (BDT) (Caron, et al., 2006; Ehlers, et al., 1997; Ropar & Mitchell, 2001; Sang, et al., 2006; Shah & Frith, 1993; Siegel, et al., 1996), although this local bias in perceptual style has not been consistently replicated (for negative findings with EFT see Brian & Bryson, 1996; Burnette, et al., 2005; Ozonoff, et al., 1991, for negative findings with BDT see Burnette, et al., 2005; Ozonoff, et al., 1991). The mixed findings have led to speculations that there are only sub-groups of individuals with ASD who show WCC, albeit the proportion of the ASD population showing WCC may still be higher than in the neuro-typical population. Examination of how sub-groups with varying perceptual styles in ASD arise may reveal important information for a deeper understanding of heterogeneity in ASD.

The default perceptual style in neuro-typical individuals is known to be globally biased i.e. visual images are processed with respect to their global rather than local details (Kimchi, 1992; Navon, 1977, 1981). Individual differences in perceptual style within the neuro-typical population have been found, and this variability has been described using the term field-dependence i.e. the extent to which perception of a visual object is influenced by the context or field that the visual object exists in (Witkin, 1950; Witkin & Asch, 1948). Central coherence and field-dependence both describe global biases in visual perception, and have employed similar tasks such as the EFT for their assessment. These two terms can therefore be used inter-changeably. For simplicity, the rest of the chapter will describe perceptual style in terms of field-dependence, so the perceptual style in individuals with ASD will be described as "less field-dependent" than neuro-typical individuals.

In addition to individual variation within the neuro-typical population for field-dependence, recent research has highlighted differences in field-dependence between

individuals from distinct cultural backgrounds (Nisbett & Miyamoto, 2005). The general assumption is that individuals from collectivistic cultures, typically Asian countries such as China, Korea, Japan, Malaysia, show higher field-dependence which parallels their social cognitive tendency to attribute behaviour to the context or situation rather than the person; whereas individuals from individualistic cultures, typically Western countries such as United States, United Kingdom, Germany, show lower field-dependence as that parallels their social cognitive tendency to attribute behaviour to the person rather than the context or situation (Berry, 1991; Nisbett & Miyamoto, 2005; Norenzayan, Smith, Kim, & Nisbett, 2002; Witkin & Berry, 1975). However, while there is empirical evidence inline with this individualism/collectivism account for perceptual style (Hedden, et al., 2008; Ji, Peng, & Nisbett, 2000; Kitayama, Duffy, Kawamura, & Larsen, 2003; Kuhnen, et al., 2001), there are also studies that have indicated alternative cultural processes which have 'reversed' the perceptual style difference between participants from a collectivistic culture and an individualistic culture (Bagley, 1995; Davidoff, Fonteneau, & Fagot, 2008; de Fockert, Davidoff, Fagot, Parron, & Goldstein, 2007; Doherty, Tsuji, & Phillips, 2008). It is therefore suggested that different cultural experiences exert a collective influence on field-dependence, and it may be the dominant cultural experience that determines whether a person displays more or less field-dependence on visuo-spatial tasks.

The argument that cultural experiences influence field-dependence raises questions about how cultural experience may modulate the ASD-TD difference in field-dependence. Evidence for an interaction of culture on the ASD-TD difference would suggest the presence of external factor(s) capable of influencing the extent to which the ASD-related visuo-perceptual behaviour is displayed. Identification of those cultural processes will make known characteristics of the learning environment that may foster the strengths and weaknesses of an individual with ASD. Investigating cultural influences on perceptual style in ASD will also further understanding of how sub-groups of individuals with ASD who show different visuo-perceptual styles may arise. The current study takes the first step in this direction of research, and attempts to explore if there is any indication of a difference in the ASD-TD difference in perceptual style, between individuals from two different cultural climates. This is the first study to compare perceptual style in individuals with ASD and TD individuals cross-culturally. The following paragraphs will review cross-cultural studies on field-dependence in neuro-typical individuals, and discuss potential

cultural processes underlying those findings to aid in making predictions on results of this study.

The EFT has demonstrated lower field-dependence in individuals with ASD, and has been employed in cross-cultural studies on field-dependence. The EFT requires participants to discriminate a target shape within a more complex figure (Witkin, et al., 1971). Higher accuracy or shorter response times on the EFT indicate better dis-embedding abilities i.e. lower field-dependence. Consistent with the individualism/collectivism account for perceptual style, one study revealed adults from Russia and Malaysia which are collectivistic cultures to have lower accuracy on the EFT i.e. higher field-dependence than adults from the United States and Germany which are individualistic cultures (Kuhnen, et al., 2001). One study however found no group difference in EFT performance, between East Asian i.e. Chinese, Korean and Japanese adults which are collectivistic cultures, and American adults (Ji, et al., 2000). In direct contrast with the individualism/collectivism account for perceptual style, yet another study found children aged nine to eleven years from collectivistic Japan and China to have higher accuracy i.e. lower field-dependence than their counterparts from individualistic America, on the children's version of the EFT (CEFT) (Bagley, 1995). Please see Appendix for Table 8.3 (pg 162) which provides a summary of the results from these studies.

The superior CEFT performance of the East Asian children in Bagley (1995)'s study may be explained by their greater experience with pictograms[2] specific to East Asian written languages which may facilitate perceptual dis-embedding skills and promote performance on the CEFT/EFT (Bagley, 1995). Ji et al (2000)'s null finding could then be explained by an interplay between the individualism/collectivism influence, and the superior dis-embedding skills due to experience with East Asian characters. The former effect would increase field-dependence in East Asian adults compared to the American adults, while the latter effect would decrease field-dependence in East Asian adults compared to the American adults. As a consequence, no group difference in field-

[2] Each East Asian character has its own meaning, and is made up of a number of symbols each with their own sub-meaning. As dis-embedding is required for deciphering the sub-symbols within an East Asian character, experience with these characters may facilitate the user's ability to dis-embed parts of a figure from a more complex figure. However, no significant correlation was found between CEFT performance and Chinese literacy in the study that compared Chinese and American school-aged children (Bagley, 1995). Therefore, it remains to be proven if East Asian language literacy can have an influence on CEFT performance.

dependence was observed between the East Asian and American adults. Experience with East Asian characters may be an alternative cultural factor that can influence field-dependence. Moreover, being in a collectivistic culture and having experience with East Asian languages appears to have opposing effects on field-dependence. It remains to be established how the ASD-TD difference in field-dependence as assessed by the CEFT/EFT, would compare in children from cultures with different combinations of these two cultural factors.

The classic rod and frame task is another assessment of field-dependence, for which there is no known published data comparing individuals with ASD and TD controls, but has been employed in cross-cultural research on field-dependence. The task set-up consists of a rod attached to a frame, and participants are required to indicate when the rod is vertical while both the rod and the frame rotate freely. Better performance on the rod and frame task suggests lower field-dependence, as accurate judgement of the alignment of the rod requires the ability to ignore irrelevant contextual information i.e. the frame. Given that the rod and frame task is considered to be a measure of field-dependence, it could be predicted that individuals with ASD would be more accurate than TD controls, so demonstrating lower field-dependence on the task. On the other hand, consistent with the individualism/collectivism account for perceptual style, a cross-cultural comparison of performance on the rod and frame task revealed East Asian participants to be less accurate than American participants on the rod and frame task, suggesting higher field-dependence in the East Asian adults compared to the American adults (Ji, et al., 2000). Useful information about external modulation (if any) of ASD-related perceptual style, may therefore be obtained by comparing individuals with ASD and TD controls from Asian and Western cultures on the rod and frame task.

The Framed Line Task (FLT) is an improvement on the rod and frame task which comprises an "Absolute" sub-test and a "Relative" sub-test (Kitayama, et al., 2003). The test stimuli consist of drawings of a line within a frame. The Absolute FLT requires participants to reproduce the exact length of the line in a test stimulus, in a second frame that could be of a different size to the test frame. Similar to the rod and frame task, it measures a participant's ability to ignore irrelevant contextual information. The Relative FLT requires participants to reproduce a line in a second frame, in the same proportion as

the line is to the frame in the test stimulus. The Relative FLT measures instead, a participant's ability to use relevant contextual information. Performance data on this latter ability are not obtainable by the rod and frame task. Therefore, the FLT provides a more encompassing measure of field-dependence than the rod and frame task and may be a better task to compare individuals with ASD and TD controls from different cultural backgrounds on.

Kitayama et al (2003) compared Japanese and American adults on the Absolute and the Relative FLT, using the dependent variable of mean absolute difference in the length of line drawn by the participants, and the correct length of the line, for trials within the Absolute or the Relative FLT. This dependent variable is termed "absolute error" hence forth. American adults were found to have lower absolute errors than Japanese adults on the Absolute FLT, which suggests that the Americans were better at ignoring irrelevant contextual information i.e. lower field-dependence (Kitayama, et al., 2003, however see Zhou, Gotch, Zhou, & Liu, 2008 a similar study, for negative findings). On the contrary, the Japanese adults were found to have lower absolute errors than the American adults on the Relative FLT, which suggests that the Japanese were better at using relevant contextual information i.e. higher field-dependence (Kitayama, et al., 2003, see Zhou, et al., 2008 for negative findings).

In addition, there is developmental research on field-dependence conducted with Japanese and American four and five year olds, using the FLT (Duffy et al, unpublished as cited in Nisbett & Miyamoto, 2005). Both groups of four year olds performed better on the Relative FLT than the Absolute FLT, with no group differences elicited. However, the American five year olds showed better performance on the Absolute FLT than Japanese five year olds, suggesting that cultural differences in field-dependence may emerge after five years of age. It remains to be established how children with ASD will perform on the FLT. Comparing children with ASD and TD children above the age of five years old from different cultural backgrounds on the FLT, will elicit useful information about the external modulation (if any) of ASD-related perceptual style. Please also see the Appendix for Table 8.4 (pg 163) which provides a summary of the results from group studies that examined cultural differences in performance on the FLT and the rod and frame task.

The FLT appears to be a task that may be influenced by individualism/collectivism but not experience with East Asian characters. A further note is that the CEFT/EFT and the FLT may be assessing different perceptual processes that contribute to field-dependence. That the same sample of East Asian and American adults in Ji et al (2000) showed different patterns of performance for the EFT and the rod and frame tasks corroborates with that suggestion (Ji, et al., 2000). Obtaining data on CEFT/EFT and FLT performance in the same sample of participants may help clarify which cultural experiences acts on which aspect of field-dependence. A comprehensive examination of field-dependence in children from cultures with different combinations of individualism/collectivism and experience with East Asian characters may therefore involve administering the FLT in conjunction with the CEFT/EFT.

To elaborate on the point that the CEFT/EFT and the FLT may be tapping into different perceptual processes that contribute to field-dependence, factorial analyses have proven field-dependence to be a multi-factorial construct i.e. comprising different underlying perceptual processes (Carroll, 1993; Milne & Szczerbinski, 2009; Pellicano, Maybery, & Durkin, 2005). In particular, the CEFT/EFT was thought to be tapping into dis-embedding processes (Milne & Szczerbinski, 2009). Another task that has elicited lower field-dependence in ASD, and has been examined in these factorial analyses, is the Block Design Task (BDT). In the BDT, participants are presented with two-dimensional test designs that are created by arranging block-face units of a set of blocks into square matrices. Participants are asked to arrange block-faces of a set of blocks, to reproduce the pattern in the test design presented to them. Good performance on the BDT is suggested to be facilitated if one can visualize the test pattern in parts rather than as a whole, which would aid matching of the individual block-faces to parts of the test pattern. Results from the factor analyses suggest that the BDT assesses visualization i.e. the ability to manipulate an object in imagination – imagining an image as its parts (Milne & Szczerbinski, 2009). The rod and frame task and the FLT have however not been included in the factor analyses, so it is not known if they assess similar or different perceptual processes compared to the CEFT/EFT and the BDT. On the basis that the BDT assesses a different perceptual process from the CEFT/EFT, it may be a good task to use together with the CEFT/EFT and the FLT to examine cultural influences on field-dependence in ASD.

To summarize, the cross-cultural literature on field-dependence in neuro-typical populations have identified at least two cultural experiences e.g. individualism/collectivism and experience with East Asian characters, that can modify the level of field-dependence one displays in tasks such as the CEFT/EFT and the FLT. It is however, possible that field-dependence is not a unitary construct, and different cultural experiences can have different effects on the perceptual sub-processes underlying field-dependence. A comprehensive examination of cultural modulation on field-dependence in ASD may therefore involve assessing individuals with ASD and TD controls on a battery of field-dependence tasks that may be tapping into different perceptual processes underlying field-dependence. This study compared children with ASD and TD children from different cultural backgrounds on the CEFT, the FLT, and the BDT. The BDT employed in this study is a modified version of the BDT designed by Caron et al (2006), in which the test designs were manipulated on the level of perceptual cohesiveness (PC) (Caron, et al., 2006). Visualization of the test designs in parts for easy matching of block-face units to reproduce the test designs has been shown by Caron et al (2006) to be more difficult with test designs of high PC, than test designs of low PC.

By convenience, children with ASD and TD children were recruited from Singapore and England. Singapore is a country in South East Asia with a collectivistic culture, in contrast with England which is a Western nation with an individualistic culture. Previous research have reported that on the 100 point scale of the Individualism-Collectivism metric, Singapore obtained a low score of 20, whereas England obtained a high score of 89 (Arrindell, et al., 1997; Hofstede, 1983). Singapore and England also differ with respect to the ethnic composition of the population and languages used. Singapore has a population consisting of 76.8% Chinese, 13.9% Malay, and 7.9% Indian (Singapore Census of Population 2000). England on the other hand has a population of which 89.9% is Caucasian (UK Census of Population 2005). Singaporean children are typically bi-lingual in English and their mother tongue i.e. Chinese for the Chinese, Malay for the Malays and Tamil for the Indians, while the English children are mostly mono-lingual in English.

It is predicted that children with ASD in both countries would exhibit lower field-dependence than their TD counterparts in the same country on all tasks. However, based on Bagley (1995)'s finding, it is expected that the Singaporean TD children may perform

better than the English TD children on the CEFT. If so, the Singapore children with ASD may show a smaller CEFT advantage over the Singaporean TD children, than the English children with ASD compared to English TD children. With the FLT, it is predicted that the Singaporean TD children may perform worse than the English TD children on the Absolute FLT, but better on the Relative FLT. As a consequence, it may be expected that the Singaporean children with ASD would show a larger difference in performance on the FLT than the Singaporean TD children, as compared with the English children with ASD and TD children. Finally with the BDT, it is predicted that the Singaporean TD children would show a larger influence of increasing perceptual-cohesiveness as compared with the English TD children. Therefore, there may again be a larger ASD-TD difference in BDT performance for the Singaporean children than the English children.

2.2 Method

Participants

A total of 19 Singaporean children with ASD, 34 Singaporean TD children, 14 English children with ASD and 36 English TD children were recruited for the study. The children were recruited by advertising the study through mainstream schools in Singapore and South Yorkshire England. A university-wide email list for staff and students of The University of Sheffield United Kingdom, who were interested in being notified of research projects recruiting human participants, was also used to contact a number of English children. Informed consent was obtained from the children's parents before they were scheduled for a testing session. Participants received a SGD20 or a GBP5 gift voucher for their time spent on the project. The study protocol was reviewed and approved by the Data Administration centre, Ministry of Education Singapore, and The University of Sheffield United Kingdom, Department of Psychology Ethics Committee.

Of the Singaporean children with ASD, the majority were of Chinese ethnicity except for one child who was of Malay descent and another child who was of Indian descent. Of the Singaporean TD children, the majority were also of Chinese ethnicity except for one child who was of Malay descent and three children who were of Indian descent. The English children with ASD and TD children were of White ethnicity, except for one TD child who was of Chinese descent. All the participants were born and raised in their home countries and have not lived in another country for more than 6 months of their lives. All the participants also completed the assessments with normal or corrected to normal vision.

Psychometric Assessments

The Wechsler Abbreviated Scale of Intelligence (WASI) was used to obtain a measure of the participants' cognitive abilities. The WASI comprises four standardized sub-tests, but due to time constraints only the Vocabulary and the Matrix reasoning sub-tests, which examine expressive language and nonverbal fluid reasoning abilities, were administered. Raw scores from the two sub-tests were converted to T-scores which were comparable between different age ranges, and culminated in an IQ score (Full2IQ). The

WASI manual acknowledges the Full2IQ to be an adequate summary of a participant's cognitive functioning.

The Autism Diagnostic Observation Schedule (Lord, et al., 2000) was administered to the children with ASD to confirm the diagnoses. The ADOS is a semi-structured assessment of communication, social interaction, and play or imaginative use of materials. It consists of standardized activities to observe the participant for behaviours thought to be crucial for the diagnosis of autism. One of four modules was selected to conduct with a participant, based on the participant's age and level of expressive language. The ADOS cut-off score for ASD is 7.

Parents of all participants were asked to complete the *Life-time* Social Communication Questionnaire (SCQ) (Rutter, Bailey, Lord, & Berument, 2003) and the Social Reciprocity Scales (SRS) (Constantino, 2002). The SCQ consists of 40 'Yes/No' questions asking whether specific autism-related behaviours had ever been present in the child, and when the child was 4-5 years old. The SCQ cut-off score for ASD is 15. The SRS consists of 65 items to which parents rate how true the statements describe their child's behaviour in the past 6 months. There is no cut-off score for the SRS, but the published mean score for subjects with PDD-NOS is at 101.5, and with a standard deviation of 23.6 (Constantino, Przybeck, Friesen, & Todd, 2000). Both questionnaires aim to elicit information on social communication and interaction difficulties that the child in question may face.

The children with ASD from Singapore and England had been given formal diagnoses by external clinical or education professionals i.e. a clinical or educational psychologist or a paediatrician on the DSM-IV criteria (APA, 2004). Of the Singaporean children with ASD, eight had a diagnosis of Autistic disorder, two had Asperger's syndrome and five had an ASD. All the Singaporean children with ASD met the ADOS criteria for an ASD. Of the English children with ASD, three had a diagnosis of Autistic disorder, and nine had Asperger's syndrome. One English participant with ASD did not meet the ADOS cut-off for an ASD, but as he has a formal diagnosis of Asperger's syndrome and scored within one standard deviation of the mean score for PDD-NOS on the SRS, his data was not excluded.

Data were selected from children who had a Full2IQ of above 75. The TD children did not have first-degree relatives with a developmental condition or SCQ scores above the cut-off for an ASD. One Singaporean child with ASD had limited verbal abilities and did not complete the Vocabulary sub-test so a Full2IQ could not be computed for him. His standardized T-score of 45 for the WASI Matrix reasoning sub-test was in the average range, so his data was not excluded. The final sample therefore consisted of 15 Singaporean children with ASD, 30 Singaporean TD children, 12 English children with ASD and 29 English TD children. Please see Table 2.1 (pg 33) for a summary of the participants' characteristics. The four groups of children were matched on chronological age, Matrix reasoning sub-test T-scores and Full2IQ.

Table 2.1 Group characteristics of Singaporean and English, participants with ASD and TD participants.

	Singapore		South Yorkshire England		One-way ANOVA
	ASD (N=15)	TD (N=30)	ASD (N=12)	TD (N=29)	F & p values
Sex	15 boys	13 boys, 17 girls	12 boys	13 boys, 16 girls	
Ethnic composition	13 Chinese 1 Malay 1 Indian	27 Chinese 1 Malay 2 Indian	12 Caucasian	29 Caucasian 1 Chinese	
Chronological Age (months)					
Mean	119	121	130	121	F(3,82)=1.47, p=0.228
S.D.	11	15	15	16	
Range	100 – 137	96 – 149	103 – 153	99 – 147	
SCQ Score[+]					
Mean	18	5	21	4	F(3,64)=52.4, p<0.001[*]
S.D.	6	4	8	3	
Range	8 – 29	0 – 11	10 – 36	0 – 8	
SRS Score[+]					
Mean	70	47	89	56	F(3,63)=19.1, p<0.001[**]
S.D.	23	11	15	12	
Range	31 – 112	29 – 73	70 – 113	47 – 103	

ADOS Total					
Mean	10		8		
S.D.	2		2		
Range	7 – 14		5 – 12		
Vocabulary sub-test T-score					
Mean	43	47	51	54	F(3,81)=4.36, p=0.007***
S.D.	11	11	9	9	
Range	23 – 60	20 – 65	33 – 63	35 – 69	
Matrix Reasoning sub-test T-score					
Mean	51	57	53	52	F(3,82)=1.85, p=0.144
S.D.	12	10	7	9	
Range	29 – 71	21 – 71	35 – 62	34 – 68	
Full Scale IQ					
Mean	97	105	105	105	F(3,81)=1.44, p=0.237
S.D.	16	13	12	14	
Range	76 – 121	79 – 124	77 – 117	81 – 130	

Note.

+ Parents of 1 Singaporean child with ASD, 8 Singaporean TD children, 3 English children with ASD and 6 English TD children did not return the SCQ and SRS questionnaires. The parent of 1 Singaporean child with ASD returned only the SCQ questionnaire but not the SRS questionnaire.

[•] *Post-hoc Games Howell comparison revealed SCQ scores of Singaporean and English children with ASD were significantly higher than those of Singaporean and English TD children. The Singaporean and English ASD children were not scored differently from each other. Neither was the Singaporean and English TD children scored differently from each other.*

[••] *Post-hoc Games Howell comparison revealed SRS scores of Singaporean children with ASD were significantly higher than those of Singaporean TD children. The SRS scores of English children with ASD from ENG were significantly higher than those of Singaporean and English TD children. The Singaporean and English ASD children were not scored differently from each other. Neither was the Singaporean and English TD children scored differently from each other.*

[•••] *Post-hoc Games Howell comparison revealed Vocabulary T-scores of the English TD children to be significantly higher than the Singaporean children with ASD and TD children.*

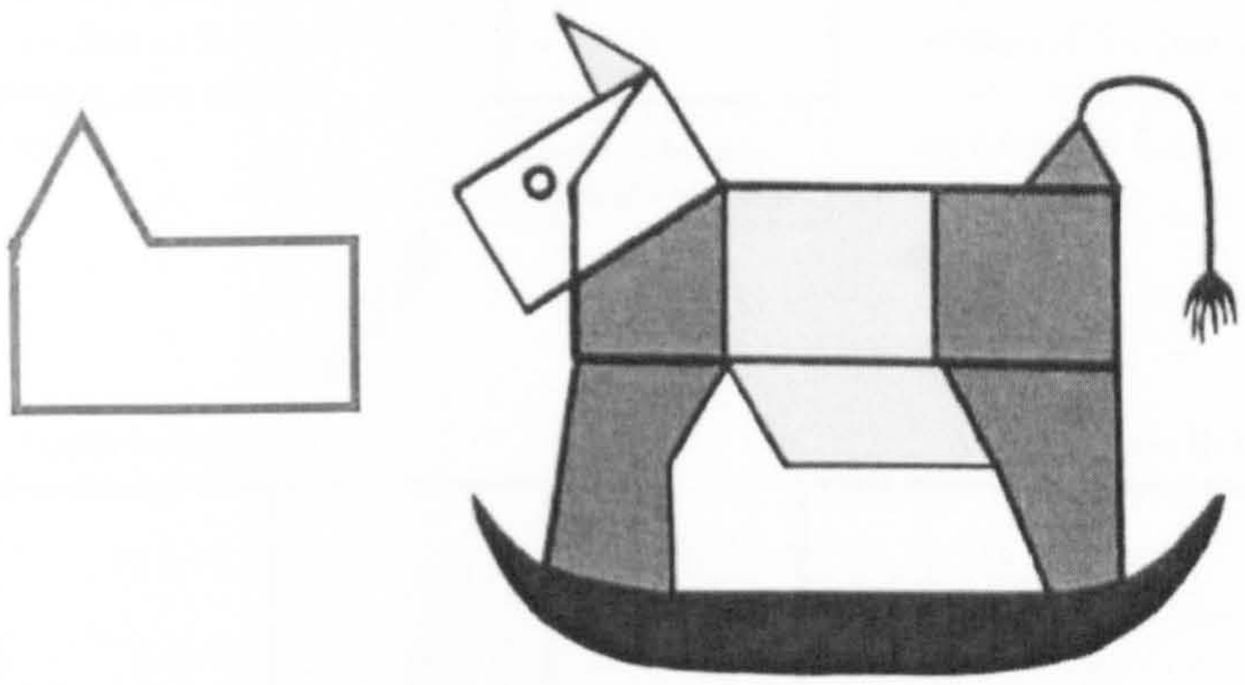
CEFT

The CEFT required participants to find target shapes that were embedded in more complex figures.

Stimuli

There were two sets of CEFT stimuli, namely the 'T' series and the 'H' series. The 'T' series (only 6 out of a total of 11 test cards) was administered as practice trials, while the 'H' series (a total of 14 test cards) provided the test trials. In the 'T' series, a triangle-shaped cardboard cut-out was the model for the target shape. In the 'H' series, a house-shaped cardboard cut-out was the model for the target shape. Figure 2.1 shows the target shape in the 'H' series on the left, and one of the test stimuli in the 'H' series on the right.

Figure 2.1 A test item from the CEFT 'H' series (from Witkin, et al., 1971).



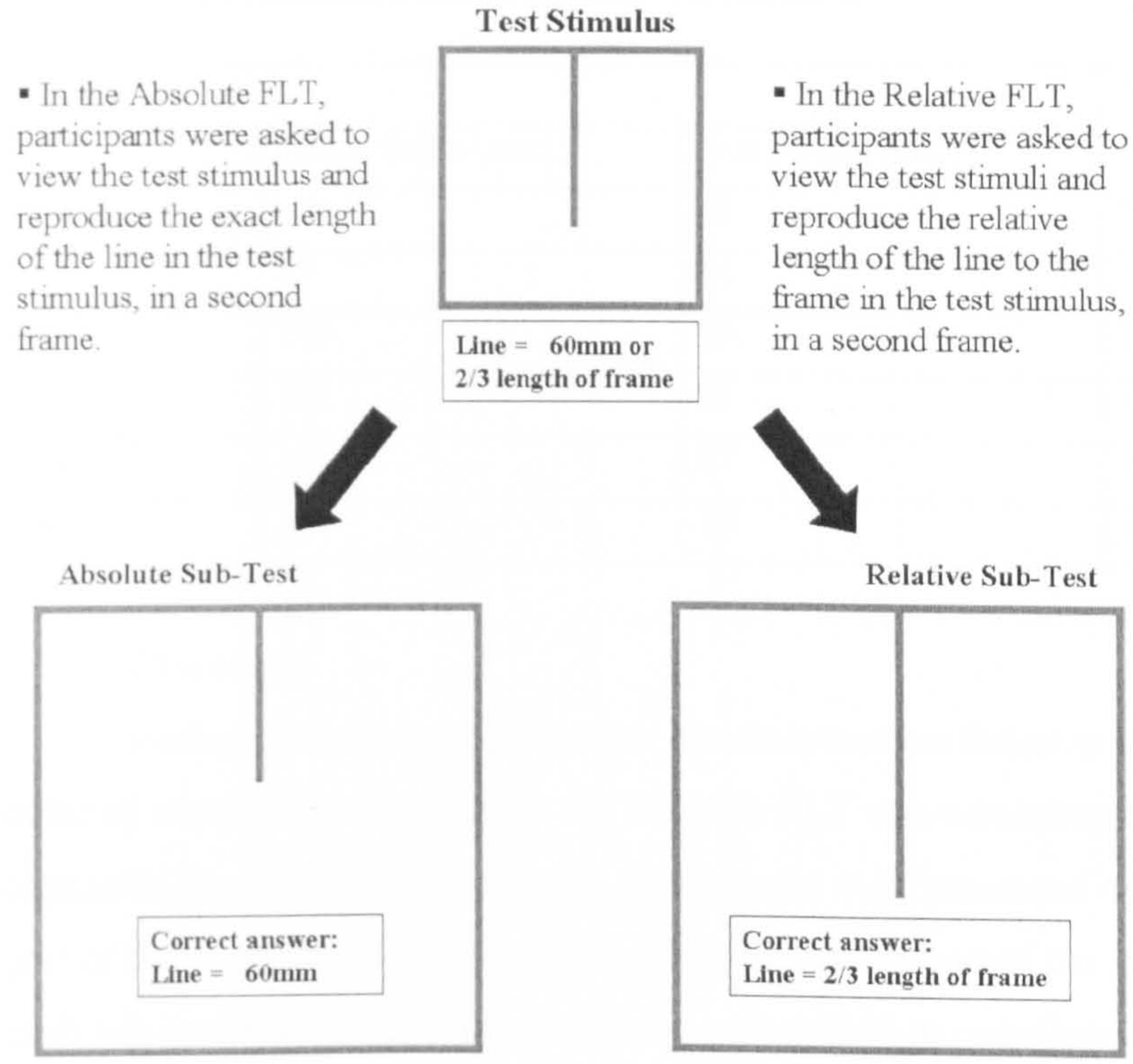
Procedure

The task was administered in accordance with instructions in the EFT manual (Witkin, et al., 1971). Participants were asked to find a target shape in a number of complex figures, and the 'T' series was administered before the 'H' series. Participants had a time limit of 120 seconds for each test card. The time taken in seconds for a participant to find the target shape in each complex figure was measured. The mean response time (RT) for correctly completed items and the total number of correct responses (ACC) for the CEFT 'H' series was calculated.

FLT

The FLT used by Kitayama et al (2003) was employed in the study. There was an Absolute sub-test and a Relative sub-test in the FLT. As shown in Figure 2.2, FLT test stimuli were computer-generated line drawings of a square frame with a line in it. In the Absolute FLT, participants were required to reproduce the exact length of a line in the test stimuli, in a second frame of the same or a different size. In the Relative FLT, participants were required to reproduce the relative length of a line in the test stimuli, in a second frame of the same or a different size.

Figure 2.2 The FLT test stimuli (adapted from Kitayama, et al., 2003).



Stimuli

The Absolute and the Relative FLT had five test trials each. The same set of test stimuli was used for both sub-tests. Test stimuli were presented on laminated sheets of paper. The second frame for each test stimulus was printed on paper, on which participants provided their answer by drawing free-hand with a marker pen. Five combinations of different relative lengths of the line to the frame, whose dimensions are shown in Table 2.2 (pg 38), were presented in random order within each sub-test. There were two test stimuli

with test frames smaller than the second frame, one had a line that was longer than half the length of the test frame (S-Lh), and the other had a line that was shorter than half the length of the test frame (S-Sh). There were another two test stimuli with test frames larger than the second frame, one had a line that was longer than half the length of the test frame (L-Lh), and the other had a line that was shorter than half the length of the test frame (L-Sh). There was a fifth test stimulus in which the test frame and the second frame were of the same dimensions (X), and would require the same answer in both the Absolute and the Relative FLT. An additional combination was used as the practice trial.

Table 2.2 Dimensions of practice and test stimuli in the FLT.

FLT			
Test Stimuli			Second Frame
Code	Frame length (mm)	Line Length (mm)	Frame length (mm)
Practice	126	63	150
S-Lh	87	62	177
S-Sh	110	29	154
X	132	55	132
L-Lh	154	87	110
L-Sh	177	30	87

Procedure

Each participant completed the Absolute and the Relative FLT successively. The order of whether the Absolute or the Relative FLT was administered first was counterbalanced across participants. Participants were presented with the test stimuli in one part of the room and then the second frame in another part of the room. Instructions for each sub-test were given and participants were asked to complete an example task, before the commencement of that sub-test. The example task was to make sure that the participants understood the instructions and involved the participants showing the assessor how the line in an example stimulus should be drawn in a frame that was smaller than the example frame, and in a frame that was bigger than the example frame. They were also given a practice trial in which feedback was given.

Lines drawn by the participants were measured, and the difference in length of the lines drawn by the participants and the correct length of the line was calculated. This

absolute error increased with the length of the correct line, as consistent with Weber's Law, perception of change in sensory stimulus intensity is sensitive to the proportional difference. Therefore performance was equated across all test stimuli by computing the percentage of the absolute error relative to the correct length (% error). Trials in which participants had a % error equal to or more than 67% were excluded from further analysis. This criterion was used to minimize the inclusion of trials in which participants lost track of what the task requirement was i.e. thinking that it was the Absolute task when it was the Relative task. Data from participants who had more than or equal to three trials that did not meet the criterion, were excluded. Mean % errors for the Absolute and the Relative FLT were obtained as averages of % error for the five test stimuli.

BDT

This study adopted the BDT used in Caron et al (2006). Participants were required to arrange block-faces of a set of identical blocks to recreate test designs presented to them. The test designs were created by using the block-faces as units, and could either be made up of four blocks in a two by two matrix, or nine blocks in a three by three matrix. There was an un-segmented condition in which the test designs were presented as a whole with the block-face units joined with each other. There was also a segmented condition in which the test designs were presented with gaps between the block-face units.

Stimuli

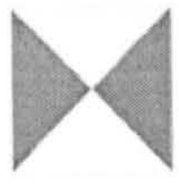
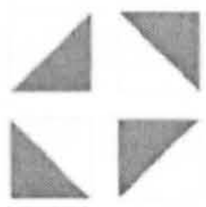
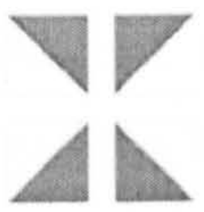
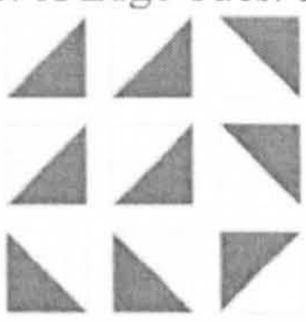
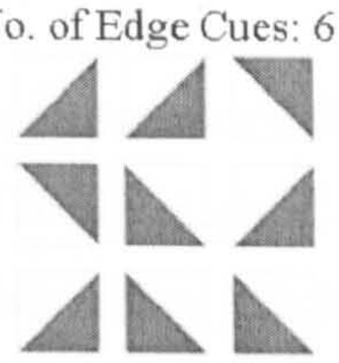
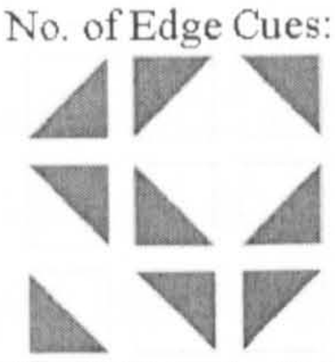
The test designs, as shown in Figure 2.3 (pg 41), were presented on laminated sheets. The test designs within each condition varied in perceptual-cohesiveness (PC). Test designs with zero PC had the maximum possible number of edge cues i.e. adjacent sides of block-face units that were of different colours, while test designs with maximum PC had zero edge cues. There were three levels of PC for each matrix size. The lowest, medium and highest PC levels in the four-block designs corresponded to four edge cues, two edge cues and zero edge cues respectively, and in the nine-block designs corresponded to twelve edge cues, six edge cues and zero edge cues respectively. There was one test design for each combination of matrix size and PC leading to six unique test designs. The same test designs were used in the un-segmented and the segmented condition, but in the segmented condition the original test designs were rotated by 90° or 180° and the block-face units

within the design were spaced 0.9 cm or 1/3 length of each block unit away from each other.

Procedure

Participants completed the un-segmented condition before the segmented condition to avoid facilitation effects. They also attempted the four-block designs before the nine-block designs within each condition. Test designs of different PC were presented in random order within designs of the same matrix size and within each condition. There was an example trial at the start of each condition in which participants were given verbal instructions and a demonstration on what to do. The participants were then asked to complete the example trial as practice. Completion time for each trial was measured in seconds. Participants were given a maximum of 120 seconds for four-block designs and a maximum of 180 seconds for the nine-block designs. As there may be individual differences and also group differences in the time that each child took to physically arrange the blocks in position, time needed to arrange four solid coloured block-faces into a two by two matrix, and time needed to arrange nine solid coloured block faces into a three by three matrix, were measured. These (baseline) times were subtracted from the trial completion time for designs with the corresponding number of blocks, to compute a construction time (CT) for each trial which is more representative of the time required by each participant to encode the test design and strategize how to complete the trial. Individual participants CTs for the same PC level were summed over four-block and nine-block test designs. This resulted in a total of six CT values from each participant, for the un-segmented and segmented condition and for the three PC levels, for further statistical analyses.

Figure 2.3 The BDT test stimuli.

	Perceptual Cohesiveness:		
	Low	Medium	High
Matrix Size: 4 block *Task:* Un-segmented	No. of Edge Cues: 4 	No. of Edge Cues: 2 	No. of Edge Cues: 0 
Matrix Size: 4 block *Task:* Segmented	No. of Edge Cues: 4 	No. of Edge Cues: 2 	No. of Edge Cues: 0 
Matrix Size: 9 block *Task:* Un-segmented	No. of Edge Cues: 12 	No. of Edge Cues: 6 	No. of Edge Cues: 0 
Matrix Size: 9 block *Task:* Segmented	No. of Edge Cues: 12 	No. of Edge Cues: 6 	No. of Edge Cues: 0 

2.3 Results

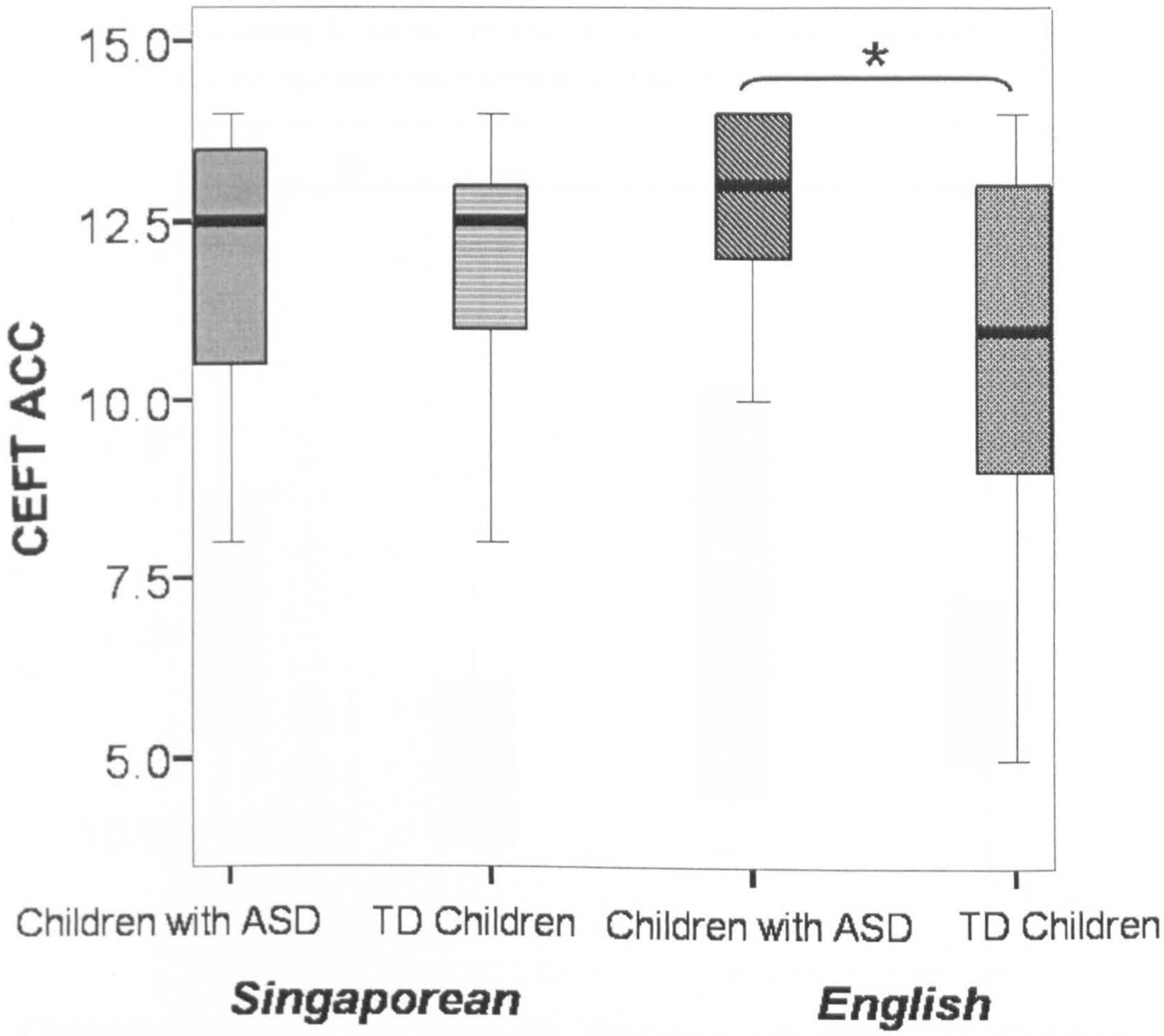
The significance level is set at 0.05 for 2-tailed tests. Effects sizes, where appropriate, are measured as the Pearson's Correlation coefficient, r. Effects sizes are considered to be small, medium and large for the r-values: 0.10, 0.30 and 0.50 respectively (Field, 2005b).

CEFT

Due to logistic difficulties, not all the Singaporean participants completed the CEFT. A total of 12 Singaporean children with ASD, 24 Singaporean TD children, 10 English children with ASD and 29 English TD children contributed to this sample. The CEFT ACC but not the RT violated assumptions of normality (Kolmogorov-Smirnov test: $p>0.011$). Both CEFT ACC and RT did not violate assumptions of homogeneity of variance (Levene's test: $F(3,71)<2.63$, $p>0.057$). Non-parametric Mann-Whitney *U* tests were used to examine between group differences for CEFT ACC and RT to enable comparison of results from both measures of CEFT performance.

As shown in Figure 2.4 (pg 43), there was a significant difference in ACC on the CEFT between the English children with ASD and the English TD children ($U=80.5$, $p=0.037$, $r=0.34$), and no other significant group differences ($U<239$, $p>0.154$, $r<0.20$). The English children with ASD showed higher accuracy on the CEFT than the English TD children, indicating that they were performing better on the CEFT i.e. displaying lower field-dependence than their TD counterparts.

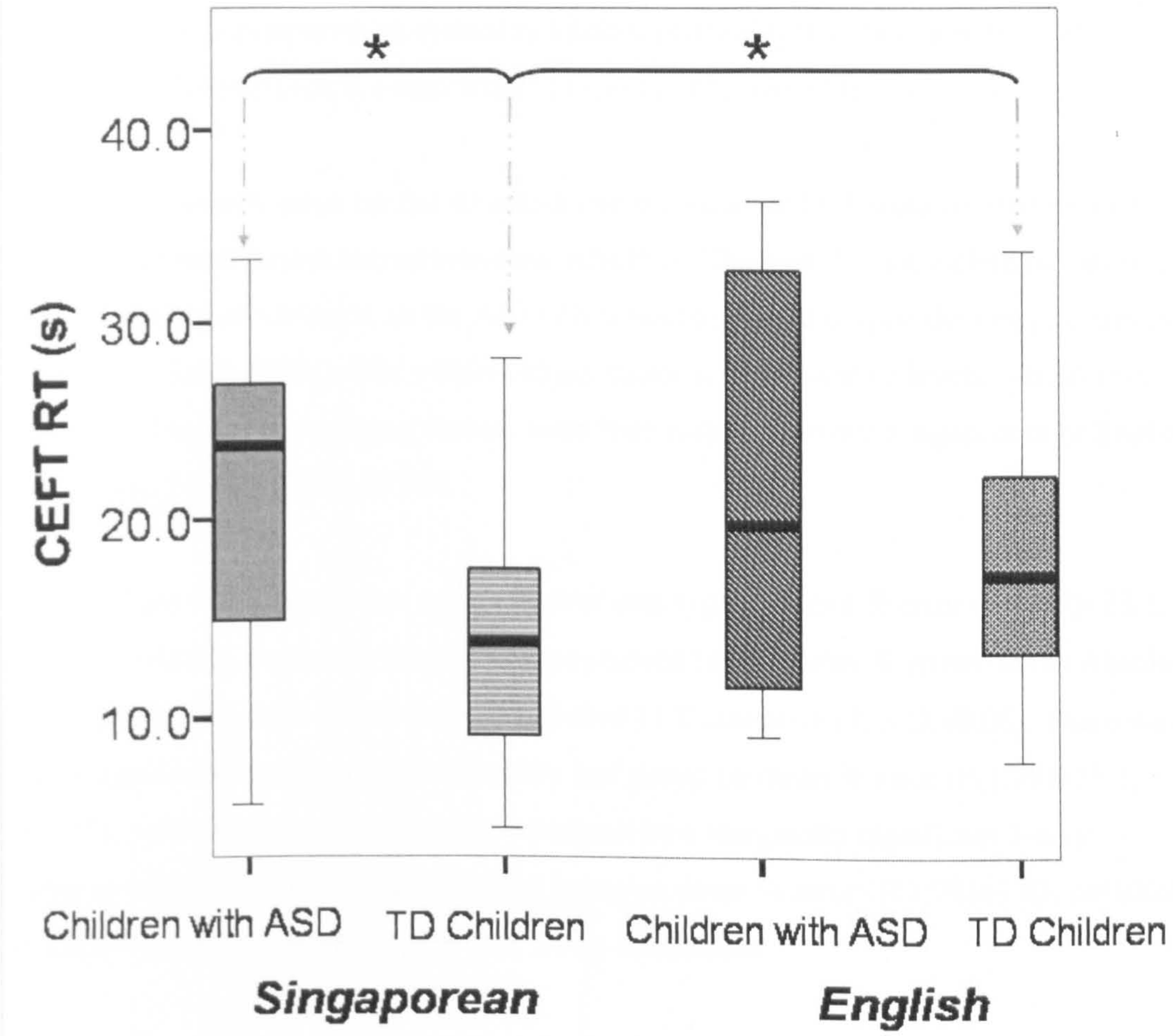
Figure 2.4 Box-plot depicting ACC on the CEFT for each group. Dark lines within the boxes indicate the median values, and error bars depict the inter-quartile range. The maximum score for the CEFT is 14, and *p<0.05.



As shown in Figure 2.5 (pg 44), there was a significant difference in RT on the CEFT between the Singaporean TD children and the Singaporean children with ASD (U=73.0, p=0.016, r=0.40), and also the English TD children (U=225.50, p=0.029, r=0.30). There were no other significant group differences in RT on the CEFT (U<137.0, p>0.118, r<0.27). Consistent with the study's initial predictions that were based on Bagley (1995)'s finding of superior CEFT performance in East Asian children compared to American children, the Singaporean TD children showed faster RT on the CEFT than the English TD children. However, contrary to previous ASD research on field-dependence, the Singaporean children with ASD showed slower RT on the CEFT than the Singaporean TD

children, indicating poorer CEFT performance i.e. higher field-dependence than their TD counterparts.

Figure 2.5 Box-plot depicting RT on the CEFT for each group. Dark lines within the boxes indicate the median values, and error bars depict the inter-quartile range. *p<0.05.



Overall, the CEFT findings provide preliminary evidence for an influence of culture on the ASD-TD difference in perceptual style, as the ACC results suggest lower field-dependence in the English children with ASD compared to the English TD children, and the RT results suggest higher field-dependence in the Singaporean children with ASD compared to the Singaporean TD children.

FLT

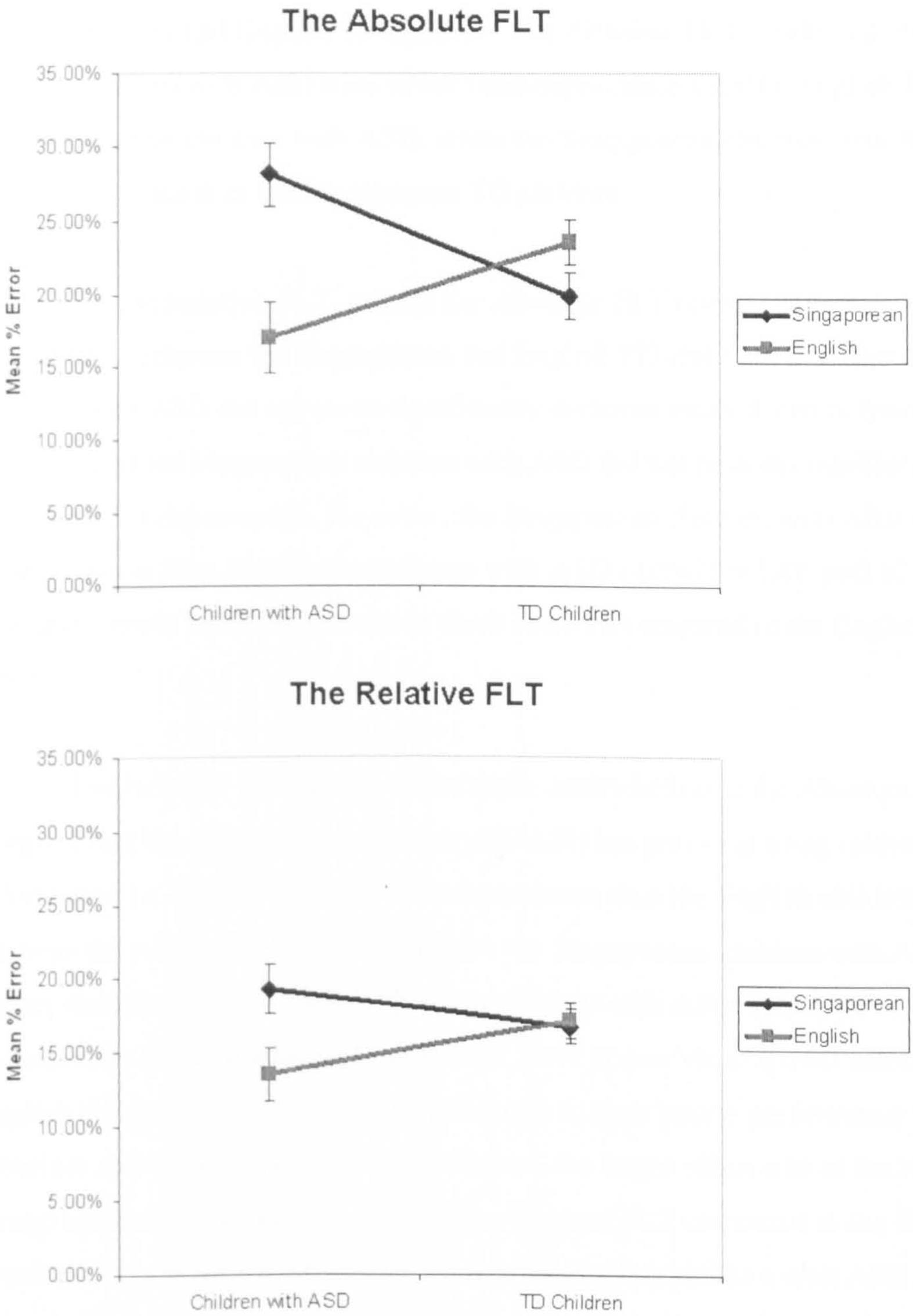
Data from two Singaporean TD children and one English TD child were excluded as they did not have more than three acceptable trials for the Absolute and the Relative FLT. A total of 15 Singaporean children with ASD, 28 Singaporean TD children, 12 English children with ASD and 28 English TD children contributed to this sample. The data did not violate assumptions of normality (Kolmogorov-Smirnov test: $p>0.099$) or homogeneity of variance (Levene's test: $F(3,79)<1.05$, $p>0.374$).

The mean % error for the Absolute and the Relative FLT were entered into a 1-within 2-between factors mixed measures ANOVA. The data did not violate the assumption of homogeneity of variance, so the ANOVA would be robust despite the unequal sample sizes used (Field, 2005a). The within-subject factor was Sub-test (2 levels: Absolute or Relative). The between-subject factors were Nationality (2 levels: Singaporean or English), and Group (2 levels: ASD or TD).

There was a significant main effect of task type on mean % error ($F(1,79)=23.2$, $p<0.001$, $r=0.48$), indicating that all groups showed higher mean % errors on the Absolute FLT (mean=0.22, S.D.=0.09) than the Relative FLT (mean=0.17, S.D.=0.06). There was also a significant interaction of nationality and group on mean % error ($F(1,79)=15.1$, $p<0.001$, $r=0.40$). However, this was subsumed by a marginally significant 3-way interaction between task, nationality and group on mean % error ($F(1,79)=3.63$, $p=0.060$, $r=0.21$). Figure 2.6 (pg 46) depicts this 3-way interaction.

2-between factors univariate ANOVAs were therefore applied separately to mean % error for the Absolute FLT and the Relative FLT. There was a significant interaction effect of nationality and group for both the Absolute FLT ($F(1,79)=14.0$, $p<0.001$, $r=0.39$), and the Relative FLT ($F(1,79)=4.23$, $p=0.043$, $r=0.23$), however the interaction effect of nationality and group for the Absolute FLT was larger than for the Relative FLT.

Figure 2.6 Line graphs showing three-way interaction between Task, Nationality and Group on FLT % error. Graph plots mean values and error bars indicate standard error of means.



Post-hoc analyses revealed that for the Absolute FLT, the English children with ASD showed *lower* mean % errors than the English TD children (t(df=38)=2.15, p=0.038, r=0.33). In contrast, the Singaporean children with ASD showed *higher* mean % errors than the Singapore TD children (t(df=41)=3.22, p=0.003, r=0.45). Furthermore, the Singaporean

children with ASD showed higher mean % errors than the English children with ASD (t(df=25)=3.34, p=0.003, r=0.56), while there were no differences in performance between the Singaporean and English TD children. The Absolute FLT results suggest that the English children with ASD have lower field-dependence than the English TD children and the Singaporean children with ASD, while the Singaporean children with ASD have higher field-dependence than the Singaporean TD children.

For the Relative FLT, as with the Absolute FLT results, there was no difference in performance between the Singaporean and English TD children. In addition, the English children with ASD did not show significantly different mean % errors from the English TD children, and the Singaporean children with ASD did not perform significantly differently from their TD counterparts. However, the Singaporean children with ASD showed higher mean % errors than the English children with ASD (t(df=25)=2.47, p=0.021, r=0.44), indicating lower field-dependence in these children compared to the English children with ASD.

The Relative FLT results are in slight contradiction to the Absolute FLT results as it suggests that the Singaporean children with ASD are poorer at using relevant contextual information i.e. a show of lower field-dependence than the English children with ASD, whereas the Absolute FLT results suggest the Singaporean children with ASD to have higher field-dependence than the English children with ASD. It may be argued that the Singaporean children with ASD in general, have poorer visuo-spatial abilities than the English children with ASD, which contributes to their poorer performance in both the Absolute and the Relative FLT. Nevertheless, the larger effect size of the Nationality and Group interaction on performance for the Absolute FLT compared to the Relative FLT provides support for the Absolute FLT that the English children with ASD may be better at ignoring irrelevant contextual information i.e. a show of lower field-dependence than the English TD children, while the Singaporean children with ASD may be poorer at ignoring irrelevant contextual information i.e. a show of higher field-dependence than the Singaporean TD children. Consistent with the CEFT results, the FLT results provide further evidence for an influence of culture on the ASD-TD difference in perceptual style.

BDT

Data from three Singaporean children with ASD, two Singaporean TD children and three English TD children were excluded as they did not complete the nine-block test designs. One further Singaporean child with ASD did not complete the baseline task (participant stacked the blocks instead of arranging the blocks to form a two by two or three by three matrix square), so his data was also excluded. A total of 11 Singaporean children with ASD, 28 Singaporean TD children, 12 English children with ASD and 26 English TD children contributed to this sample. The data violated assumptions of normality (Kolmogorov-Smirnov test: $p>0.002$) and homogeneity of variance (Levene's test: $F(3,73)<4.47$, $p>0.006$). Even so, the ANOVA was used in the examination of interaction effects as it is known to be robust towards these violations (Field, 2005a). However, as a precaution, non-parametric post-hoc analyses were carried out to ensure that any significant results in the ANOVA were not artefacts of the violation of assumptions.

The dependent variable CT was entered into a 2-within 2-between factors mixed measures ANOVA. The within-subject variable was Task (2 levels: Un-segmented or Segmented) and Perceptual Cohesiveness (3 levels: low, medium, or high). The between-subject factors were Nationality (2 levels: Singaporean or English), and Group (2 levels: ASD or TD). The green-house geisser correction was used when sphericity was violated. CT group means and standard deviations, for the un-segmented and segmented condition and for the three PC levels, collapsed over four-block and nine-block test designs, are presented in Table 2.3.

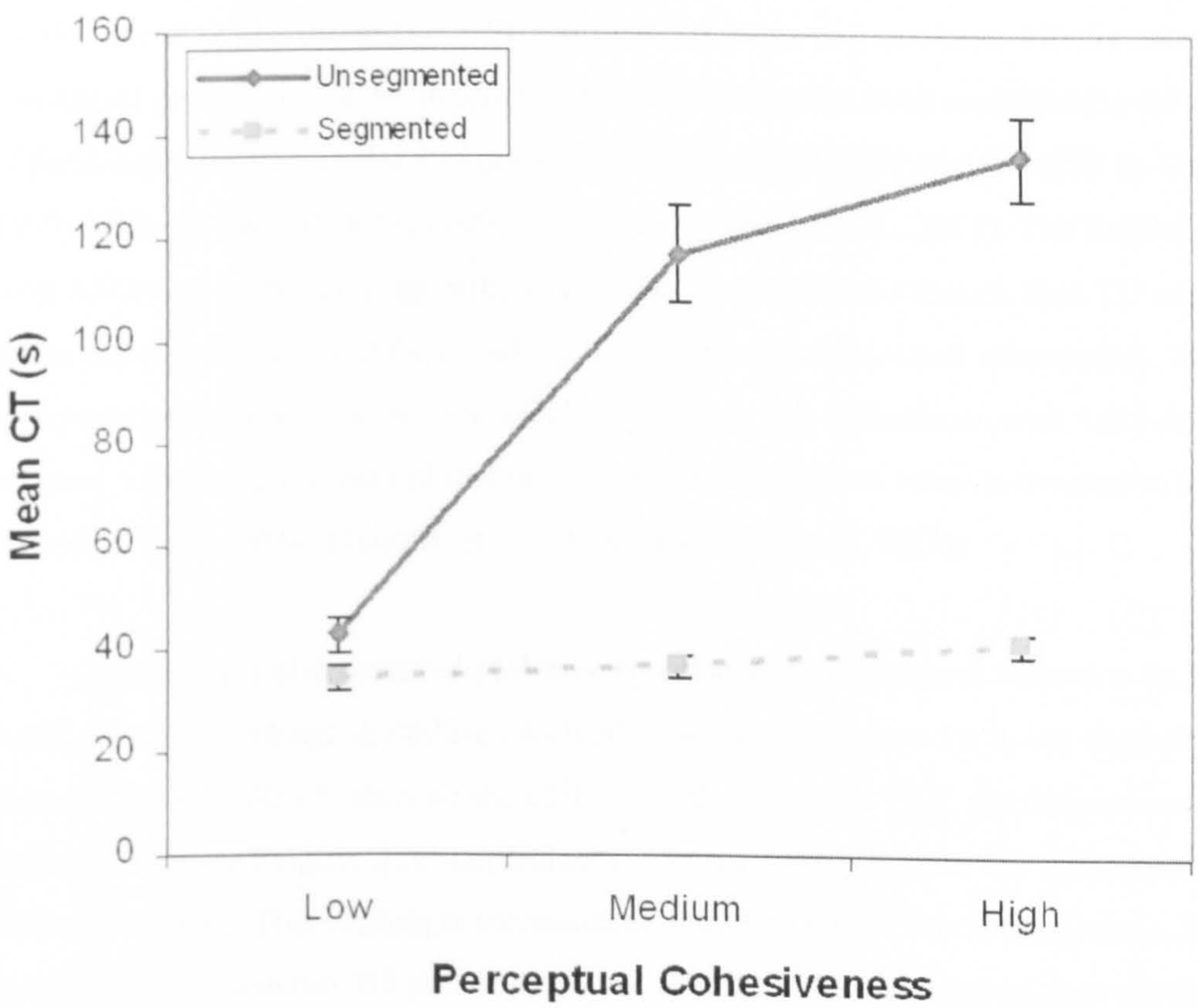
Table 2.3. CT (seconds) group means and standard deviations (in parentheses).

	Task Type					
	Un-segmented			Segmented		
	PC Level			PC Level		
	Low	Medium	High	Low	Medium	High
Singaporean ASD	53.8 (54.3)	96.2 (79.2)	117.8 (77.8)	29.3 (17.5)	34.1 (25.0)	34.9 (23.1)
Singaporean TD	31.0 (15.8)	98.0 (82.0)	136.0 (79.0)	28.0 (13.9)	29.9 (13.3)	36.9 (19.0)
English ASD	51.3 (38.2)	128.0 (82.9)	151.3 (57.8)	44.1 (15.3)	45.0 (18.3)	53.2 (20.6)
English TD	47.4 (24.4)	141.5 (78.7)	137.2 (70.1)	39.9 (23.7)	41.9 (20.3)	42.7 (19.1)

There were significant main effects of task type ($F(1,73)=130$, $p<0.001$, $r=0.80$), perceptual cohesiveness ($F(2,146)=69.0$, $p<0.001$,$r=0.70$) and a significant interaction of task type and perceptual cohesiveness ($F(2,146)=49.1$, $p<0.001$, $r=0.64$). The children had longer mean CTs for the un-segmented condition than the segmented condition ($T=0.0$, $p<0.001$, $r=0.61$). As shown in Figure 2.7, the children also displayed longer CTs for test patterns of the highest PC than the medium PC and the lowest PC ($T<62.5$, $p<0.001$, $r>0.59$), and also for test patterns of the medium PC than the lowest PC ($T=823.5$, $p=0.001$, $r=0.27$). The interaction of task type and perceptual cohesiveness was driven by there being a larger significant effect of PC within the un-segmented condition ($\chi^2(2)=103.1$, $p<0.001$), than the segmented condition ($\chi^2(2)=9.77$, $p=0.007$).

The significant interaction of task type and perceptual cohesiveness suggested that the experimental manipulation was successful. However, no cultural or ASD-TD differences in BDT performance were observed.

Figure 2.7 Line Graph depicting two-way interaction of Task and Perceptual Cohesiveness on CT for the BDT. Graph plots mean values and error bars indicate standard error of means.



2.4 Discussion

The study presents findings from an evaluation of field-dependence between children with ASD and TD children, from Singapore and England, on the CEFT, the Absolute FLT, the Relative FLT and the BDT. This is the first study to compare participants with ASD and TD controls on field-dependence using the Absolute and the Relative FLT. Most importantly, this is also the first cross-cultural comparison of field-dependence in children with ASD and TD children using the CEFT, the Absolute and Relative FLT and the BDT.

The results showed that the English children with ASD demonstrated lower field-dependence or weak central coherence (WCC) on the CEFT and the Absolute FLT, when compared with the English TD children. These findings are consistent with that of previous research that have elicited WCC in children with ASD on different visuo-spatial tasks, a majority of which were conducted in Western nations (Happé & Frith, 2006). WCC in ASD was however not replicated in the English children with ASD and English TD children on the BDT, and not elicited with the Relative FLT. The discrepancy in ASD-TD difference for the Absolute and the Relative FLT suggests that the two sub-tests may be assessing perceptual processes that are independent of each other but both contribute to the construct of field-dependence (similar to suggestions for the CEFT/EFT and the BDT by Carroll, 1993; Milne & Szczerbinski, 2009; Pellicano, Maybery, et al., 2005). The English children with ASD may be better at ignoring irrelevant contextual information than TD controls, but are as capable as TD controls at making use of relevant contextual information. This latter interpretation is consistent with research suggesting that individuals with ASD do not have an issue with using relevant global or contextual information when instructed to do so (Ozonoff, et al., 1994; Plaisted, et al., 1999; Rinehart, et al., 2000).

The results also revealed preliminary evidence for a cultural influence on WCC in ASD, as while the English children with ASD showed evidence for lower field-dependence than the English TD children on the CEFT and the Absolute FLT, the Singaporean children with ASD showed higher field-dependence than their Singaporean TD counterparts on these same tasks. This finding is inconsistent with the study's initial predictions, as even though the Singaporean TD children showed better CEFT performance than the English TD

children as indicated by the RT results, in accordance to Bagley (1995), it was expected that the Singaporean children with ASD would still show lower field-dependence than the Singaporean TD children, albeit the ASD-TD difference would be smaller than for the English children. Instead, the Singaporean children showed an ASD-TD difference in perceptual style in a "reversed" direction to that observed in the English children. The following paragraphs will first address the null finding of WCC in ASD on the BDT, and then discuss the finding of a cultural influence on the ASD-TD difference in field-dependence.

Contrary to previous research, neither superior performance of individuals with ASD on the BDT, nor a lesser difference between the un-segmented and the segmented condition in the individuals with ASD compared to TD controls (as found in Caron, et al., 2006; Ehlers, et al., 1997; Ropar & Mitchell, 2001; Sang, et al., 2006; Shah & Frith, 1993; Siegel, et al., 1996, for negative findings see Burnette, et al., 2005; Ozonoff, et al., 1991), nor a smaller influence of perceptual-cohesiveness on BDT performance in the individuals with ASD compared to the TD individuals (as found in Caron, et al., 2006), were replicated in this study. It is possible that the lack of group differences observed on the BDT is due to a couple of methodological issues with the BDT in this study. Firstly, it was not determined if the sample of children with ASD in this study had BDT peaks in their cognitive profile or not. Caron et al (2006)'s study only found superiority in BDT performance for participants with ASD who were identified to have BDT peaks in their cognitive profile, compared to TD participants who were not identified to have BDT peaks. This difference in BDT performance was not present when the ASD performance was compared to TD participants who were identified to have BDT peaks. The present data cannot provide evidence for the presence or absence of the BDT peak in cognitive profiles of the children, as only two of the four standardized sub-tests in the WASI were administered, excluding the Block Design sub-test. The prevalence of a BDT peak in the cognitive profile i.e. better performance on the BDT relative to performance on other cognitive tasks was estimated to occur in only 22-38% of the high functioning ASD population (Siegel et al, 1996). The lack of an ASD-TD difference on BDT performance in this study may therefore be because the sample of children with ASD did not have BDT peaks in their cognitive profiles. Future attempts to examine BDT performance in ASD could group participants with ASD and without ASD based on presence or absence of a BDT peak in their cognitive profile as Caron et al (2006)

have done. This procedure will produce sub-groups of participants with ASD and TD participants that are more homogenous, and make data on their performance on the various field-dependence tasks more easily interpretable.

Secondly, the BDT used in this study may have been unsuitable for attempting to elicit group differences and interactions of group with levels of perceptual cohesiveness of the test designs, for children eight to twelve years old. This study's BDT was modelled after the BDT used in Caron et al (2006)'s study, and are both different from the BDT utilized in other studies (Ehlers, et al., 1997; Shah & Frith, 1993; Siegel, et al., 1996) in that the level of perceptual cohesiveness of the test designs was manipulated. What is different between the BDT used here and the BDT in Caron et al (2006)'s study, is that the latter was pitched at the level of adolescents and adults, while the participants in this study were between the ages of eight and twelve. Caron et al (2006)'s study used three matrix sizes for their test designs i.e. two by two, three by three, and four by four matrix size test designs, so this study attempted to make the task more achievable for eight to twelve year olds, by excluding the largest matrix size, using only two by two and three by three matrix size test designs. Even so, the BDT may still be too complex for these children, requiring of them cognitive processes that are not fully developed at their age. If so, the BDT may have been as difficult for the children with ASD as the TD children at higher levels of perceptual cohesiveness and would have masked any advantage of WCC in the children with ASD when compared with the TD children. This undesirable situation in exacerbated by there only being three levels of perceptual cohesiveness i.e. lowest, medium, highest used, with huge changes in difficult for the children between those levels. A possible re-design of the BDT for children eight to twelve years old might include more test designs at intermediate levels of perceptual cohesiveness.

The present findings suggest that WCC in ASD may not be culturally universal, and justifies greater emphasis on research on low level visual perception in ASD, rather than the higher perceptual processes, for the objective of unravelling fundamental differences between individuals with ASD and TD individuals. The Singaporean TD children showed better performance on the CEFT than the English TD children, as predicted by the notion that experience with East Asian characters facilitates dis-embedding abilities. However, contrary to predictions by the individualism/collectivism account for perceptual style, there

was no cultural difference in FLT performance for the Singaporean and English TD children. The Singaporean children with ASD also did not show a lower field-dependence than the Singaporean TD children on the CEFT, as a study conducted with Chinese children in Shanghai found (Sang, et al., 2006). It may be clear from the data in this study that there can be cultural influences on the ASD-TD difference in field-dependence. However, considering the discrepancies with the initial predictions of the study's results that assumed effects of individualism/collectivism and the experience with East Asian characters on field-dependence, it is unclear what cultural processes may underlie the observed interaction of cultural environment and ASD. Future research would benefit from obtaining field-dependence measures in conjunction with quantifiable data on the extent of enculturation i.e. degree to which the participants assimilate information about their culture (Suinn, Ahuna, & Khoo, 1992), and also cultural factors such as individualism/collectivism, schooling style, and language, for understanding aspects of the cultural environment that may contribute to variation in perceptual style.

Nevertheless, a speculative account of how interaction of cultural experiences and ASD on field-dependence arises can be suggested for further verification. The account uses the enhanced perceptual functioning (EPF) model (Mottron, et al., 2006), which proposes that individuals with ASD have different dominant cognitive processes from TD individuals. More specifically, it may be that individuals with ASD are more perceptually driven i.e. show dominance of lower level perceptual processes in comparison with higher level cognitive functioning, and that TD individuals are more conceptually-driven i.e. show dominance of higher level cognitive processes compared to lower level perceptual processes. Different dominance cognitive processes in individuals with ASD and TD individuals may mean that these individuals are strongly influenced by different aspects of the same culture, leading to these individuals displaying varying levels of field-dependence. For example. a recent study found evidence that cultural differences in the perceptual environment can influence individuals' pattern of attention (Miyamoto, Nisbett, & Masuda, 2006). In the study, scenes from Japanese cities were rated to be more ambiguous and crowded than scenes from American cities. It was found that both Japanese and American participants if primed with Japanese scenes in a change-blindness task attended more to changes in the context/background, but if primed with American scenes attended more to the salient object changes. It was suggested that there were characteristics of scenes from

Japanese cities that can support processing of contextual information and promote field-dependence more so than scenes from American cities. No ratings have been done on the physical environment in Singaporean and England. However if Singapore's and England's physical environments is assumed to be similar to Japan's and America's physical environments respectively, and that the children with ASD from both Singapore and England are conditioned more by the external perceptual environment than the TD children, the children with ASD may adopt disparate perceptual styles as dictated by their different physical environments. The Singaporean children with ASD would be more likely to show higher field-dependence, and the English children with ASD would be more likely to show lower field-dependence. Also, assuming that the TD children are more conceptually-driven, the Singaporean and English TD children may be more influenced by differences in their learning environment i.e. what and how subjects are taught in school, than the children with ASD. There is no actual data on how the schooling environment in Singapore and England may differ from each other, but the presence of differences may lead to TD children from the two countries showing varying levels of field-dependence. Moreover, the Singaporean TD children may benefit more than the Singaporean children with ASD from a specific learning environment that fosters dis-embedding abilities and the ability to ignore irrelevant contextual information, which resulted in them showing lower field-dependence than their ASD counterparts. It has not been established if the physical environment and schooling environment can influence field-dependence, but the above illustration suggests how the interaction of cultural experience and ASD on field-dependence may occur. Further research is required to examine these claims.

Conclusion

The present findings suggest that WCC in ASD may not be culturally universal, and justifies greater emphasis on research on low level visual perception in ASD, rather than the higher perceptual processes, for the objective of unravelling fundamental differences between individuals with ASD and TD individuals. It is unclear what cultural processes may underlie the observed interaction of the cultural environment and ASD, but it is hoped that with further investigation, these cultural processes can be identified, and characteristics of the external environment that may foster strengths and weaknesses of individuals with ASD and TD individuals may be elucidated.

3 Chapter Three –

Electrophysiological correlates of low level visual perception in ASD: Visual Evoked Potentials elicited by parallel and hyperbolic, first and second order gratings

3.1 Introduction

Children and adolescents with ASD have been found to have atypicalities in low level visual perception. As reviewed in chapter one, there is evidence that individuals with ASD exhibit deficits in perception of orientation and direction-of-motion of second order gratings (Bertone, et al., 2003, 2005), global motion in RDK and motion Glass patterns (Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000; Spencer & O'Brien, 2006) and global form in Glass patterns (Spencer & O'Brien, 2006). Individuals with ASD have also shown superior discrimination of orientation and intact discrimination of direction-of-motion of first order gratings (Bertone, et al., 2003, 2005).

Perception of first order gratings require processes that can detect changes in luminance i.e. contrast. These contrast detecting processes are thought to occur in the primary visual area V1 (Dumoulin, et al., 2003; Smith, et al., 1998). Perception of second order gratings require in addition to contrast detection, integration of those local contrast signals for the overall pattern to be perceived (Larsson, Landy, & Heeger, 2006). These integration processes have been thought to occur in the primary visual area V2 and extra-striate visual area V3 (Dumoulin, et al., 2003; Smith, et al., 1998). RDK, motion and form Glass patterns require either or both local and global integration for global motion or form to be perceived. Global motion and form perception are thought to involve neural processes occurring in the extra-striate visual areas (Braddick, et al., 2000). It was therefore suggested that individuals with ASD may have general visual difficulties with "complex" stimuli i.e. stimuli which require visuo-integrative processes, and that these processes may be atypical in ASD (Bertone, et al., 2003, 2005). This suggestion is based however only on behavioural evidence, where behavioural responses are only end measures of a series of perceptual and responses processes (Luck, 2005b). The behavioural evidence for deficits in perception of second order stimuli, global motion and form stimuli in ASD can only be an indirect indication of atypical visuo-integrative processes in ASD.

Visual evoked potentials (VEP) may be a more appropriate measure for assessing low level visual processes than behavioural responses. Previous research has also found VEP indicators of visuo-integrative processes associated with "complex" stimuli (Allison, Puce, Spencer, & McCarthy, 1999; Ellemberg, Lavoie, et al., 2003). The following paragraphs will describe the advantages of VEP as a measure of low level visual processes and review the research that have found VEP "markers" of visuo-integrative processes.

VEP are event-related potentials (ERP) elicited by visual stimuli. VEP are extracted from electroencephalograms by averaging segments of electroencephalography (EEG) recordings produced in response to visual stimulation. EEG measures scalp electrical activity produced by neural activity. It is able to record neural processing of stimuli without the person making an overt response, and allows online monitoring of neural activity related to the presentation of a visual stimulus. Neural activity associated with different stages of visual processing prior to behaviour responses to visual stimuli can therefore be captured by EEG. EEG is also particularly suitable for assessing low level visual perception because it has temporal resolution in the order of milliseconds, so can detect changes in neural activity due to perceptual processes that occur within the first few hundred milliseconds of stimulus onset.

VEP are commonly extracted from EEG recordings from posterior electrode regions which approximate neural activity within the visual cortex, such as Oz (international 10-10 electrode system). The VEP waveform consists of a series of positive and negative deflections which are referred to as VEP components. VEP components are thought to reflect neural activity that is generated within the visual cortex and can reflect different stages in visual perception (Luck, 2005b). The peak amplitude of a VEP component quantifies the amount of neural response to visual stimulation, while the peak latency quantifies the timing of that neural response. A VEP component with a large peak amplitude and a short peak latency can indicate a large amount of neural processes being devoted to the perception of a presented stimulus, within a short amount of time.

VEP elicited by parallel first order and second order moving sinusoidal gratings have been investigated in neuro-typical adults (Ellemberg, Lavoie, et al., 2003). The VEP had a classic tri-phasic waveform that comprised of three VEP components P1, N1 and P2.

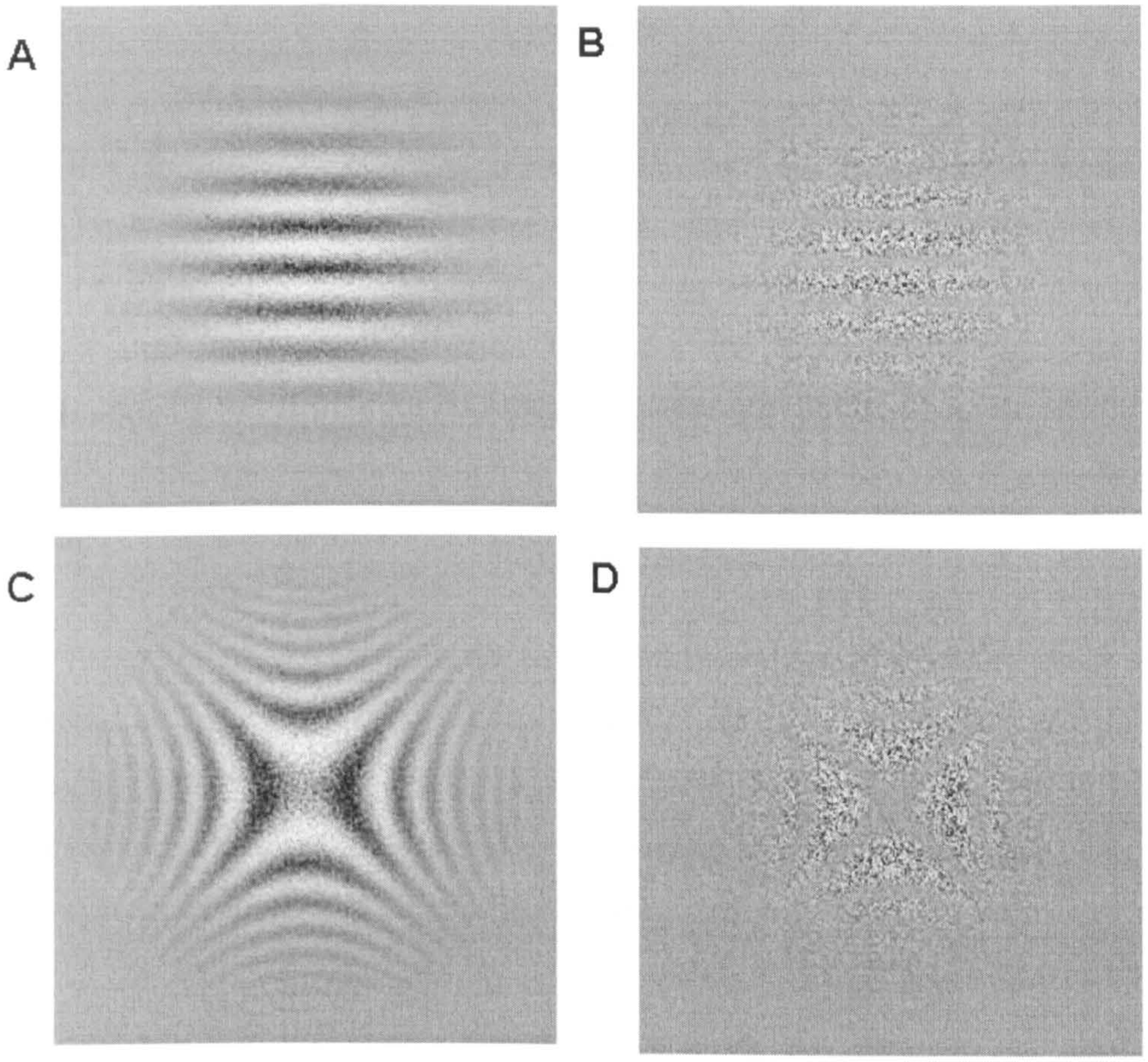
P1 and P2 refer to the first and second positive deflection post-stimulus onset respectively, while N1 refers to the first negative deflection post-stimulus onset (Luck, 2005b). VEP elicited by second order gratings were found to have longer P1 and N1 latencies than the VEP to first order gratings. The longer VEP component latencies to second order gratings were thought to reflect the occurrence of additional visuo-integrative processes required for the perception of the second order gratings. Thus, ASD-TD differences in VEP latencies to second order gratings relative to first order gratings may reflect atypicalities in the additional visuo-integrative processes for perception of second order gratings in ASD.

There is another class of low level visual stimuli which require neural processes in addition to those provided by the primary visual area V1 - non-cartesian stimuli such as concentric, radial and hyperbolic sinusoidal gratings (Gallant, Braun, & Van Essen, 1993; Gallant, Connor, Rakshit, Lewis, & Van Essen, 1996; Hegde & Van Essen, 2000, Gallant, Shoup, & Mazer, 2000; Wilkinson, et al., 2000). Non-cartesian gratings are thought to require intermediate form processes, and to activate the extra-striate visual areas V2 and V4 more so than V1 (Gallant, et al., 1993; Gallant, et al., 1996; Hegde & Van Essen, 2000, Gallant, et al., 2000; Wilkinson, et al., 2000). VEP elicited by parallel, concentric, radial and hyperbolic first order gratings, have been examined using intra-cranial recordings (during brain surgery) from the visual cortex, in adults with epilepsy who do not have known pathology within their visual cortex (Allison, et al., 1999). The participants' averaged N1 was found to be larger for hyperbolic gratings than for parallel gratings (Allison, et al., 1999). There is no published data on perception of hyperbolic gratings in ASD. Nevertheless, ASD-TD differences in the N1 component amplitude to hyperbolic gratings relative to parallel gratings may reflect atypicalities in the additional visuo-integrative processes required for perception of hyperbolic gratings.

Therefore, this study investigated VEP in children with ASD and TD children. Stimuli used to elicit the VEP were parallel first order, parallel second order, hyperbolic first order and hyperbolic second order gratings. The gratings used in the study are shown in Figure 3.1 (pg 58). It is predicted that if the children with ASD have atypicalities in visuo-integrative processes required for second order gratings, they would show shorter/longer VEP latencies to second order gratings *relative to* first order gratings, than the TD controls. Also, if the children with ASD have atypicalities in visuo-integrative

processes required for the hyperbolic gratings, they may show a less defined N1 component to hyperbolic gratings *relative to* parallel gratings, when compared with TD controls.

Figure 3.1 Parallel and hyperbolic, first and second order sinusoidal gratings.



A: Parallel first order grating; **B:** Parallel second order grating; **C:** Hyperbolic first order gratings; **D:** Hyperbolic second order grating

3.2 Method

Participants

A total of 23 typically-developing (TD) children and 13 children with ASD were recruited for the study. A university-wide email list for staff and students interested in being notified of research projects recruiting human participants was used to contact all the TD children and 3 of the children with ASD. An existing list of participants from a previous study was used to contact 10 of the children with ASD. Informed consent was obtained from the children's parents prior to the start of the study. A £10 book voucher was presented to the children as a token of appreciation. The study protocol was consistent with previous research practices within the research group and was also approved by the University of Sheffield Ethics committee. The total testing session lasted between one and two hours.

Parents were asked if their children have had vision tests and if any vision problems (e.g. strabismus, double-vision) were reported. All participants in the ASD group were given vision tests by a trained orthoptist, and no previously unreported vision problems were identified. There were two TD participants who did not have vision tests, but they had no known vision problems. All participants had normal or corrected-to-normal vision.

Psychometric Assessments

Full2IQ scores were obtained for the TD children and the children with ASD using the WASI, which provided a measure of the children's cognitive functioning. Parents of all child participants were asked to complete the *Lifetime* version of the Social Communication Questionnaire (SCQ) (Rutter, et al., 2003) to provide a measure of each participant's social functioning. The ADOS was also administered to each participant with ASD (Lord, et al., 2000), to confirm clinical diagnoses of ASD. The WASI, SCQ and ADOS were described in greater detail in chapter two's Method section.

Apparatus and Stimuli

Stimuli were presented on a 17" Viewsonic E96f Ultrabrite CRT monitor (75Hz frame rate, 1024x768 pixels). The monitor was driven by a Microsoft Windows XP

computer with Intel Pentium 4 processor. An adjustable chair positioned the participants at 116 cm viewing distance from the computer screen.

Stimuli were created in Matlab 6.5, and were grey scaled sinusoidal gratings which appeared centrally on a grey background (Luminance (L) = 10.9 cd/m^2). The gratings were convolved with a Gaussian envelope. The gratings were at spatial frequency 2.0 cycles per degree and subtended 8.0° by 8.0°, from the specified viewing distance. The space-average L of each grating was 17.2cd/m^2.

Horizontal parallel first order gratings (G_p) were created using the equation

$$G_p(x, y) = L_o\{1 + m\sin[2\pi fx]\}$$

Where L_o is the mean luminance baseline of the grating

m is a constant, giving modulation depth

f is a value that denotes the spatial frequency of the grating

θ denotes the orientation of the grating, by angles in radians anti-clockwise from the horizontal

x and y represented values in the mesh grid space that the grating was created (Gallant, et al., 1993)

Hyperbolic first order gratings (G_h) were created using the equation

$G_h(x, y) = L_o\left\{1 + m\sin\left[2\pi f\left\langle\left(y^2 - x^2\right)/(2\pi)^2\right\rangle\right]\right\}$ (Gallant, et al., 1993).

The above first order gratings had noise added to them to create a similar textured appearance as the second order gratings. Second order forms of the parallel and hyperbolic gratings were generated by multiplying G_p and G_h respectively, with noise. This resulted in parallel and hyperbolic gratings that were defined by contrast (C) instead of luminance. f had to be adjusted such that spatial frequency of corresponding first and second-order gratings were equivalent.

The contrast of the gratings, as defined by a Michelson contrast, was calculated as $[(L_{Max} - L_{Min})/(L_{Max} + L_{Min})]$, and equated for all four stimuli. The Michelson contrast for the four stimuli was matched at 92.3%.

Participants were kept motivated by a simple response task whereby images of cartoon characters were randomly interspersed between the stimuli presentations, and participants were required to make a button press when they spotted a cartoon character. There were a total of 57 images of cartoon characters which were grey-scaled and presented centrally on the computer screen. These images subtended 4.1 by 4.1° visual angle.

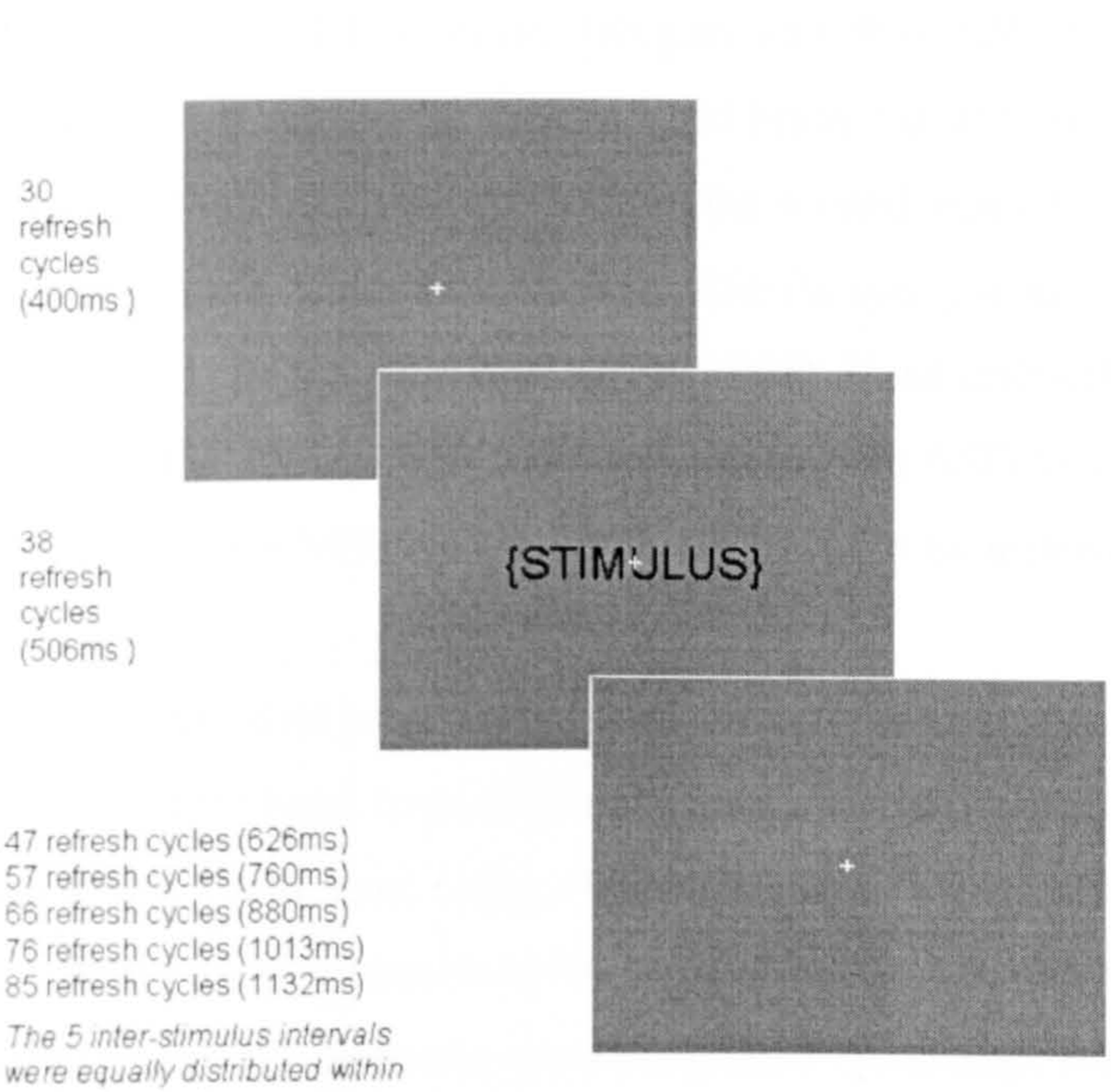
A white fixation cross of size 0.2 by 0.2° visual angle was also positioned at the centre of the display throughout the entire experiment, and participants were reminded to maintain their eye gaze on the cross.

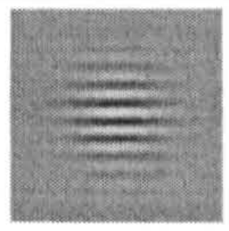
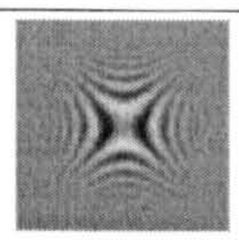
Procedure

As depicted in Figure 3.2 (pg 62), the task was an oddball experiment, run via the E-prime software (Psychology Software Tools Inc., www.pstnet.com). The parallel first order, parallel second order, hyperbolic first order and hyperbolic second order gratings were each presented 75 times. The 57 cartoon images were each presented once. Presentations of all images were pseudo-randomly intermixed and divided into five blocks of 71-72 trials with equal proportions of the four stimuli in each block. Participants were asked to perform button presses when a cartoon image appeared on the computer screen. 16% of trials in the entire experiment contained a target. For these target trials, accuracy and reaction times for correct trials were measured and compared between the TD children and the children with ASD.

Each stimulus remained on the screen for 38 monitor refresh cycles (506ms). The inter-stimulus intervals were randomly assigned one of five durations: 77 refresh cycles (1026ms), 87 refresh cycles (1160ms), 96 refresh cycles (1280ms), 106 refresh cycles (1413ms) or 115 refresh cycles (1532ms). The inter-stimulus interval was varied to prevent overlapping waves from preceding stimuli appearing in the averaged wave-forms (Luck, 2005a). Therefore one block of trials lasted approximately for two minutes and there were breaks of 0.5 to 1 minute between single blocks of trials.

Figure 3.2 A schematic illustration of the experimental task procedure.



Stimulus	No. of presentations
	75
	75
	75
	75
	57

Participants were informed about how blinking might affect the data. They were instructed to limit their blinking during the blocks of trials and if they were to blink during the blocks of trials, to do so during the inter-stimulus intervals. The experiment was conducted in a dimmed sound-proof room.

EEG recording

EEG was continuously recorded while participants completed the experimental task. A 128 channel Electrical Geodesics Sensor Net was used (Tucker, 1993). The signals were amplified (x1000) and filtered online at a range of 0.01 to 80.0Hz. The recordings were digitally sampled at 250Hz and data was stored in a Power Macintosh G4 computer. The electrode impedance was kept below 50 kΩ and the recordings were referenced to the vertex electrode.

During application of the electrode net, head circumferences of all participants were measured. Measurements were taken from above the glabella (area between the eye-brows) and around to the inion (part of the scalp over the occipital bone), using a measuring tape.

There is data suggesting that head circumference has a weak but significant positive correlation with P1 latencies (Gregori, Pro, Bombelli, Riccia, & Accornero, 2006). ASD has also been associated with reduced brain size at birth, rapid brain growth resulting in enlarged head circumferences up to the second year of life and to level off by adolescence and adulthood (Courchesne, 2004; Courchesne, Carper, & Akshoomoff, 2003; Courchesne, et al., 2001; Redcay & Courchesne, 2005). Head circumference was therefore compared between the TD children and the children with ASD to verify that any ASD-TD differences observed in the VEP may not be accounted for by differences in head size.

Offline EEG data processing

Recordings from each participant were processed using Netstation 4.2. Each recording was filtered using a band-pass of 1.0Hz to 30.0 Hz, then segmented into epochs of 100ms pre-stimulus to 450ms post-stimulus onset for the children data. Channels with more than 30% of epochs containing EEG recordings with amplitudes of more than 100.0μv maximum to minimum values were excluded (large deviations in electrical potentials are improbable in biological systems and may indicate artefacts). For all data, the recordings from channels that were excluded were replaced with data interpolated from remaining channels (using the "bad channel replacement" function in Netstation 4.2). In addition, epochs that had more than 10 channels that were excluded, contributing to its data, were also removed. Eye blinks and eye movement were detected using a maximum to minimum threshold of 55.0μv. The threshold value was the default value in the Netstation artefact detection function, which is more conservative then more commonly used threshold values of ±100μv (Picton, et al., 2000). Epochs containing eye blinks and eye movements were rejected.

"Good" epochs of EEG recording in response to parallel first order gratings, parallel second order gratings, hyperbolic first order gratings and hyperbolic second order gratings, were averaged for each participant. The averaged epochs were then baseline corrected, and re-referenced to the average of all electrode recordings.

Data Selection

EEG data from individual participants were required to have at least 35 good epochs for each stimulus, to qualify for inclusion in the statistical analysis. Data from 20 TD

children and 11 children with ASD had at least 35 good epochs for each stimulus. However, to match the TD children and the children with ASD on chronological age, data from 6 TD children who were above the age of 185 months, were excluded. Data from 14 TD children and 11 children with ASD contributed to the final sample, and the groups were matched on chronological age, head circumference and IQ. The TD children were found to have a larger mean number of good epochs than the children with ASD. This latter difference is a potential confound for any ASD-TD differences elicited, thus this issue will be re-considered in a section of confounding factors in the Results section. Table 3.1 (pg 65) presents a summary of the participants' characteristics, including the mean values for chronological age, head circumference, IQ and number of good epochs.

The children with ASD had been given formal diagnoses by external clinical professionals i.e. a clinical psychologist or a paediatrician on the DSM-IV criteria (APA, 2004). Of the children with ASD, three had a clinical diagnosis of Autistic disorder, six had Asperger's syndrome, one had ADHD with ASD difficulties, and one was diagnosed with ASD and non-verbal learning difficulties. One participant with Asperger's syndrome also had a co-morbid diagnosis of ADHD and Dyspraxia. This participant was taking Atomoxitine (70mg) once daily for his ADHD. One TD participant had taken medication for gastric flu a couple of days before the testing session. No other participants were taking medication during the week leading up to the testing session. There were four children with ASD and two TD children in the final sample, who were born pre-mature (3-9 weeks).

One child who had a formal diagnosis of Autistic disorder attained an ADOS total score of 6 which was below the ADOS cut-off for ASD. His data was however not excluded from the ASD sample as he did have an existing diagnosis of ASD given by a qualified professional and he was also scored a high 32 by his parent on the SCQ which was above the SCQ cut-off for ASD of 15.

Table 3.1 Group characteristics of participants with ASD and TD participants.

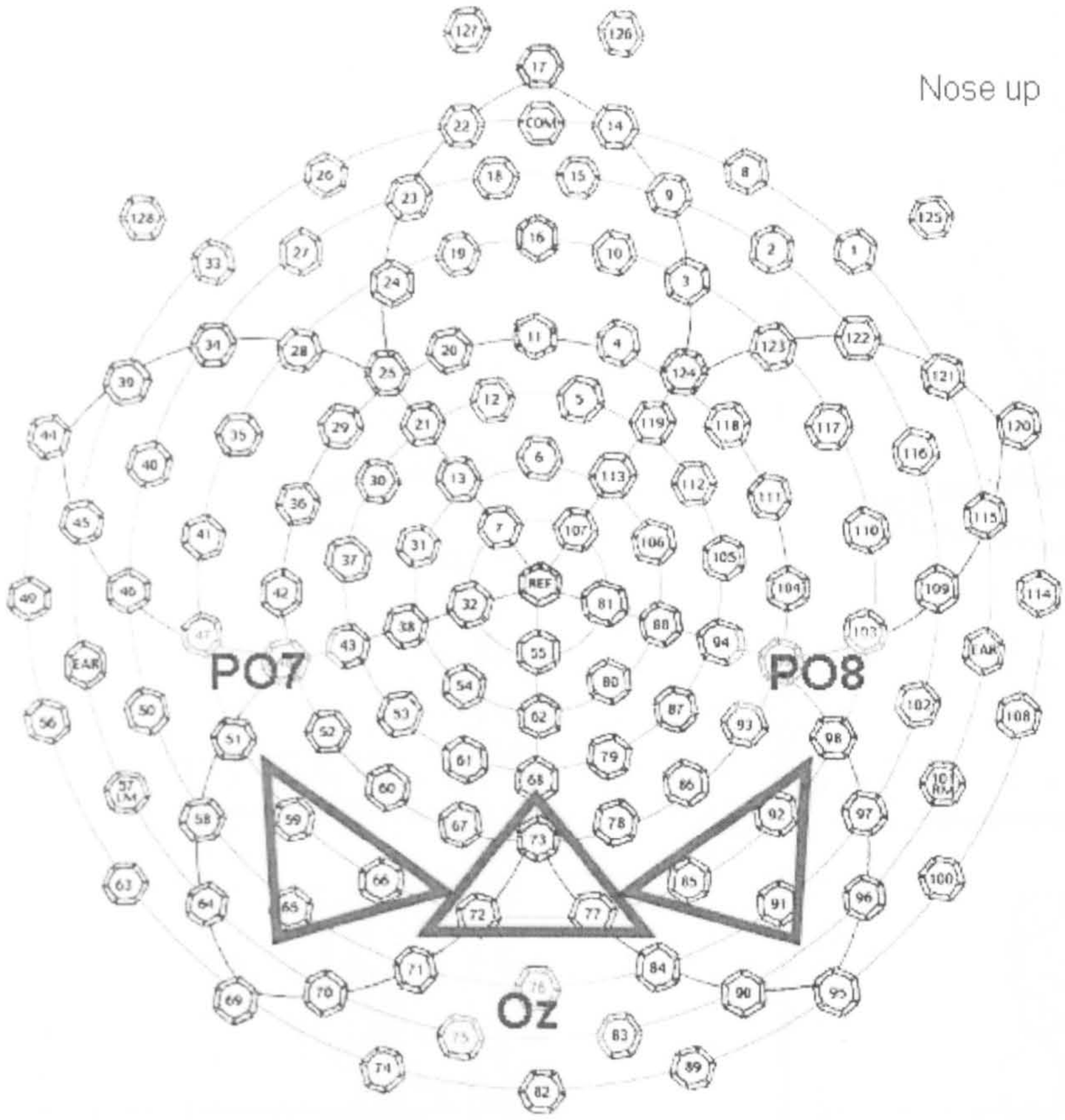
	ASD (N=11)	TD (N=14)	t & p values
Sex	10 boys, 1 girl	6 boys, 8 girls	
Vision Issues	9 Normal Vision 2 Corrected Vision	9 Normal Vision 5 Corrected Vision	
Handedness	8 right handed 3 left handed	12 right handed 1 left handed 1 data missing	
Chronological Age (months)			
Mean	130	135	t(df=23)=0.398, p=n.s.
S.D.	28	28	
Range	100-183	99-185	
Head Circumference (cm)			
Mean	54.7	55.0	t(df=23)=0.378, p=n.s.
S.D.	2.3	1.5	
Range	52.5-58.4	52.3-57.5	
Full Scale IQ			
Mean	107	113	t(df=23)=1.02, p=n.s.
S.D.	14	13	
Range	88-130	92-138	
No. of good epochs			
Mean	45	56	t(df=23)=3.26, p=0.003
S.D.	7	10	
Range	36-56	36-71	
SCQ Score			
Mean	24	4	t(df=23)=9.63, p<0.001
S.D.	7	3	
Range	12-36	0-8	
ADOS Total			
Mean	11		
S.D.	4		
Range	6-18		

3.3 Results

P1 was defined as the first positive deflection in the averaged waveforms occurring between 100-200ms post-stimulus onset (see pg 67 for Figures 3.4 and 3.5). P1 amplitudes and latencies were extracted as averages over electrodes in region Oz i.e. electrodes 73, 72 and 77 (International 10-10 equivalents to electrodes on EGI sensor nets Luu & Ferree, 2000, see pg 67 for Figure 3.3). Oz approximates the scalp region over the primary visual cortex. P1 was only analyzed from Oz as visual inspection of the VEP data suggested P1 was largest in Oz compared to VEP in the other posterior electrodes. P1 was also previously investigated in Oz (Doucet, Gosselin, Lassonde, Guillemot, & Lepore, 2005; Ellemberg, Lavoie, et al., 2003).

N1 was defined as the first negative deflection in the averaged waveforms, occurring between 150-350ms post-stimulus onset (see Figures 3.4 and 3.5). N1 amplitudes and latencies were extracted as averages over region PO7 i.e. electrodes 66, 59 and 65 and region PO8 i.e. electrodes 85, 91 and 92 (International 10-10 equivalents to electrodes on EGI sensor nets Luu & Ferree, 2000, as shown in Figure 3.3). PO7 and PO8 approximate the scalp region over the left and right lateral occipital cortical regions respectively. N1 was only analyzed from PO7 and PO8 because visual inspection of the VEP data suggested N1 was better defined in the lateral electrode regions than in Oz. There is also electrophysiological evidence proposing N1 to have a lateral occipital cortical source (Arroyo, et al., 1997; Gonzalez, Clark, Fan, Luck, & Hillyard, 1994; Hillyard & Anllo-Vento, 1998).

Figure 3.3 Location of Oz, PO7 and PO8, on the 128 channel Electrical Geodesics Sensor Net.



Significance level for the statistical analyses is set at 0.05 for 2-tailed tests. Effects sizes are measured as the Pearson's Correlation coefficient, r. Values of 0.10, 0.30 and 0.50 denote small, medium and large effect sizes respectively. Interaction effects were of interest in this study, therefore the ANOVA was applied regardless of whether the data violated assumptions of normality and/or homogeneity of variance or not. The use of the ANOVA in this study is justified because the ANOVA is known to be robust towards these violations (Field, 2005a), and any significant ANOVA results were supported by non-parametric post-hoc tests.

Figure 3.4 Grand averaged VEP waveforms for the TD children.

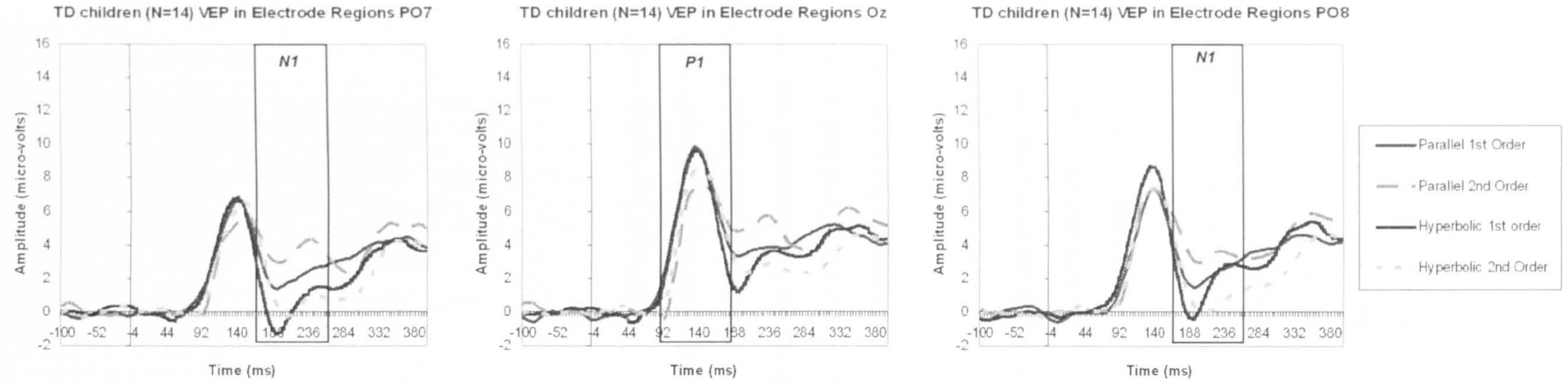
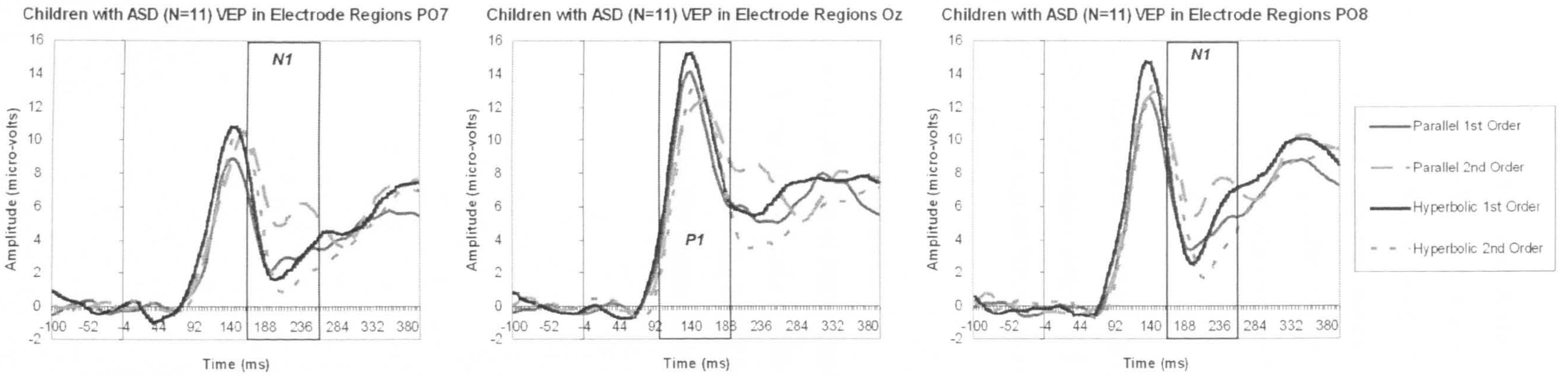


Figure 3.5 Grand averaged VEP waveforms for the children with ASD.



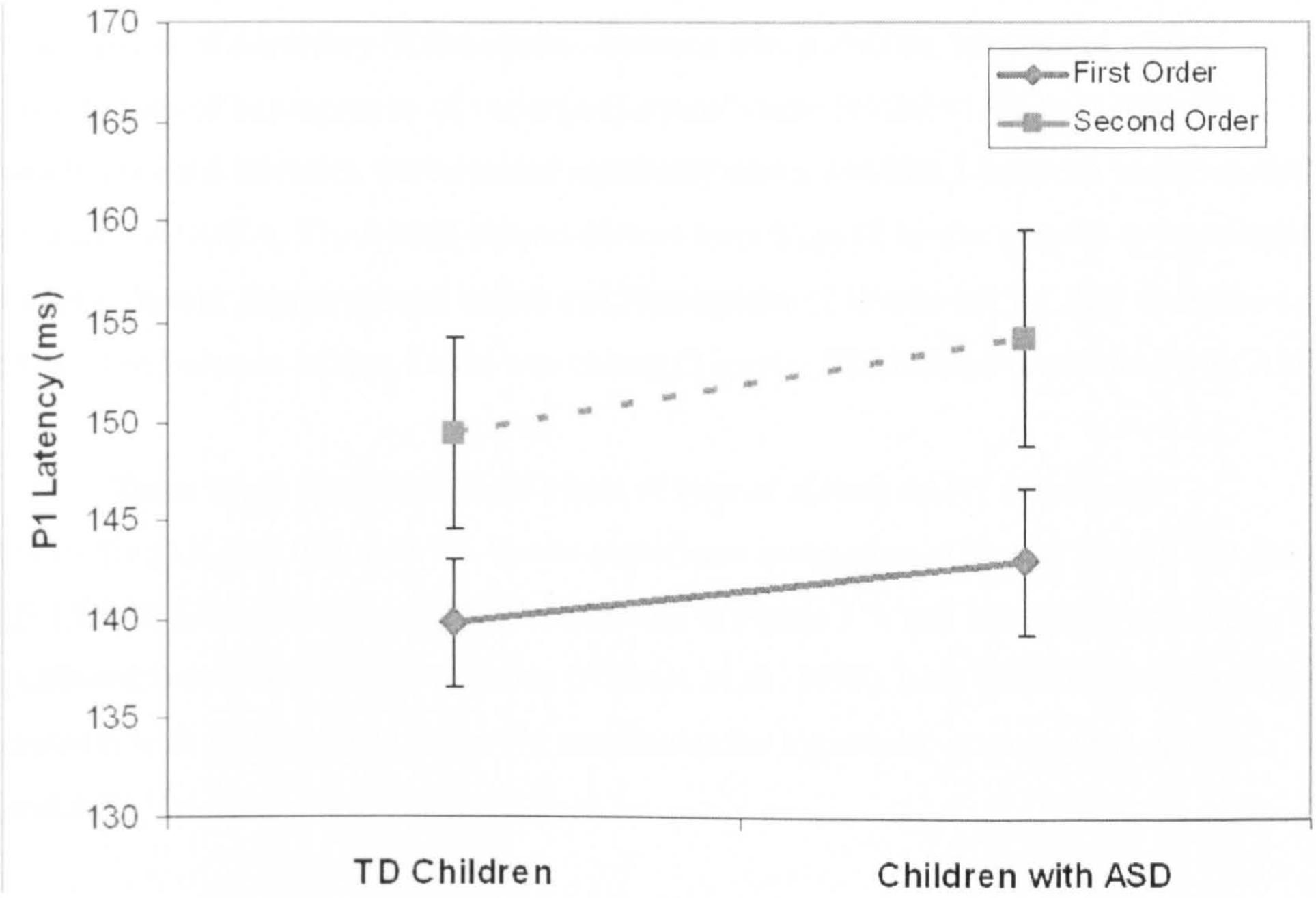
P1/Oz

P1 amplitudes and latencies of the TD children and the children with ASD did not violate assumptions of normality (Kolmogorov-Smirnov test: $p>0.072$), and also not assumptions of homogeneity of variance (Levene's test: $F(1,23)<3.90$, $p>0.060$).. P1 amplitudes and latencies were entered separately into a 2-within 1-between factors mixed measures ANOVA. The within-subject factors were Type (2 levels: parallel or hyperbolic), and Order (2 levels: first or second order). The between-subject factor was Group (2 levels: TD children or children with ASD).

There was a significant main effect of group on P1 amplitudes ($F(1,23)=6.82$, $p=0.016$, $r=0.48$). The children with ASD showed larger P1 amplitudes (mean=15.3, S.D.=4.00) than the TD children (mean=10.3, S.D.=5.22). This group difference was verified by a Mann Whitney *U* test ($U=37.0$, $p=0.029$, $r=0.44$).

There was a significant main effect of order of stimuli on P1 latencies ($F(1,23)=13.6$, $p=0.001$, $r=0.61$), but no significant interaction of order of stimuli and group ($F(1,23)=0.516$, $p=0.480$, $r=0.15$). As depicted in Figure 3.6 (pg 70), and inline with previously published data from adult participants (Ellemberg, Lavoie, et al., 2003), both the TD children and the children with ASD showed longer P1 latencies for second order gratings than first order gratings.

Figure 3.6 Line graph depicting mean P1 latencies for first and second order gratings in the TD children and children with ASD. Error bars indicate standard error of the means.

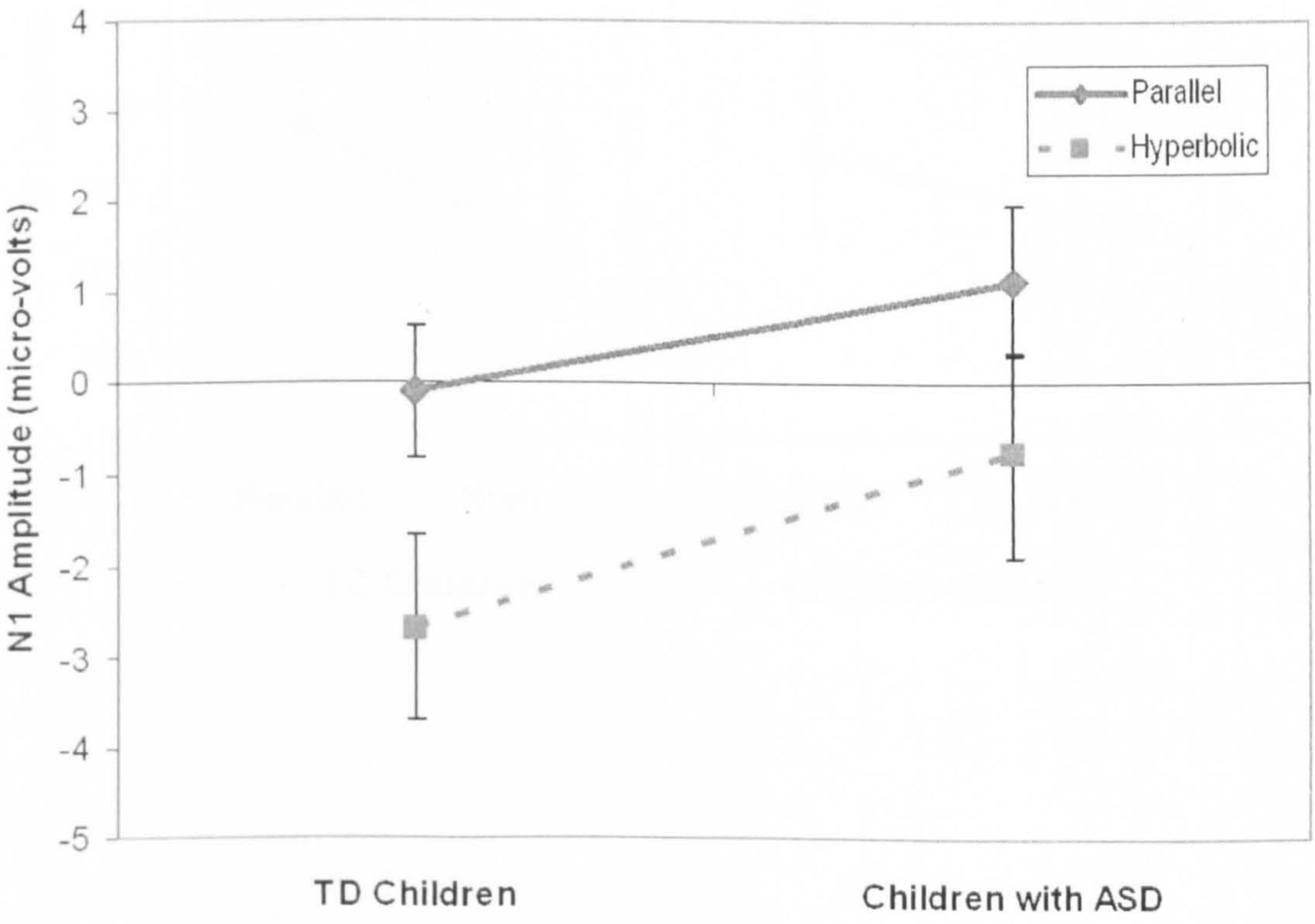


N1/PO7/PO8

N1 amplitudes and latencies of the TD children and the children with ASD violated assumptions of normality (Kolmogorov-Smirnov test: $p>0.005$), but did not violate assumptions of homogeneity of variance (Levene's test: $F(1,26)<1.08$, $p>0.303$). N1 amplitudes and latencies were entered separately into a 3-within 1-between factors mixed measures ANOVA. The within-subject factors were Type (2 levels: parallel or hyperbolic), Order (2 levels: first or second order) and Hemisphere (2 levels: left i.e. PO7 or right i.e. PO8). The between-subject factor was Group (2 levels: TD children or children with ASD).

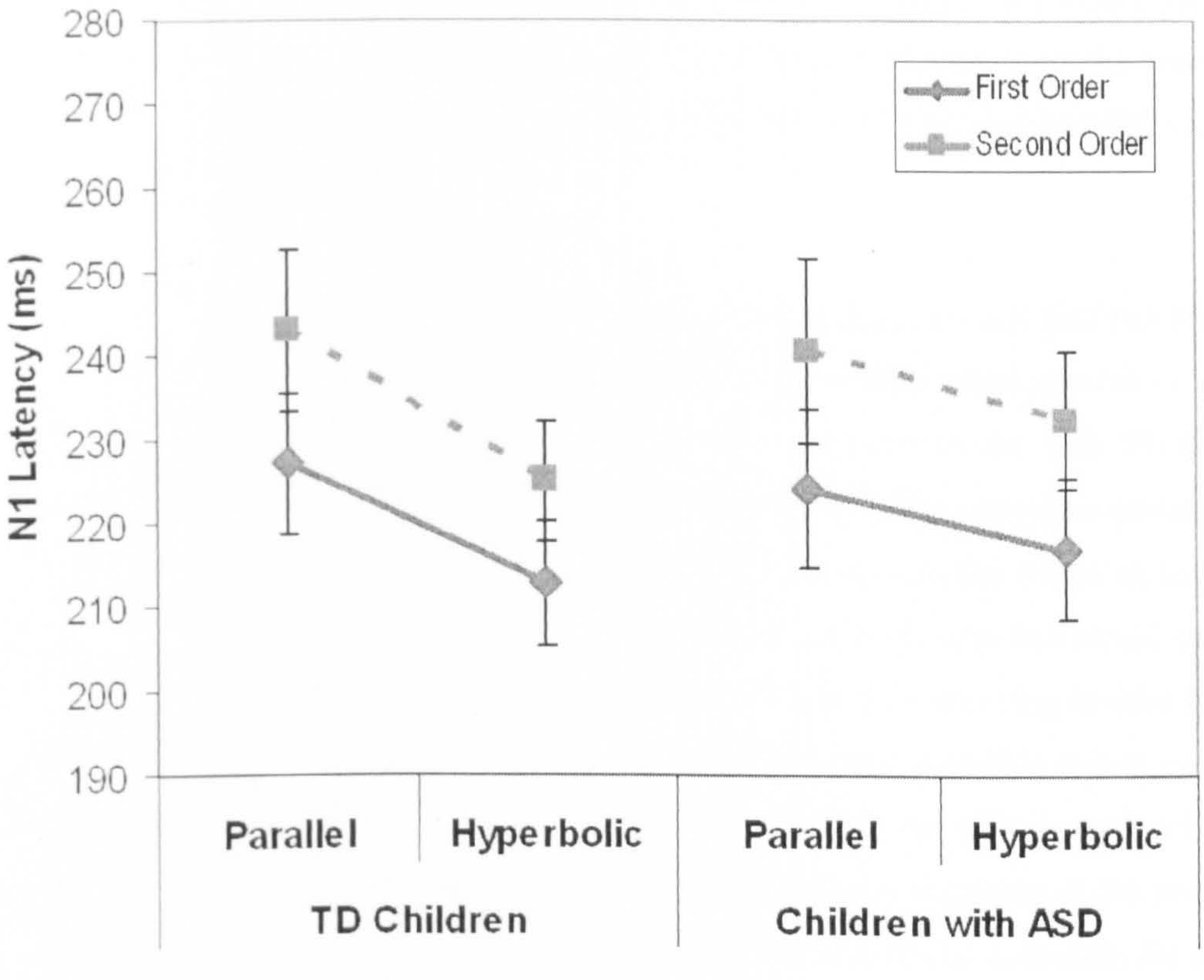
There was a significant main effect of type of stimuli on N1 amplitudes ($F(1,23)=30.8$, $p<0.001$, $r=0.76$), but no significant interaction of type of stimuli and group ($F(1,23)=0.676$, $p=0.419$, $r=0.17$). As depicted in Figure 3.7, and inline with previously published data from adult participants (Allison, et al., 1999), both the TD children and the children with ASD showed larger N1 amplitudes for hyperbolic gratings than parallel gratings.

Figure 3.7 Line graph depicting mean N1 amplitude for parallel and hyperbolic gratings in the TD children and children with ASD. Error bars indicate standard error of the means.



There was a significant main effect of type of stimuli on N1 latencies ($F(1,23)=5.42$, $p=0.029$, $r=0.44$), but no significant interaction of type of stimuli and group ($F(1,23)=0.668$, $p=0.422$, $r=0.17$). There was a significant main effect of order of stimuli on N1 latencies ($F(1,23)=10.8$, $p=0.003$, $r=0.57$), but no significant interaction or order of stimuli and group ($F(1.23)=0.048$, $p=0.829$, $r=0.05$). As depicted in Figure 3.8, and inline with previously published data from adult participants (Allison, et al., 1999; Ellemberg, Lavoie, et al., 2003), both the TD children and the children with ASD showed longer N1 latencies to second order gratings than first order gratings, and also faster N1 latencies to hyperbolic gratings than parallel gratings.

Figure 3.8 Line graph depicting mean N1 latency for parallel and hyperbolic, first and second order gratings in the TD children and children with ASD. Error bars indicate standard error of the means.



Summary of findings

The results indicate no evidence for atypicalities in visuo-integrative processes in the children with ASD for second order gratings and hyperbolic gratings. Both the children with ASD and the TD children showed longer VEP latencies to second order than first order gratings, and larger N1 amplitudes to hyperbolic gratings than parallel gratings. However, the children with ASD showed larger P1 amplitudes regardless of type and order of stimuli than the TD children.

Are there confounding factors that could account for the elevated P1 amplitudes in the children with ASD compared to TD children?

There were no significant differences in mean head circumferences and Full2IQ scores between the children with ASD and TD children, thus these factors are unlikely to contribute to the elevated P1 amplitude observed in the children with ASD compared to TD controls. This is confirmed by there being no significant correlations of the overall P1 amplitude with head circumference ($r(df=23)=-0.164$, $p=0.432$), and Full2IQ scores ($r(df=23)=0.055$, $p=0.793$).

The children with ASD contributed less data to the statistical analysis than the TD children, as the children with ASD had a significantly smaller mean number of good epochs than the TD children. This difference is a potential confound for the ASD-TD difference in overall P1 amplitude. The larger the data set contributed by an individual participant, the higher the likelihood of greater variability in VEP between epochs within an individual. Greater variations in peak latency of P1 between epochs within an individual may result in lower averaged P1 amplitudes. The TD children may then be showing smaller P1 amplitudes than the children with ASD, because there may be greater within participant variation in the peak latency of P1 in the TD children than the children with ASD. This possibility was examined by conducting a between group comparison of the standard deviation of the peak latency of P1 for epochs within participant. Latencies for a maximum peak within 100 to 200ms post stimulus onset i.e. P1 for individual epochs were extracted for each participant and the standard deviation of those peak latencies were then calculated for each participant. There was no significant difference in the standard deviation of the peak latency of P1 within participants ($t(df=23)=0.153$, $p=0.880$), between the children with ASD (mean=21.6, S.D.=4.1) and the TD children (mean=21.9, S.D.=3.5). There was

also no significant correlation of the overall P1 amplitude with standard deviation of the peak latency of P1 (r(df=23)=-0.334, p=0.102). Therefore, the likelihood that the ASD-TD difference in P1 amplitudes observed in this study may be an artefact of a significant difference in the number of epochs contributing to data from the children with ASD and the TD children can be ruled out.

The possibility that differences in task engagement between the children with ASD and the TD children may have contributed to the ASD-TD difference in overall P1 amplitudes observed, was also examined. There was no significant group difference in reaction times to correctly identified target trials (TD children: mean=492ms, S.D.=55, ASD children: mean=504ms, S.D.=60), although a significant group difference in accuracy for target trials (t(df=23)=4.0, p=0.001) was found. The TD children (mean=51, S.D.=3) had higher accuracy than the children with ASD (mean=44, S.D.=5), which suggests that the TD children may have been paying more attention to the task, and therefore may be paying more attention to the visual stimuli, than the children with ASD. Increased visual attention should however be associated with larger P1 amplitudes in the TD children (Kanwisher & Wojciulik, 2000), which is not what was observed. It is therefore unlikely that attentional factors would play a role in the ASD-TD differences in overall P1 amplitudes.

3.4 Discussion

Contrary to the study's initial predictions, the children with ASD did not show differences in VEP elicited by parallel *relative to* hyperbolic, first *relative to* second order gratings, when compared with TD children. Both the children with ASD and the TD children showed longer VEP latencies to second order than first order gratings, and a larger N1 amplitude to hyperbolic than parallel gratings. These results therefore indicate no evidence that visuo-integrative processes in children with ASD for second order and hyperbolic gratings are atypical. However, the children with ASD did display elevated P1 amplitudes regardless of the type and order of stimuli compared to the TD children. This increased activity of the visual cortical region in the first 100-200ms after stimulus onset may be important for explaining atypical low level visual perception observed in children with ASD.

The following paragraphs will address the null finding of ASD-TD differences in visuo-integrative processes as measured by VEP, and then the results suggesting increased activity of the visual cortical region in the children with ASD within the first 100-200ms after stimulus onset. This Discussion will then conclude with a couple of suggestions on this study's limitations, and present ideas for a different analysis to be conducted with the data, which provides the rationale for chapter four.

In line with previous data collected from adults, both the children with ASD and the TD children showed longer VEP latencies to second order than first order gratings (Ellemberg, Lavoie, et al., 2003), and a larger N1 amplitude to hyperbolic than parallel gratings (Allison, et al., 1999), which demonstrated the children with ASD not to have atypicalities for visuo-integrative processes associated with perception of second order and hyperbolic gratings. It should however be noted that this study did not measure the children's actual contrast sensitivities for perception of the gratings stimuli, and there have only been previous behavioural evidence for differential processing of first and second order gratings in ASD (Bertone, et al., 2003, 2005), and no evidence for atypical perception of hyperbolic gratings in ASD. It is therefore possible that the children with ASD in this sample are not showing atypical visuo-integrative processes as indicated by VEP, because they do not have atypicalities in perception of second order and hyperbolic gratings as

measured by behavioural responses. Additionally, gratings presented in this study were presented at contrasts much high than typical contrast thresholds, and may have elicited VEP in a way that obscured any group differences in VEP latencies to second order relative to first order gratings, and in N1 amplitudes to hyperbolic relative to parallel gratings. Future studies could explore VEP elicited by parallel and hyperbolic, first and second order gratings, in children with ASD and without ASD, at near threshold contrast.

There is also a likelihood that the null finding of any ASD-TD difference in VEP elicited by first order relative to second order, and parallel relative to hyperbolic gratings in this study, may be because VEP elicited by second order gratings and hyperbolic gratings were not yet fully mature in the children. There is behavioural evidence suggesting that the perception of second order gratings improves from childhood to adulthood (Ellemberg, Lewis, et al., 2003; Lewis, Kingdom, Ellemberg, & Maurer, 2007). Furthermore, VEP elicited by non-cartesian first order gratings i.e. radially-modulated concentric gratings were not found to be adult-like by 13 years of age (Doucet, et al., 2005). It therefore remains to be established if an electrophysiological investigation of low level visual perception in ASD, conducted with older adolescents and adults, may reveal atypicalities in visuo-integrative processes. The mean ages in both samples of participants in Bertone et al (2003) i.e. 12 years and Bertone et al (2005) i.e. 22 years, which found impaired motion and orientation perception of second order gratings in the participants with ASD, were also higher than the mean age of 11 years of the children with ASD in this study.

Assuming that the children with ASD in this study, as previous literature suggests, do have impaired perception of "complex" stimuli such as second order and hyperbolic gratings, and that the visuo-integrative processes appear not to be the issue, there may be ASD atypicalities at other stages of visual processing. The children with ASD showed larger P1 amplitudes regardless of the type and order of stimuli than the TD children. It may be speculated that this increased activity of the visual cortical region within the first 100-200ms of stimulus onset in ASD reflects over-representation of local contrast signals in the visual cortical region. Over-representation of local contrast signals in the visual cortex would be beneficial for perception of first order gratings, as first order gratings are defined by contrast signals, thus accounting for the previous finding of superior discrimination of orientation of first order gratings in ASD (Bertone, et al., 2005). On the

other hand, the perception of second order gratings require the initial perception of local contrast signals, and then integration of those contrast signals for the overall pattern to be perceived (Larsson, Landy, & Heeger, 2006). Over-representation of local contrast signals in second order gratings may on the contrary interfere with the integrative processes, and make less prominent the perception of the overall global pattern in the second order gratings, which can explain the previous finding of impaired perception of second order gratings in individuals with ASD (Bertone, et al., 2003, 2005). Similarly for hyperbolic gratings, over-representation of local contrast signals may interfere with the visual processes that are needed to integrate the different local orientation signals across space, for perception of the overall hyperbolic pattern. Over-representation of local contrast signals in ASD may lead to difficulties in perception of "complex" stimuli. Increased activity of the visual cortical region in the first 100-200ms after stimulus onset may reflect a mechanism underlying atypical low level visual perception in ASD. Future research should attempt to correlate perceptual sensitivity measures of parallel and hyperbolic, first and second order gratings, with VEP elicited by these gratings in individuals with ASD, to verify this conjecture.

It is acknowledged that the VEP view of the dynamics of the brain is a somewhat blinkered perspective of neural functioning (Makeig, Debener, Onton, & Delorme, 2004; Makeig, et al., 2002). The VEP is a single-dimension measure that indicates the mean change in electrical potential from baseline with time (Makeig, et al., 2004). There are other dimensions of neural activity such as frequency of the EEG oscillatory activity, and the extent of phase-locking of EEG signals to an event of interest, that are not considered within the VEP framework. Also, the VEP is produced by averaging single trial EEG data, time-locked to an event of interest (Makeig, et al., 2002). The averaged response is only able to elicit neural activity that is phase-locked to the reference event i.e. evoked activity, and is not reflective of neural activity that does not occur at a constant phase lag from the reference event i.e. induced activity. Induced neural activity is as important a factor to consider as evoked neural activity in the endeavour to elicit the electrophysiological correlates of visual perception in ASD (Herrmann & Demiralp, 2005). In consideration of the above, VEP can only demonstrate a limited view of the neural processes underlying low-level visual perception in ASD.

A separate issue from the limitation of VEP analysis is that of signal mixing when analyzing EEG data from single scalp electrodes as done in this study. This issue may also have resulted in subtle differences in VEP to parallel and hyperbolic, first and second order gratings, between the children with ASD and TD children being obscured. EEG measured at each scalp electrode is a mixture of signals from various cortical and non-cortical sources e.g. eyes, muscles (Onton, Westerfield, Townsend, & Makeig, 2006). Some of these signals may arrive at a single scalp electrode from different directions with different polarities and cancel each other's effects within a single electrode EEG recording. The mixing of the signals at a single scalp electrode would be different for separate individuals. This variability in 'contamination' of neural signals of interest has the potential to influence whether between group differences in neural activity are observed (Milne, Scope, Pascalis, Buckley, & Makeig, 2009).

Thus, in light of the technical issues surrounding the EEG analysis conducted in this study, the next chapter i.e. chapter four attempted to maximize the potential of the EEG data collected and to make improvements to the 'purity' of neural signals being compared between groups, by conducting time-frequency and independent component analyses on the EEG data. A time-frequency analysis enabled EEG power i.e. event-related spectral perturbations (ERSP) in response to an event to be extracted. ERSP is a double-dimension measure that indicates the mean change in EEG power from baseline at a particular frequency of oscillation with time. It provides a further dimension of neural activity i.e. frequency of oscillation for analysis than VEP can. Moreover, single trial EEG data are transformed into the frequency domain and then averaged. Thus, the ERSP is not only representative of evoked neural activity, but induced neural activity as well. The inclusion of both evoked and induced neural activity in the investigation would enable a more holistic examination of neural responses to visual stimuli in individuals with ASD. Independent component analysis (ICA) was also employed to separate the multi-channel EEG data into temporally independent processes (Onton, et al., 2006). Its use enabled EEG activity from independent cortical sources relevant to visual perception to be isolated for further EEG power analyses. Most importantly, the time-frequency analysis and the ICA adopted in chapter four permitted a deeper research question– the issue of atypical neuro-connectivity in the visual cortical region in ASD, to be examined. This research question will be introduced in the next chapter.

Conclusions

The present findings provide no evidence that visuo-integrative processes, associated with perception of second order gratings and hyperbolic gratings, are atypical in children with ASD. The results did indicate increased activity of the visual cortical region within the first 100-200ms of visual stimulation in ASD, which may reflect over-representation of local contrast signals in the visual cortical region of individuals with ASD, that would facilitate perception of first order gratings, but have detrimental effects on the later stage visuo-integrative processes required for perception of second order gratings or more complex stimuli.

4 Chapter Four –

Electrophysiological correlates of low level visual perception in ASD: Gamma-band EEG power elicited by parallel and hyperbolic, first and second order gratings

4.1 Introduction

Chapter three revealed VEP evidence for increased activity in the visual cortical region in ASD, in response to parallel and hyperbolic, first and second order gratings. This increased activity may be an indication of atypical neuro-connectivity within the visual cortical region (Belmonte, et al., 2004), which is a conjecture that is consistent with theories that suggest atypical neuro-connectivity to underlie ASD symptomology (Barnea-Goraly, et al., 2004; Belmonte, et al., 2004; Brock, Brown, Boucher, & Rippon, 2002; Casanova, Buxhoeveden, & Gomez, 2003; Castelli, et al., 2002; Gustafsson, 1997; McClelland, 2000; Rippon, Brock, Brown, & Boucher, 2007; Rubenstein & Merzenich, 2003). More specifically, the theories postulate increased neuro-connectivity within functional cortical regions, and/or reduced long-range neuro-connectivity between functional cortical regions, in ASD. The majority of the research on neuro-connectivity in ASD has however been focused on brain regions implicated in social and language functioning, and there is limited knowledge of neuro-connectivity in the visual cortical region in ASD.

VEP is only an indirect indicator of neuro-connectivity, and also for reasons stated in chapter three's Discussion, is a not the most comprehensive measure of neural activity. Gamma-band EEG power, a measure of local neural synchrony, is a more direct indicator of the level of neuro-connectivity within functional cortical regions (Keil, Muller, Ray, Gruber, & Elbert, 1999; Müller, et al., 1996; Singer & Gray, 1995; von Stein & Sarnthein, 2000). Gamma-band (30 to 100Hz) neural activity comprises fast oscillatory activity with small amplitudes (Chatrian, Bickford, & Uihlein, 1960; Fries, Nikolic, & Singer, 2007), while lower frequency band activity such as alpha (8 to 12 Hz) or theta (4 to 8 Hz) activity comprises slower oscillatory activity with larger amplitudes (von Stein & Sarnthein, 2000). The research suggests that neural activity is synchronized at higher frequencies when the region of neural interactions is small, such as in short-range neural assemblies within functional cortical regions, and that it is synchronized at lower frequencies when the region

of neural interaction is large, such as in long-range neural assemblies between functional cortical regions (von Stein & Sarnthein, 2000). Gamma-band neural activity is thus likely to be the product of short-range neural interactions within functional cortical regions. Neural synchrony reflects the degree to which neurons are firing in coordination with each other, and is facilitated by increased connectivity between neurons. Gamma power in response to visual stimuli may therefore provide indication of the level of neuro-connectivity within the visual cortical region.

To date, there are three studies which have investigated gamma power in response to visual stimuli in individuals with ASD (Brown, Gruber, Boucher, Rippon, & Brock, 2005; Grice, et al., 2001; Milne, Scope, et al., 2009), although the results have not been interpreted in terms of local neuro-connectivity. The following paragraphs will review those findings and suggest what the results may mean for neuro-connectivity within the visual cortical region in ASD.

Gamma power was measured from frontal and parietal cortical regions as opposed to visual cortical regions in two of those studies (Brown, et al., 2005; Grice, et al., 2001), and was used as an indicator of perceptual binding (Tallon-Baudry & Bertrand, 1999). Perceptual binding refers to the higher level perceptual process of integrating features of a visual image to form a coherent percept. Grice et al (2001) compared gamma power in response to upright and inverted faces, between adults with ASD and neuro-typical adults (Grice, et al., 2001). Upright faces are thought to engage more perceptual binding processes and elicit more gamma power as global processing is known to be the most efficient strategy for perception of upright faces, whereas inverted faces are thought to utilize feature-based processing which would elicit less gamma power (Farah, Wilson, Drain, & Tanaka, 1998). There were no group differences in the overall gamma power elicited by upright and inverted faces in the adults with ASD and neuro-typical adults. The adults with ASD showed as much gamma power to these stimuli as the neuro-typical adults. However, wherein the neuro-typical adults showed the expected larger gamma power responses to upright faces than inverted faces, the adults with ASD showed no such differentiation, suggesting that perceptual binding processes in individuals with ASD may be atypical. In a different study, Brown et al (2005) investigated gamma power in response to Kanisza figures, in adolescents with ASD and TD adolescents (Brown, et al., 2005). Kanisza figures

consist of a number of inducers that are arranged in positions, which may or may not produce subjective contours that form illusory shapes, such as triangles or rectangles. Kanisza figures in which illusory shapes were present would elicit more perceptual binding processes, and therefore more gamma power, than Kanisza figures in which illusory shapes were not present. Similar to Grice et al (2001)'s results, the TD adolescents showed larger gamma power responses to kanisza figures with an illusory rectangle than without an illusory rectangle, and the adolescents with ASD did not show such a differentiation, again suggesting that perceptual binding processes in individuals with ASD may be atypical.

Even so, there is an alternative explanation for Grice et al (2001) and Brown et al (2005)'s findings. In line with the EPF model for ASD (Mottron, et al., 2006), there is a possibility that the different pattern of gamma power activation between the individuals with ASD and TD controls in Grice et al (2001) and Brown et al (2005) reflects distinct dominant neural processes in the individuals with ASD and TD individuals. The gamma power activation measured in the individuals with ASD may be dominated by the initial low level visual processes, while that of the TD individuals may be dominated by the higher level perceptual processes involved in perceptual binding as intended by the experimental design. This interpretation is plausible in light that gamma power was extracted from single scalp electrodes in both studies, which contain a mixture of signals from different cortical sources (Onton, et al., 2006). Therefore, the gamma power extracted for the participants with ASD and TD participants in both studies may contain different weightings of the higher level perceptual processes and the initial low level perceptual processes. The gamma power activation reported in the participants with ASD was no different for upright and inverted faces, and Kanisza figures with and without illusory rectangles. The upright faces are perceptually identical to the inverted faces except for their orientation, while the Kanisza figures with and without illusory rectangles are also perceptually similar except for the orientation of the inducers. At the initial perceptual level, these pairs of stimuli may activate the primary visual area V1 most similarly. The lack of differentiation in gamma power activation to the pairs of stimuli observed in the participants with ASD may thus be a display of over-whelming gamma power elicited by the visual stimuli i.e. increased neuro-connectivity within the primary visual areas. In fact, the adolescents with ASD in Brown et al (2005) also showed increased overall gamma power to both types of kanisza figures than the TD controls. Nevertheless, an investigation

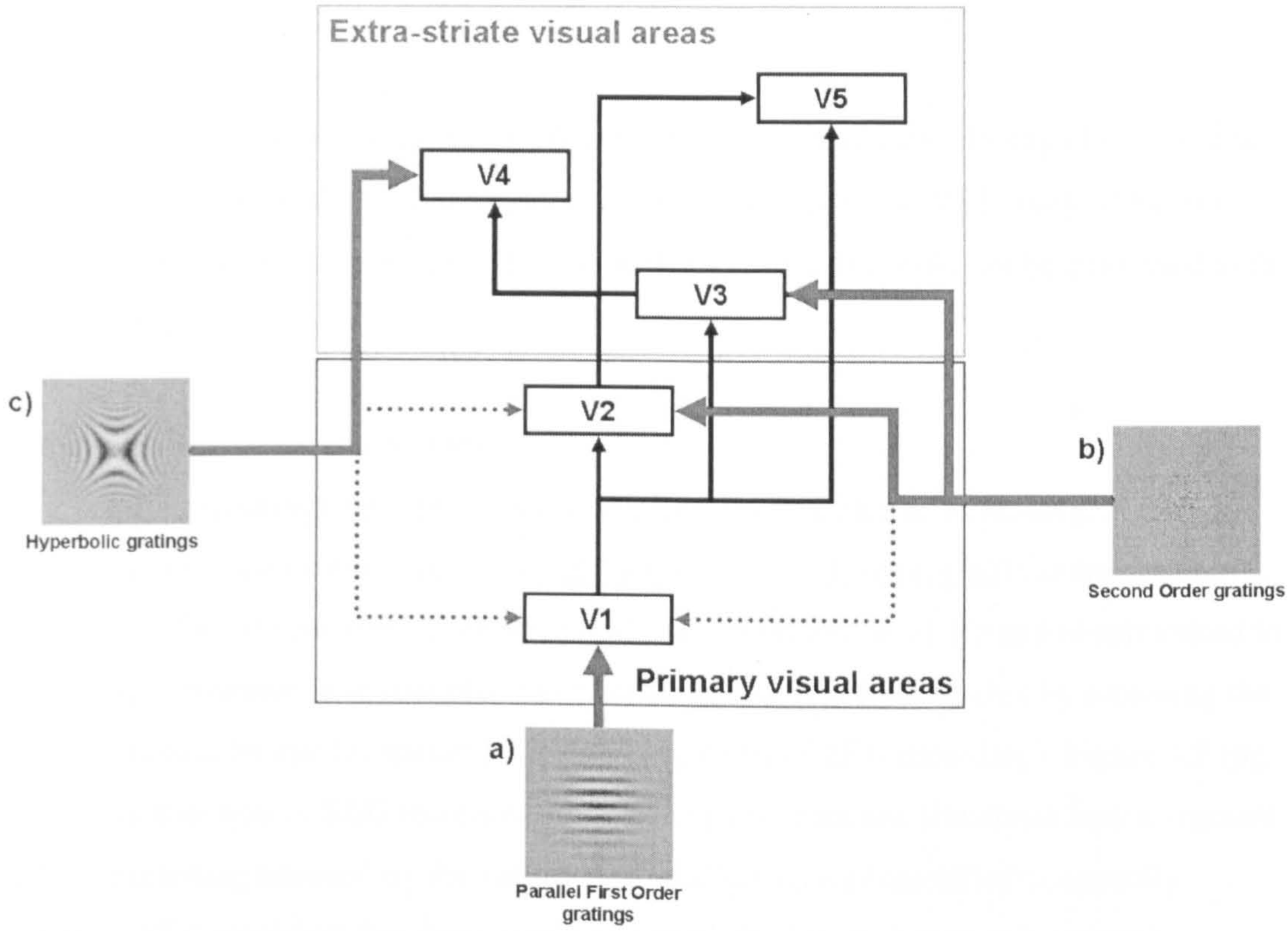
of gamma power elicited by low level visual stimuli is warranted to directly assess the neuro-connectivity hypothesis in visual cortical regions in ASD.

A third study compared gamma power responses to parallel first order gratings of four different spatial frequencies between children with ASD and TD children (Milne, Scope, et al., 2009). Perception of parallel first order gratings of different spatial frequencies are known to involve visual processes within primary visual area V1, as neurons within primary visual area V1 have been found to be selective for gratings of different spatial frequencies (Ng, Bharath, & Li, 2007; Singh, Smith, & Greenlee, 2000). Independent component analysis was conducted on the multi-electrode EEG data, and gamma power was examined within the range of 30 to 40Hz from cortical sources located in or near the visual cortex. The TD children showed increases in gamma power to gratings of increasing spatial frequency. The children with ASD however showed a smaller increase in gamma power to gratings of increasing spatial frequency. The TD children can therefore be said to have greater gamma power selectivity for gratings of different spatial frequency than the children with ASD. There was no significant group difference in overall gamma power between the children with ASD and the TD children. However, reduced selectivity of gamma power for gratings of different spatial frequencies in the children with ASD may be a consequence of increased gamma power in the visual cortical regions, which could make differences in gamma power responses to gratings of different spatial frequencies less prominent. Reduced selectivity of gamma power for gratings of different spatial frequencies may be an indirect indication of increased neuro-connectivity within the visual cortical region in ASD. Again, further investigation of gamma power elicited by low level visual stimuli is warranted to directly assess the neuro-connectivity hypothesis in visual cortical regions in ASD.

The present study therefore sought to determine if there is atypical neuro-connectivity in the visual cortical region in ASD, by comparing gamma power elicited by parallel and hyperbolic, first and second order grating, between children with ASD and TD children, using the EEG data from the previous chapter. As shown in Figure 4.1 (pg 85), parallel and hyperbolic, first and second order gratings are known to require different levels of engagement of the primary visual area V1, V2, and the extra-striate visual areas (Dumoulin et al., 2003; Smith et al., 1998; Gallant et al., 1993; Gallant et al., 1996; Hegde

& Van Essen, 2000; Gallant et al., 2000; Wilkinson et al., 2000). The results may determine if there is increased neuro-connectivity within primary visual area V1, and/or reduced neuro-connectivity between the primary visual areas V1, V2 and the extra-striate visual areas, in individuals with ASD. It is predicted that if there is indeed increased neuro-connectivity within primary visual area V1, the children with ASD may show increased gamma power to parallel first order gratings compared to the TD individuals. If there is decreased neuro-connectivity between the functional visual cortical regions, the children with ASD are likely to show lower gamma power for hyperbolic and/or second order gratings compared to the TD controls.

Figure 4.1 A schematic diagram of the human visual system (adapted from Bullier, 2001).



The black solid arrows indicate connectivity between the visual areas. The solid blue arrows indicate greater activation of a visual area than the dotted blue arrows

a) Neural processes involved in the perception of parallel first order gratings are thought to occur predominantly in the primary visual area V1 (Dumoulin, et al., 2003; Smith, et al., 1998). b) The additional neuro-integrative processes involved in perception of second order gratings are thought to occur in V2 and the extra-striate visual area V3 (Dumoulin, et al., 2003; Smith, et al., 1998). c) Hyperbolic gratings are thought to activate extra-striate visual area V4, more so than primary visual area V2, than primary visual area V1, compared to parallel gratings (Gallant, et al., 1993; Gallant, et al., 1996; Hegde & Van Essen, 2000, Gallant, et al., 2000; Wilkinson, et al., 2000)..

4.2 Method

Participants

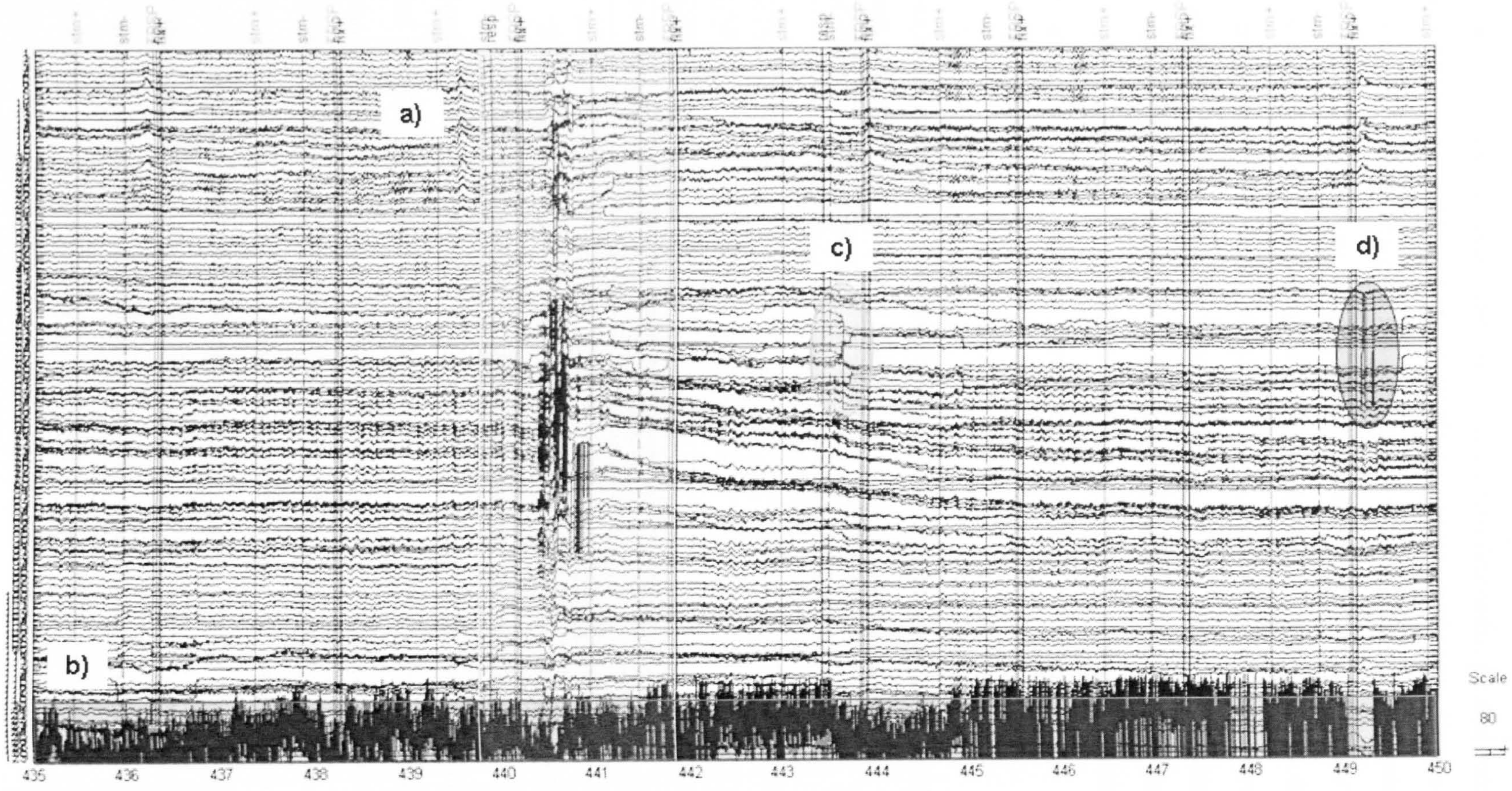
The final sample in this study composed of 13 typically developing (TD) children and 11 children with ASD, all of whom contributed to data in the VEP study. Data from one TD child could not be processed because that specific file could not be converted to the format required.

ICA and time-frequency decomposition

EEG recordings were processed using EEGLAB (Delorme & Makeig, 2004) - a freely available open source toolbox (http://www.sccn.ucsd.edu/eeglab) running under Matlab 7.4 (The Mathworks). Data were high-passed filtered at >1 Hz and re-referenced to the average reference. The first phase of artefact rejection was conducted by screening the continuous data by eye for spatially distorted segments of EEG recordings. Figure 4.2 (pg 87) shows a section of EEG recording from a TD participant and illustrates how a segment of EEG recording (marked by the yellow box labelled a)) was identified as spatially distorted. EEG segments that were marked as spatially distorted were subsequently removed. Channels which consistently showed large deviations in EEG amplitudes and spatially distorted segments within their recordings were also removed. Aberrations in the EEG recording within channels that can lead to a channel being rejected were marked in Figure 4.2, within the pink box b), the green oval c) and the blue oval d).

The remaining data were decomposed by ICA, using the runica algorithm (Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997). The average number of time-points processed for the TD children was 151,088 (S.D.=6,353, mean time equivalent = 10min 4sec), and for the children with ASD was 137,114 (S.D.=17,403, mean time equivalent = 9min 8sec). An independent sample t-test revealed that on average, the children with ASD contributed less data than the TD children to the ICA decompositions ($t(df=12.3)=2.52$, $p<0.026$).

Figure 4.2 A section of EEG recording from a TD participant.



The yellow box a) highlights a spatially distorted segment of the EEG recording, the pink box b), the green oval c), and the blue oval d) highlights aberrations in the EEG recording within channels that may contribute to a channel being rejected.

The data was segmented into epochs of 2000ms (-500 to 1500 ms post-stimulus onset), that correspond to visual stimulation by parallel first order, parallel second order, hyperbolic first order and hyperbolic second order gratings, separately. Epochs within each condition were baseline corrected, using the epoch segment 200 to 0ms pre-stimulus onset. As described in the preceding paragraphs, individual participant EEG data that contained spatially-distorted segments were already detected by eye and removed, thus the participants were left with a smaller number of epochs than the maximum possible with 75 trials for each type of grating. The mean numbers of epochs preserved for subsequent analyses, for each condition and for each group, are presented in Table 4.1. The mean number of epochs across all conditions that were preserved for the TD children was significantly greater than the mean number of epochs for the ASD children (t(df=13.3)=2.51, p=0.026).

Table 4.1 Means and standard deviations (in parentheses) of number of epochs processed for each type of stimuli, in TD children and Children with ASD.

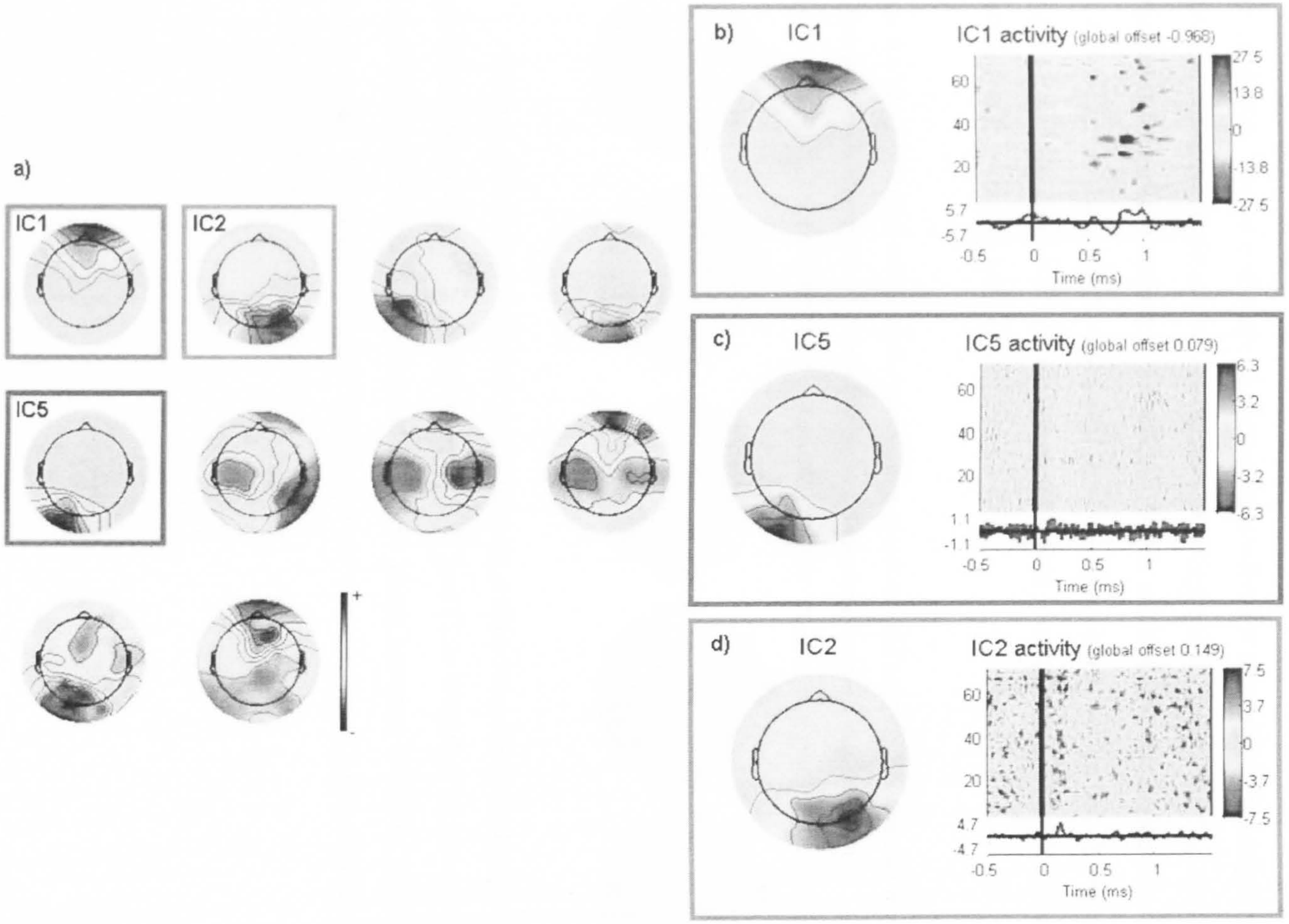
Type of stimuli	No. of Epochs	
	TD Children (N=13)	ASD Children (N=11)
Parallel 1st order	69 (5.0)	62 (10.9)
Parallel 2nd order	69 (5.3)	60 (8.7)
Hyperbolic 1st order	69 (4.4)	61 (11.0)
Hyperbolic 2nd order	69 (4.3)	61 (9.0)

Source locations of the resultant independent components were estimated by applying inverse dipole modelling methods to a standard boundary element head model (Oostendorp & van Oosterom, 1989). Components whose dipole fitting had more than 15% residual variance, whose dipole locations were not within the standard boundary element head model, and whose scalp maps resembled artefacts i.e. eye blinks, eye movements, cardiac pulse, muscle activity, line noise, were excluded from further analysis. Figure 4.3 (pg 90) shows a) scalp maps of 10 independent components (IC) produced from ICA of a TD child participant. Scalp maps display the power distribution for EEG oscillatory activity across the surface of participant(s) head, with red indicating positive power values, and blue indicating negative power values, as shown by the colour bar. ERP image plots (to the right side of b), c) and d) in Figure 4.3) represent the change in electrical potential with time for individual epochs. The x-axis of each plot indicates time, the y-axis of the plot

indicates the trial number, and the colour of the data point in the plot represents the amplitude of the potential. The ERP averaged across all the trials is shown below the ERP image plot. IC1 is identified as a component resembling eye blinks due to the high power in the frontal region of the scalp map and also random 'spots' of high potential regions within the ERP image plot as shown on the right side of b). IC5 is identified as a component resembling muscle activity due to the high power being localized in one region of the scalp map, and the high frequency of the ERP waveform as shown in c).

The dipole locations for components in this study were unlikely to be accurate indicators of source locations, as the standard boundary element head model assumed an adult-size head circumference, whereas the data it was applied to was from children. Therefore, while dipole locations were used as a criterion for excluding outlier components, scalp maps were used for selecting components that had a higher likelihood of showing neural activity in the visual cortical region. Higher power in the posterior region of a scalp map is a probable indicator of neural activity in the visual cortical regions of a component. Components that appeared to represent such activity were identified for each participant. Figure 4.3 d) displays IC2, a component from data of a TD participant that is likely to represent neural activity in the visual cortical regions. A total of 99 components that resembled visual cortical sources were retained; 54 components were from the TD children, 45 components were from the children with ASD. The average number of components preserved for each group was 4.2 (S.D.=1.14) for the TD children, and was 4.1 (S.D.=0.94) for the children with ASD. There were no significant group differences in the number of components identified in each group ($t(df=22)=0.145$, $p=0.886$).

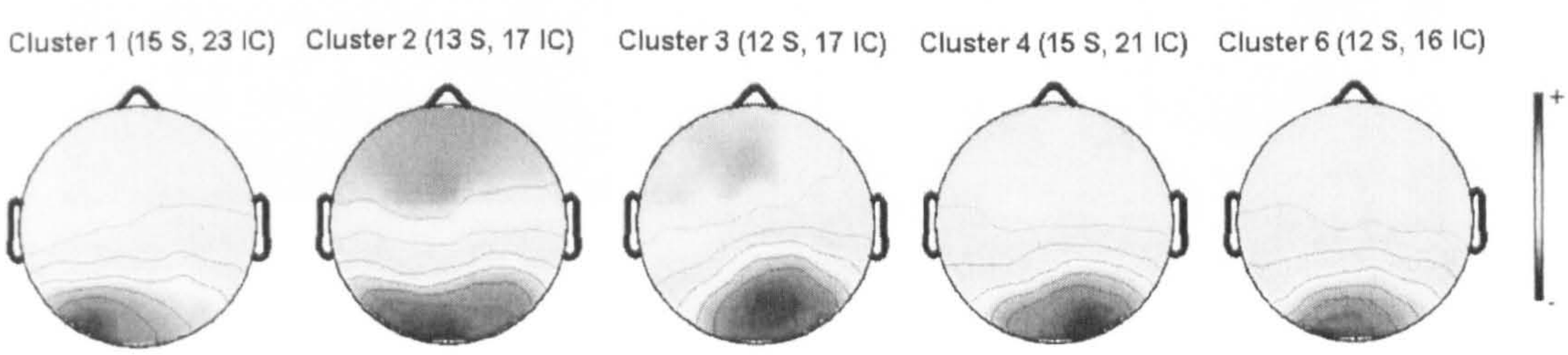
Figure 4.3 An example of output from ICA conducted on data from a TD participant.



a) The ICA resulted in 10 independent components, b) IC1 is identified as a component representing eye blinks, c) IC5 is identified as a component representing muscle activity, d) IC2 is identified as a component representing visual cortical activity.

The selected components were then clustered in two stages. The first stage was conducted using the k-means algorithm in EEGLAB. Gamma-band EEG activity was defined in this study as within 30 to 40Hz. Therefore, components were grouped in terms of how similar they were with regards to i) spectra activity within 30 to 40 Hz, ii) event-related potentials (ERP) occurring between 0 to 210ms post stimulus onset, iii) the scalp activity distribution of those components, iv) their dipole locations, v) event-related spectral power (ERSP) and inter-trial coherence (ITC) measures between 0 to 210ms post stimulus onset and within 30 to 40 Hz. As shown in Figure 4.4, five clusters of components were produced. The second stage of clustering involved screening and reassigning individual components from the five clusters of components, to produce two clusters of components henceforth named C01 and C02. It was ensured that components included in C01 and C02 were not outliers compared to other components within the clusters, in terms of dipole locations and ERSP. Scalp maps and dipole locations for C01 and C02 are illustrated in Figures 4.5 and 4.6 (pg 92 and 93).

Figure 4.4 Five clusters of components representing visual cortical activity. The number of subjects (S) and independent components (IC) contributing to the cluster are shown in parentheses.



Gamma power was extracted by performing a time frequency decomposition on single trial data epochs for all components in C01 and C02. Wavelets of 12-cycle windows (444ms wide) generated ERSP values at 200 time points between -278.0 to 1274.0 ms post stimulus onset. The mean change in spectral power was computed relative to baseline activity 100 to 0 ms pre-stimulus onset.

Figure 4.5 Scale map, dipole locations and ERSP images for parallel and hyperbolic, first and second order gratings in C01.

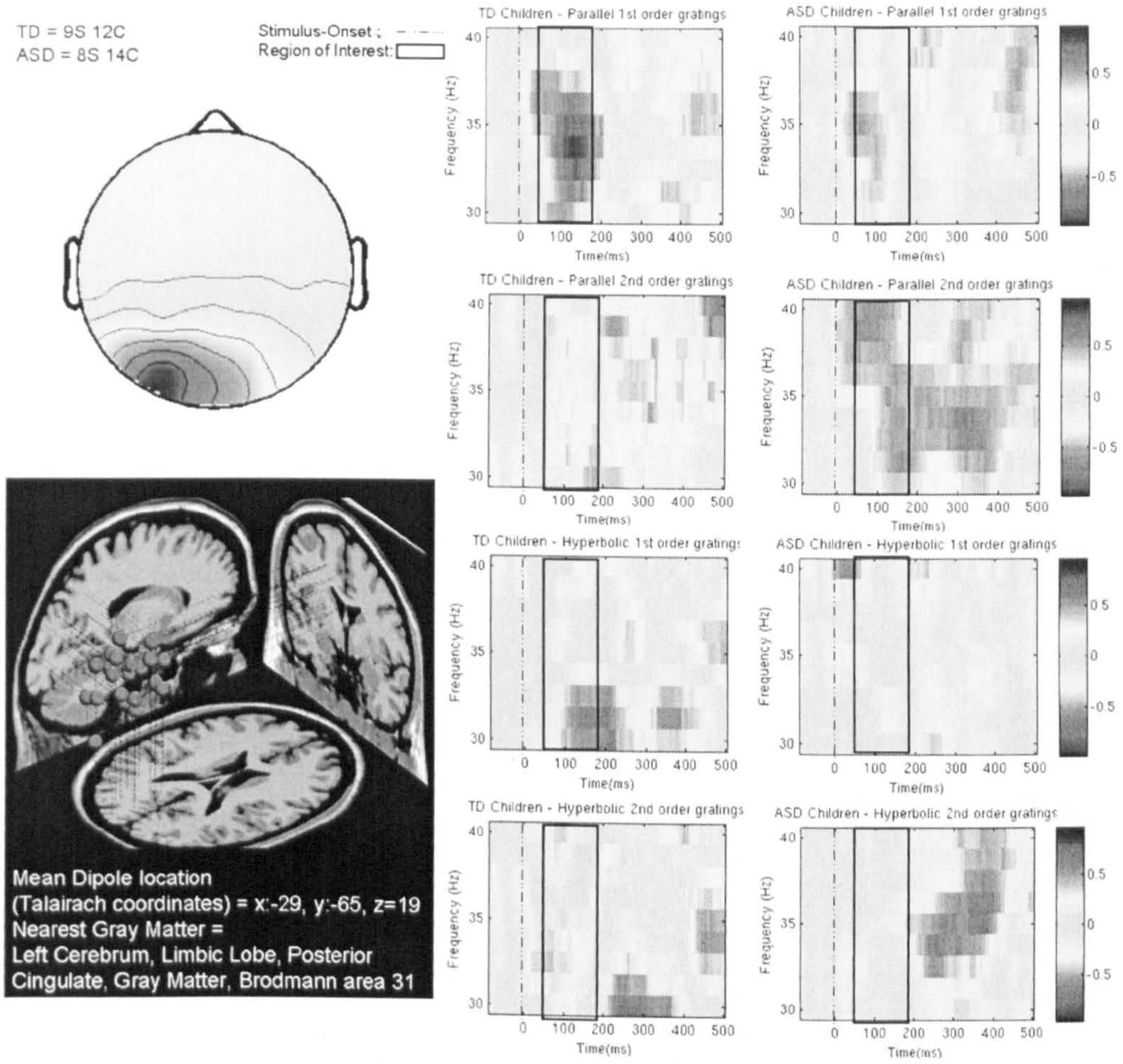
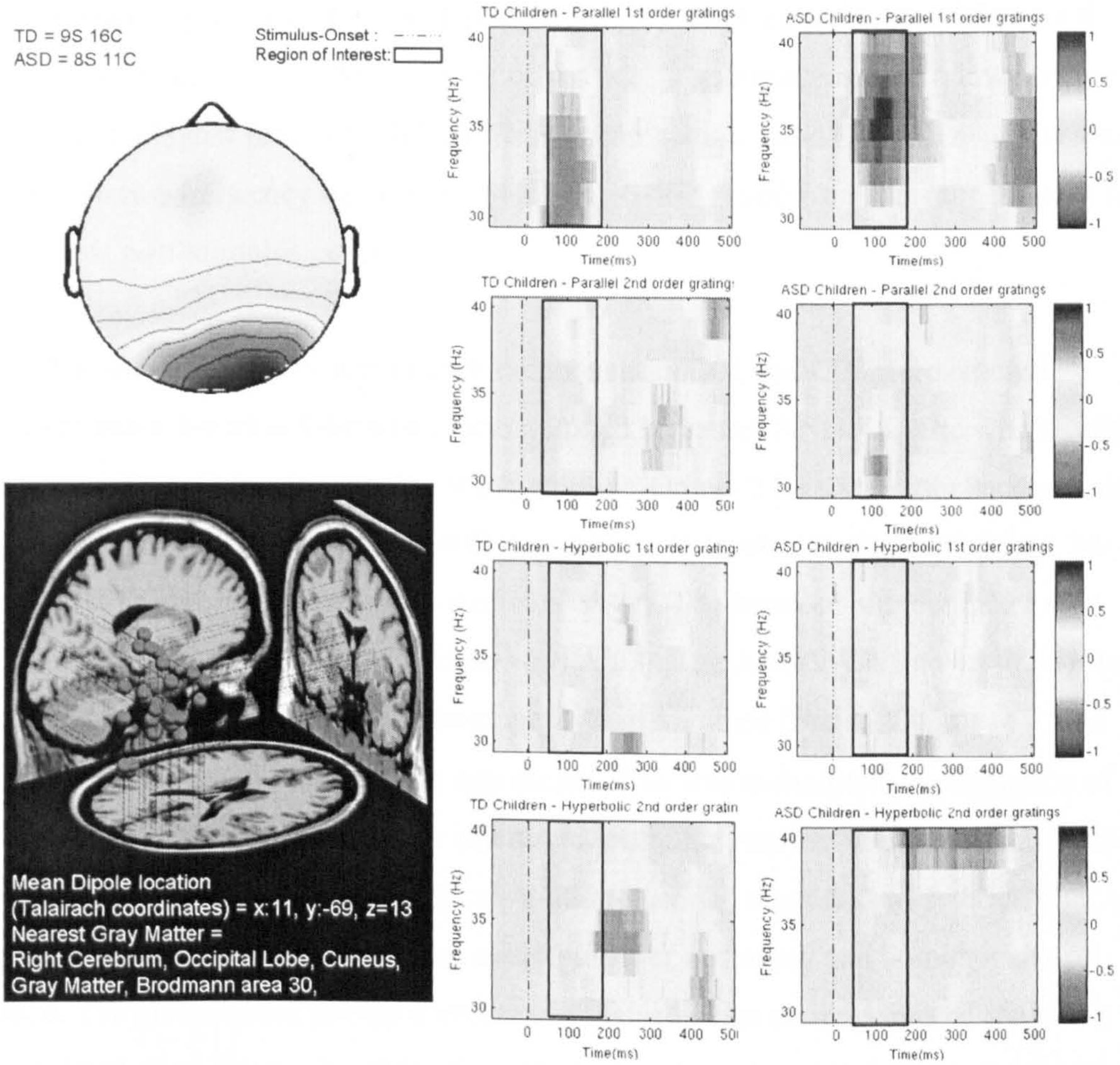


Figure 4.6 Scale map, dipole locations and ERSP images for parallel and hyperbolic, first and second order gratings in C02.



4.3 Results

Visual inspection of the ERSP images for C01 and C02 in Figures 4.5 and 4.6 respectively, suggested that there may be differences in gamma power at a lower range (31-35Hz) and at a higher range (36-40Hz). Thus, mean gamma band (30-40Hz) power was examined in two frequency bands (31-35Hz and 36-40Hz) and five 30ms time blocks from 30 to 180ms post-stimulus onset.

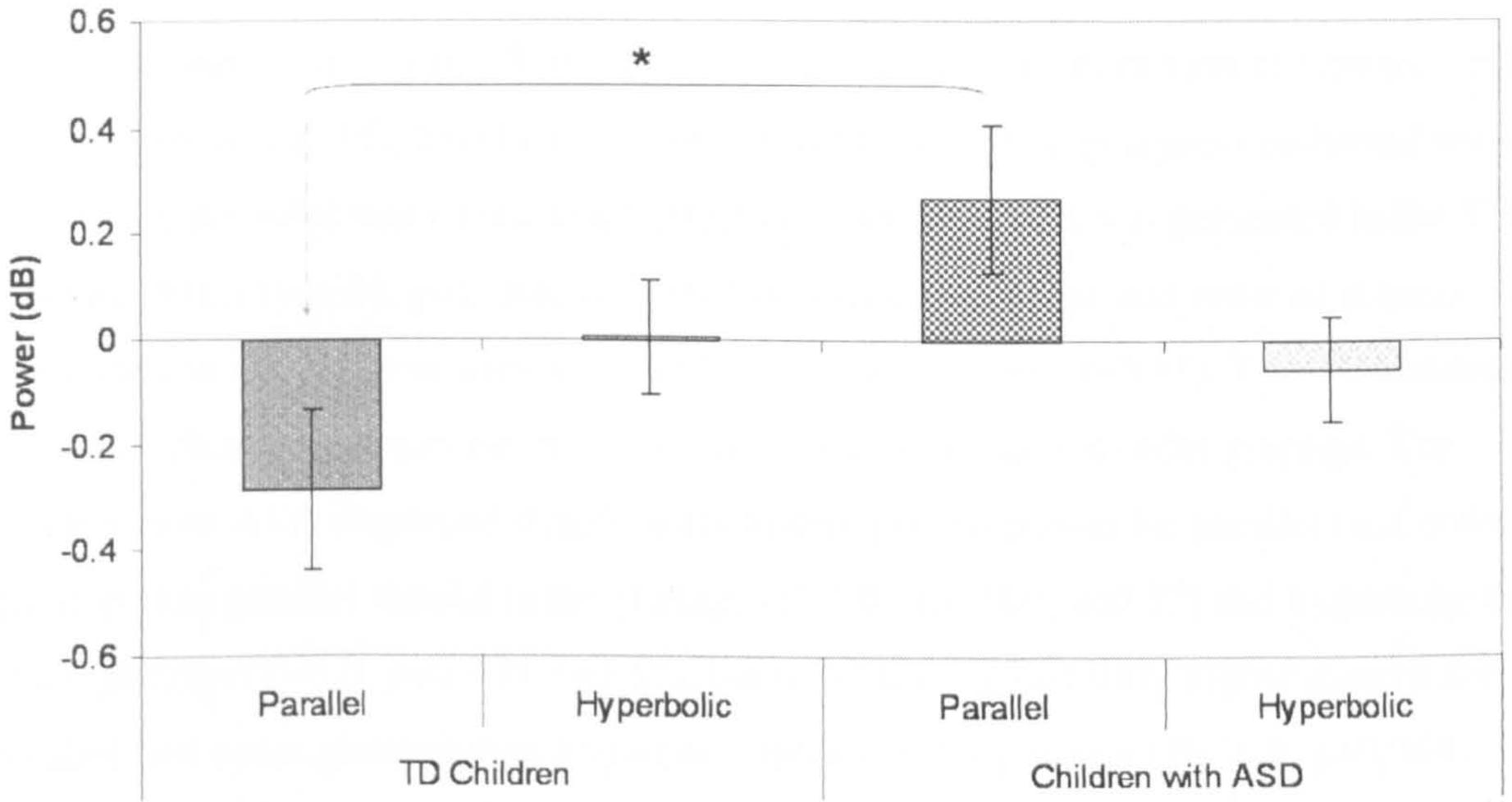
The mean gamma power of each component in C01 and C02 were entered separately into a 4-within 1-between factors mixed measures ANOVA. The within-subject factors were Type (2 levels: parallel or hyperbolic), Order (2 levels: first or second order), Frequency (2 levels: 31-35Hz or 36-40Hz) and Time (5 levels: 30-60ms, 60-90ms, 90-120ms, 120-150ms, 150-180ms post-stimulus onset). The between-subject factor was Group (2 levels: TD children or Children with ASD). The ANOVA is known to be robust towards violations of normality and homogeneity of variance (Field, 2005a), so it was employed even if the violations were significant. This was to facilitate investigation of interaction effects and to allow better interpretation of the results. Non-parametric post-hoc tests were used to ensure that main effects and interactions identified with the ANOVA were not artefacts of the data violating assumptions of normality and homogeneity of variance. The green-house geisser correction was used when assumptions of sphericity were violated. Significance level for the statistical analyses is set at 0.05 for 2-tailed tests. Effects sizes are measured as the Pearson's Correlation coefficient, r. Values of 0.10, 0.30 and 0.50 denote small, medium and large effect sizes respectively.

C01

C01 consisted of data from 9 TD children (12 components) and 8 children with ASD (14 components). Data from C01 did not violate assumptions of normality (Kolmogorov-Smirnov test: $p>0.149$), but did for assumptions of homogeneity of variance (Levene's test: $F(1,24)<5.09$, $p>0.033$).

There was a significant interaction of type of stimuli and group ($F(1,24)=6.93$, $p=0.015$, $r=0.47$) on gamma power in C01. As shown in Figure 4.7, there was a significant group difference in gamma power for parallel gratings ($U=41$, $p=0.027$, $r=0.43$) but not for hyperbolic gratings ($U=82$, $p=0.940$, $r=0.02$). The children with ASD showed higher gamma power to parallel gratings than the TD children.

Figure 4.7 Bar Graph depicting mean gamma power to parallel and hyperbolic gratings for each group in C01. Error bars indicate standard error and *p<0.05.



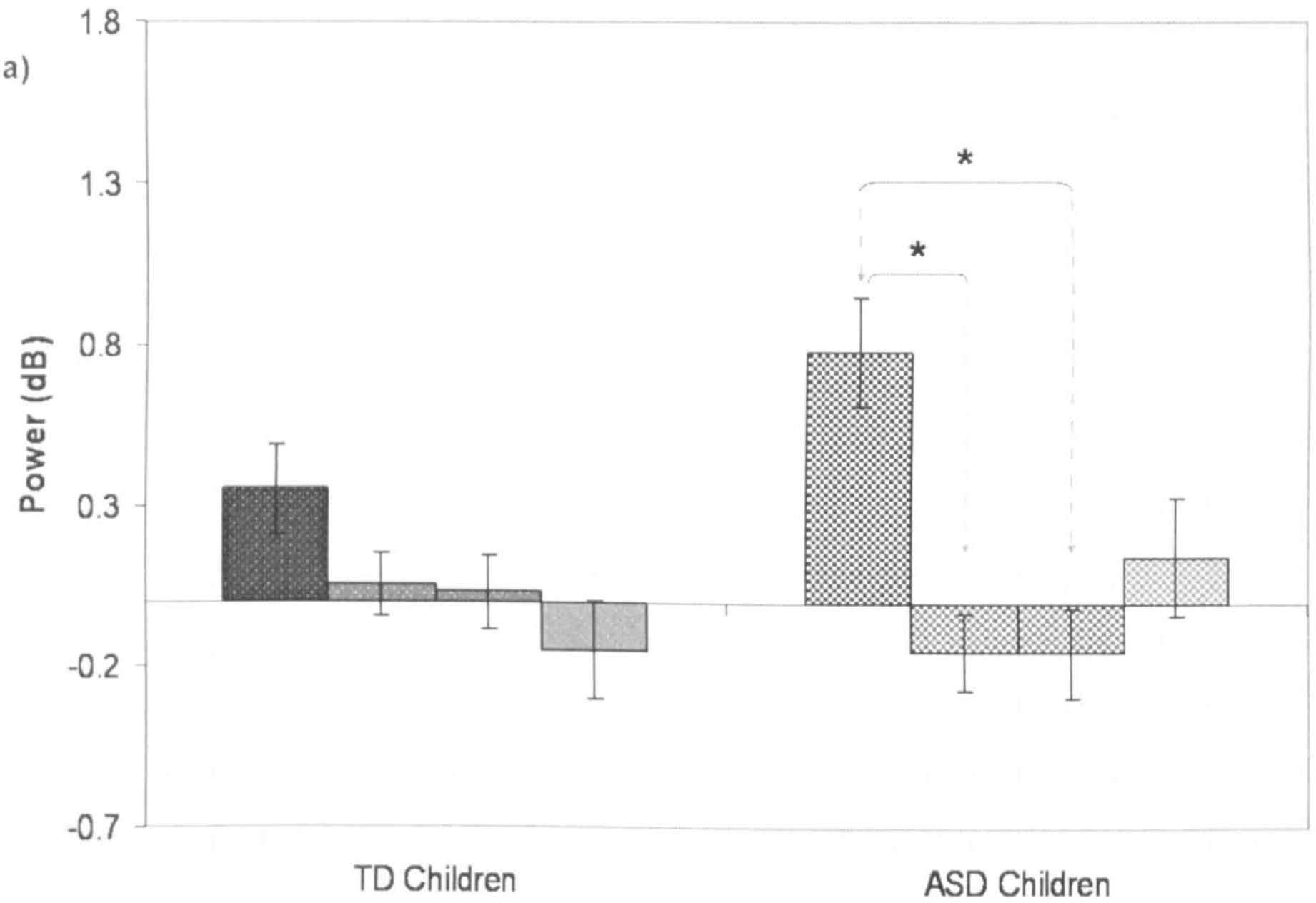
C02

C02 consist of data from 9 TD children (16 components) and 8 children with ASD (11 components). Data from C02 did not violate assumptions of normality (Kolmogorov-Smirnov test: $p=0.140$), but did so for assumptions of homogeneity of variance (Levene's test: $F(1,25)<5.98$, $p>0.022$).

There were significant main effects of type of stimuli ($F(1,25)=5.12$, $p=0.033$, $r=0.41$), order of stimuli ($F(1,25)=7.21$, $p=0.013$, $r=0.47$), and a significant interaction of type and order of stimuli ($F(1,25)=16.9$, $p<0.001$, $r=0.63$) on gamma power in C02. The latter interaction was displayed in Figure 4.8 b) (pg 95). Post-hoc analyses revealed that this interaction was driven by gamma power for parallel first order gratings being significantly higher than for parallel second order gratings, hyperbolic first order gratings, and hyperbolic second order gratings ($T<64.0$, $p<0.002$, $r>0.58$).

As shown in Figure 4.8 a) (pg 97), there was also an interaction of type and order of stimuli with group ($F(1,25)=11.6$, $p=0.002$, $r=0.56$). Post-hoc analyses conducted within each group revealed that only a main effect of order of stimuli was presented in the TD children ($F(1,15)=4.63$, $p=0.048$, $r=0.49$), but a significant type and order of stimuli interaction in the children with ASD ($F(1,10)=19.8$, $p=0.001$, $r=0.81$). The TD children showed higher overall gamma power for first order than second order gratings. The children with ASD displayed significantly higher gamma power for parallel first order gratings than parallel second order gratings ($T=3.0$, $p=0.005$, $r=0.57$) and hyperbolic first order gratings ($T=3.0$, $p=0.005$, $r=0.57$), but only near significantly higher gamma for parallel first order gratings than hyperbolic second order gratings ($T=11.0$, $p=0.054$, $r=0.42$).

Figure 4.8 Bar graphs depicting three-way interaction of Type, Order and Group on gamma power in C02.

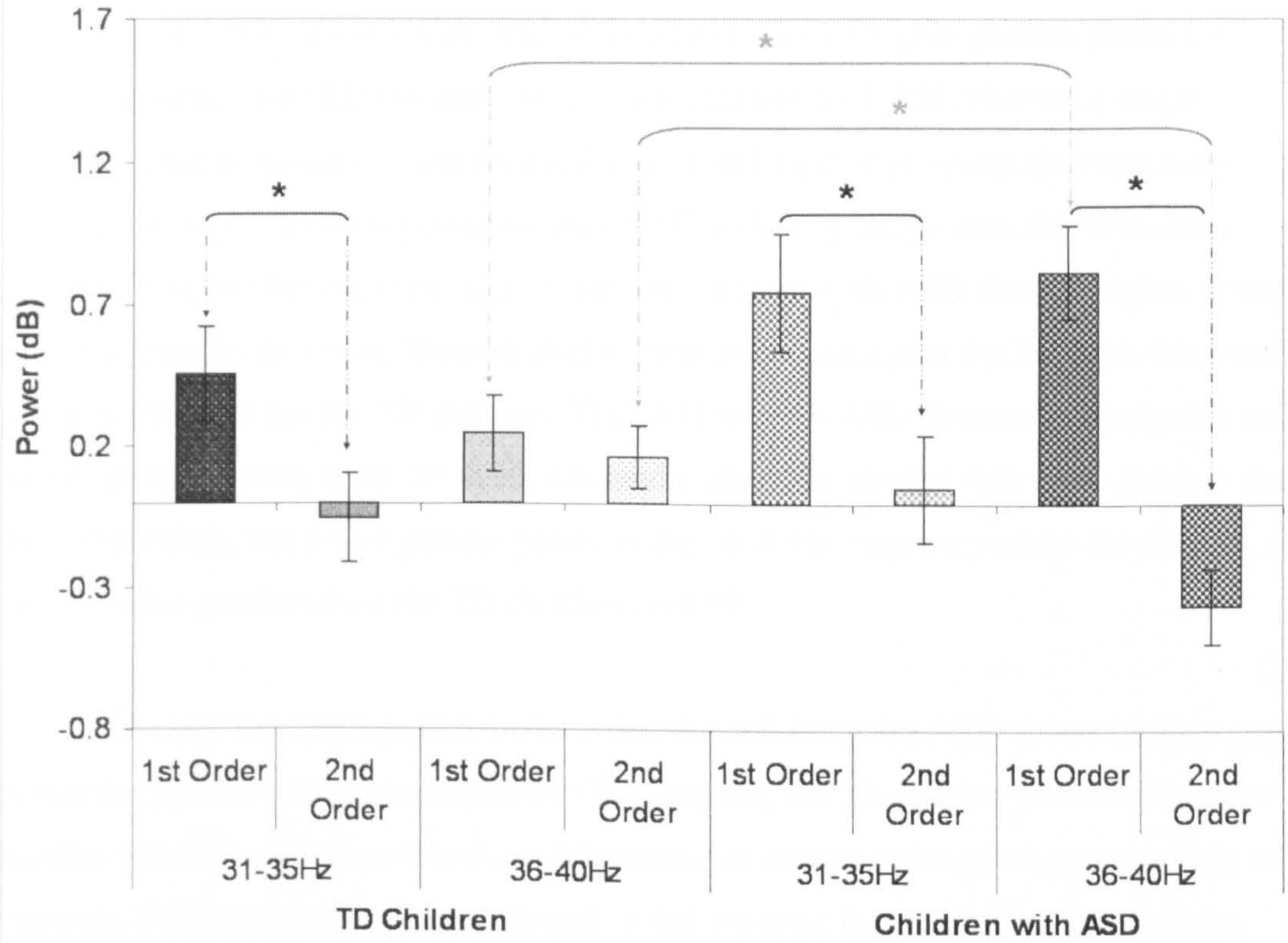


a) Mean gamma power values are plotted for parallel and hyperbolic, first and second order gratings in TD children and children with ASD, b) mean gamma power values are plotted for parallel and hyperbolic, first and second order gratings in the group combined. Error bars denote standard error of means.

There was a significant interaction of order of stimuli, frequency and group ($F(1,25)=5.13$, $p=0.032$, $r=0.41$) on gamma power in C02. In view of post-hoc analyses conducted for the significant interaction of type and order of stimuli with group on gamma power described in the previous paragraph, in which the children with ASD only showed an effect of order for parallel stimuli and not hyperbolic stimuli, further investigation of the significant interaction of order of stimuli, frequency and group was isolated to the parallel stimuli.

Figure 4.9 (pg 99) depicts the interaction of order of stimuli, frequency and group on gamma power for parallel stimuli only. There was a significant main effect of order ($F(1,25)=25.4$, $p<0.001$, $r=0.71$), an interaction of order of stimuli and group ($F(1,25)=6.82$, $p=0.015$, $r=0.46$), and an interaction of order of stimuli, frequency and group ($F(1,25)=6.16$, $p=0.020$, $r=0.44$) on gamma power for parallel gratings in C02. This interaction of order of stimuli and group was significant for the 36-40Hz frequency band ($F(1,25)=12.0$, $p=0.002$, $r=0.57$), but not for the 31-35Hz frequency band. As indicated by the black brackets in Figure 4.9, the children with ASD showing significantly higher gamma power for parallel first order gratings than parallel second order gratings in both frequency bands ($T<9.0$, $p<0.032$, $r>0.46$), but the TD children only showing that effect of order in the 31-35Hz frequency band ($T=15.0$, $p=0.004$, $r=0.48$) and not the 36-40Hz frequency band ($T=60.0$, $p=0.706$, $r=10$). As indicated by the grey brackets in Figure 4.9, the children with ASD also showed significantly higher gamma power than the TD children at the 36-40Hz frequency band, for parallel first order gratings ($U=48.0$, $p=0.050$, $r=0.38$), but lower gamma power than the TD children at the 36-40Hz frequency band, for parallel second order gratings ($U=34.0$, $p=0.007$, $r=0.51$).

Figure 4.9 Bar graphs depicting three-way interaction of Order, Freq and Group for gamma power to parallel gratings in C02. Graph plots mean values and error bars denote standard error.



4.4 Discussion

In C01, the children with ASD showed evidence of higher gamma power for parallel gratings than TD children. In C02, the children with ASD showed a larger differentiation in gamma power for parallel first order gratings versus the three other gratings i.e. higher gamma power for parallel first order gratings than the three other gratings, than the TD children. In addition, the children with ASD showed higher gamma power to parallel first order than parallel second order gratings at the 36-40Hz frequency range in C02, but not the TD children. The children with ASD demonstrated significantly higher gamma power at the 36-40Hz frequency range for parallel first order gratings than the TD children, but lower gamma power at the 36-40Hz frequency range for parallel second order gratings than the TD children, in C02.

Overall, the findings demonstrate that the children with ASD showed higher gamma power for parallel gratings compared to TD controls, and also higher gamma power for parallel first order gratings *relative to* hyperbolic or second order gratings, compared to TD controls. The current results are different to that reported by Milne et al (2009) which reported no group difference in overall gamma power elicited by parallel first order gratings, and larger increases in gamma power to parallel first order gratings of increasing spatial frequency in the TD children, than for the children with ASD. The children with ASD in the current study not only showed higher gamma power for parallel gratings than hyperbolic gratings, they also showed larger selectivity for parallel first order gratings compared to the more "complex" gratings. There were however, a few differences in stimuli characteristics of the parallel first order gratings used here and in Milne et al (2009) which may have contributed to the discrepancy in the results. Milne et al (2009) used gabor patches that did not have noise added, which were presented at a lower luminance contrast of 68%, in diagonal (45°) orientation.

Gamma power is thought to be indicative of neuro-connectivity within functional cortical regions (von Stein & Sarnthein, 2000), and parallel and first order gratings are thought to require engagement of the primary visual area V1 more so than V2 and the extra-striate visual areas, while hyperbolic and second order gratings require greater engagement of V2 and the extra-striate visual areas (Larsson, Landy, & Heeger, 2006). The

findings present a strong indication that individuals with ASD may have increased neuro-connectivity within primary visual area V1. It was also observed that the children with ASD showed lower gamma power at the 36-40Hz frequency range for parallel second order gratings than the TD children, in C02. Therefore, there is some indication that there may be reduced neuro-connectivity within the visual cortical region in individuals with ASD compared to TD controls, for gratings requiring engagement of the different functional visual cortical regions.

Increased neuro-connectivity within primary visual area V1 can account for enhanced sensitivity of individuals with ASD to discriminating orientation of static parallel first order gratings (Bertone, et al., 2005). As described in chapter one, lateral connections between the orientation-selective V1 neurons have been proposed to shape orientation selectivity in V1 neurons (Andrews, 1965; McLaughlin, Shapley, Shelley, & Wielaard, 2000; Shapley, Hawken, & Ringach, 2003). A computer simulation of the neuronal architecture of primary visual area V1 have also confirmed that increased neural connectivity within V1 i.e. between the orientation-selective V1 neurons, can promote more efficient processing of orientation information of visual stimuli (Gustafsson, 1997). The observation of enhanced orientation perception of parallel first order gratings in individuals with ASD (Bertone, et al., 2005) may therefore be attributed to increased lateral connections between orientation-selective neurons in V1. Further investigation correlating gamma power responses and contrast sensitivity measures for orientation perception of parallel first order gratings, in individuals with ASD and TD individuals, is warranted to establish an association between neuro-connectivity and orientation perception of parallel first order gratings.

The pattern of ASD-TD differences in gamma power at 36-40Hz range, for parallel first and second order gratings in C02, parallel the behavioural performance observed in individuals with ASD and TD controls for orientation discrimination of parallel first and second order gratings in Bertone et al (2005)'s study (Bertone, et al., 2005). The children with ASD in this study showed higher gamma power at the 36-40Hz range to parallel first order gratings than the TD children, and lower gamma power at the 36-40Hz range to parallel second order gratings than the TD children, as the individuals with ASD in Bertone et al (2005)'s study showed increased sensitivity for orientation of parallel first order

gratings than the TD controls, and reduced sensitivity for orientation of parallel second order gratings than the TD controls. Thus, although no perceptual sensitivity measures for parallel first and second order gratings were collected from participants in this study, it can be speculated that the increased gamma power at the 36-40Hz range in C02 in the children with ASD for parallel first order gratings herein could be a reflection of enhanced processing of the orientation of parallel first order gratings.

On a further note, the results discussed in the previous paragraph also revealed subtle differences in the frequency range of gamma power to low level visual stimulation in the children with ASD and the TD children, which may reflect atypicalities in the spatial extent of neural interaction within the visual cortical region in the children with ASD. The children with ASD showed higher gamma power at the 36-40Hz range for parallel first order gratings than parallel second order gratings in C02, but not the TD children. The TD children only showed an effect of order on gamma power to parallel gratings at the 31-35Hz frequency range, as did the children with ASD. The effect of order of stimuli on gamma power to parallel first and second order gratings at the higher frequency range in the children with ASD, but not in the TD children, may be a reflection of differences in the spatial extent of neural interactions within the visual cortex. Neural activity synchronized at higher frequencies are thought to reflect smaller distances across neural interactions (von Stein & Samthein, 2000). It is proposed that the differential effect of order on gamma power at the higher gamma-band frequency range in the children with ASD may indicate a smaller spatial extent of neural interactions in the visual cortical region of these individuals, than the TD children. This conjecture is consistent with findings from post-mortem and structural imaging studies that revealed presence of narrowed mini-columns in the frontal and temporal cortical regions in individuals with ASD (Casanova, et al., 2003). This gamma-band frequency range effect would therefore be an interesting finding to follow up on in future studies.

The results reported in this chapter provide support for the speculation on chapter three's VEP finding that increased activity of the visual cortical region within the first 100-200ms of visual stimulation in the children with ASD may reflect over-representation of local contrast signals in the visual cortical region. The present results suggest increased neuro-connectivity in the primary visual area V1 in ASD, which is likely to be associated

with over-representation of local contrast signals in the visual cortical region as primary visual area V1 is known for contrast detecting processes (Dumoulin, et al., 2003; Smith, et al., 1998). Chapter three found no evidence that visuo-integrative processes, associated with perception of second order gratings and hyperbolic gratings, are atypical in children with ASD. Therefore the results from both studies suggest that individuals with ASD are more likely to have atypicalities with the initial visual processes for local contrast detection occurring within primary visual area V1, rather than with the later stage visuo-integrative processes, and this may be brought about by increased neuro-connectivity within the primary visual area V1.

It is herein acknowledged that there are a number of imperfections in the way the EEG data were collected and analyzed in this study. Eye tracking data was not collected in conjunction with the EEG recording, which presents the possibility that gamma power measured in this study may be an artefact of miniature saccades dynamics rather than neuronal oscillations (Melloni, Schewiedrzik, Rodriguez, & Singer, in press; Yuval-Greenberg, Tomer, Keren, Nelken, & Deoueil, 2008). However micro-saccadic artefacts are more likely to occur between 200 to 300ms post- stimulus onset, to show maximum activity around the eyes and minimum activity posteriorly with averaged referencing. It is therefore unlikely that the current analysis of gamma power responses between 0 to 210ms post-stimulus onset from components that show maximum activity in the posterior scalp region would be strongly influenced by saccadic activity. Also, it has already been mentioned that the dipole locations of the components produced from the ICA may be inaccurate as a standard boundary element head model which assumed an adult-size head circumference was used for the children data. In addition, different channels and different numbers of channels were preserved for individual participants, which may have led to the children with ASD being found to contribute a significantly lesser amount of data than the TD children for the ICA decomposition. It is not clear how this could have impacted on the quality of the ICA decomposition for the different sets of data. There was also a discrepancy in the mean numbers of epochs preserved for statistical analyses with the children with ASD having a lower number of epochs than the TD children, which is not the ideal case for comparing neural responses for the children with ASD and the TD children on equal standing. Nevertheless, the limitations in the data analysis would have made it more difficult for group differences in gamma power response to visual stimulation to be

revealed, between the children with ASD and TD children. It is therefore unlikely that these limitations have any influence on the significance of the findings in the study.

Furthermore, the use of ERSP as a measure of gamma-band EEG activity in this study may still only provide a narrowed view of gamma-band activity in visual perception in ASD. The gamma power in this study i.e. total gamma power measures a combination of evoked and induced gamma-band neural activity. Evoked gamma band oscillatory activity is gamma power that is phase-locked to a reference event, while induced gamma-band oscillatory is gamma power that is not phase-locked to the reference event. Total gamma power therefore provides an indication of the extent of production of gamma band oscillatory activity, while evoked gamma power may inform on the timing of those responses to the reference event. A further measure that is highly correlated with evoked gamma power is inter-trial coherence which indicates the extent of phase-locking of the neural signals to the reference event of interest. The present study therefore can only report on the production of gamma band oscillatory activity to visual stimuli in children with ASD and TD children, but it unable to directly inform on whether there are issues with timing the neural activity to visual stimuli between groups. A recent study investigated gamma-band MEG activity for auditory stimuli in children with ASD and TD children (Rojas, Maharajh, Teale, & Rogers, 2008), and found an interaction of group with different measures of gamma band activity i.e. evoked, induced and inter-trial coherence. The children with ASD showed lower evoked gamma power than the TD children, higher induced gamma power than the TD children, and reduced inter-trial coherence for gamma-band MEG activity than the TD children. The children with ASD also did not show differences in the total gamma power elicited, when compared to the TD children. The results were interpreted as that the children with ASD were not likely to have a deficiency in the production of gamma-band oscillatory activity, but may have a greater issue with timing the gamma-band neural activity to external stimulation. Future research using this multi-measure approach for investigating gamma band oscillatory activity in ASD to visual stimuli, would help decipher which aspects of gamma band activity i.e. production and timing may be atypical in low level visual perception in ASD and would provide a more comprehensive depiction of the brain dynamics underlying low level visual perception in ASD.

Conclusions

The children with ASD showed elevated gamma power for parallel and first order gratings, relative to hyperbolic and second order gratings, compared to TD controls. The findings strongly suggest that individuals with ASD may have increased neuro-connectivity within primary visual area V1. The results from both chapters three and four suggest that individuals with ASD are more likely to have atypicalities with the initial visual processes for local contrast detection occurring within primary visual area V1, rather than with the later stage visuo-integrative processes, and this may be brought about by increased neuro-connectivity within the primary visual area V1.

5 Chapter Five –

Magnocellular and Parvocellular Pathway Functioning and Their Contribution to Motion Processing in Adolescents with ASD and Their Siblings

5.1 Introduction

As described in chapter one, there is some evidence for global motion perception difficulties in ASD (Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000; Spencer & O'Brien, 2006, for negative findings see de Jonge, et al., 2007; Del Viva, et al., 2006; Milne, et al., 2006; Takarae, et al., 2008). Global motion perception deficits in ASD have been attributed to atypicalities along the dorsal visual stream (Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000). The dorsal visual stream is a cortical pathway that interconnects the primary visual area V1, the extra-striate areas such as V2, V3 and V5, and the inferior parietal areas (Merigan, et al., 1997; Mishkin, Ungerleider, & Macko, 2001). It is thought to be responsible for visual location of objects and motion perception in the human visual system. Visual information is transmitted from the retina to the dorsal visual stream along the sub-cortical visual tracts i.e. the magnocellular (M) and the parvocellular (P) pathways, via the lateral geniculate nucleus, with the M pathway being the dominant contributor (Merigan, et al., 1997; Merigan & Maunsell, 1993). Global motion perception deficits in ASD have therefore been speculated to be a result of atypical visual inputs from the sub-cortical M and P pathways (Milne, et al., 2002; Plaisted, et al., 1999).

Three independent studies have investigated the integrity of M and P pathways in individuals with ASD and TD individuals, using measures of contrast sensitivity to detecting gratings of specific spatial and temporal frequency parameters (Bertone, et al., 2005; Davis, et al., 2006; Pellicano, Gibson, et al., 2005). The M pathway is thought to respond optimally to stimuli moving at low spatial frequencies and high temporal frequencies, while the P pathway is thought to respond optimally to high spatial frequency stimuli that are stationary or slow moving (Merigan & Maunsell, 1993). M pathway functioning was assessed using gaussian (low spatial frequency) stimuli flickering at a temporal frequency of 10Hz (Pellicano, Gibson, et al., 2005), gratings at a spatial frequency of 0.5cpd and flickering at a temporal frequency 6Hz (Bertone, et al., 2005,), and gratings at a spatial frequency of 0.5cpd and flickering at a temporal frequency 12.5Hz (Davis, et

al., 2006). None of the studies reported significant group differences in contrast sensitivity between participants with ASD and TD controls, suggesting M pathway functioning to be intact in ASD. Two of those studies also examined P pathway functioning in ASD. Bertone et al (2005) presented gratings at a spatial frequency of 6cpd and flickering at a temporal frequency of 1Hz, and found no significant group difference in contrast sensitivity (Bertone, et al., 2005). In contrast, Davis et al (2006) presented gratings at a spatial frequency of 13.4cpd and flickering at a temporal frequency of 2Hz, and demonstrated reduced contrast sensitivity in the participants with ASD compared with TD controls (Davis, et al., 2006). Therefore, there is only some evidence indicating impaired P pathway functioning in ASD. Please see the Appendix for Table 8.5 (pg 165), which summarizes ASD-related experimental studies in which measures of M and P pathway functioning have been examined.

It has however been argued that the stimulus size used in previous investigations of M and P pathway functioning in ASD were too large, and that may have made the tests insensitive to group differences in M pathway functioning (Plaisted & Davis, 2005). Based on evidence indicating that the response of a magnocellular cell in the lateral geniculate nucleus is greatly suppressed by stimulation outside of its receptive field (Solomon, White, & Martin, 2002), it was suggested that large stimuli may dampen neural responses within the M pathway. The visual stimuli used in Bertone et al (2005), Pellicano et al (2005) and Davis et al (2006)'s studies, which subtended 10 degrees visual angle, 6.3 degrees visual angle (estimated from the reported SD of 3.15 degrees visual angle), and 5.23 degrees visual angle, respectively, may have been too large to optimally assess M pathway functioning in individuals with ASD and TD controls. There are to date no published results directly addressing this issue, although it was recommended by Plaisted and Davis (2005) that a stimulus size of 1 to 2 degrees visual angle would be appropriate for targeting the M pathway neural response (Plaisted & Davis, 2005).

The M pathway is also selectively sensitive to luminance contrast, and almost insensitive to chromatic contrast, while the P pathway is selectively sensitive to chromatic contrast (particularly on the red/green dimension of colour space), and almost insensitive to luminance contrast (Merigan & Maunsell, 1993). Luminance and chromatically defined gratings are therefore alternative stimuli for assessing M and P pathway functioning.

Luminance and chromatic gratings have yet to be used for investigating M and P pathway functioning in individuals with ASD, and can be useful stimuli to utilize as they would provide converging evidence for determining M and P pathway functioning in ASD. They have been employed in an investigation of M and P pathway functioning in infants at risk of developing ASD, as described in greater detail in the following paragraph.

McCleery et al (2007) examined M and P pathway functioning in 6-month-old infants at high risk of developing ASD and 6-month-old infants who did not have a history of developmental disorders in the family (McCleery, Allman, Carver, & Dobkins, 2007)[3]. Luminance (light/dark) and chromatic (red/green) gratings that optimally stimulate the M and P pathways respectively were used as test stimuli. The infants' contrast sensitivity for detecting the test stimuli were measured using a forced-preferential looking paradigm. The infants at high risk of ASD showed higher contrast sensitivity for luminance gratings, but similar contrast sensitivity for chromatic gratings when compared with the infants at low risk of ASD. The results suggest that the infants at high risk of ASD had enhanced M pathway functioning and typical P pathway functioning. The infants at high risk of ASD in the study had not been reported to develop ASD by the time they could have been reliably diagnosed. Thus it was proposed that enhanced M pathway functioning may relate more to the broader autistic phenotype[4], rather than to the ASD itself.

In addition to comparing the absolute contrast sensitivity for detecting luminance and chromatic stimuli separately between groups, McCleery et al (2007) also evaluated the *relative* contrast sensitivity to luminance gratings versus chromatic gratings in the infants at high and low risk of ASD, which would verify if the balance between M and P pathway functioning is typical in individuals with ASD. The relative functioning of M versus P pathway was quantified as the log ratio of contrast sensitivity for luminance gratings to

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[3] ASD cannot be reliably diagnosed before 2 years of age. Therefore, many researchers are investigating infant siblings of individuals with ASD to uncover underlying neurobiological markers associated with ASD early in development. This methodology is justified as ASD is believed to have a strong genetic component (Ciaranello & Ciaranello, 1995; Muhle, et al., 2004) and epidemiological studies have found ASD occurrence rates in siblings of individuals with ASD to be 50 to 150 times greater than rates in the general population (Ciaranello & Ciaranello, 1995). Parents and siblings of individuals with ASD have also been found to show autistic-like behavioural characteristics albeit to a milder degree (Bailey, et al., 1995; Bailey, Palferman, Heavey, & Le Couteur, 1998; G. Dawson, et al., 2002; Piven, et al., 1997).

[4] The broader autism phenotype refers to autistic-like personality and behavioural traits of a milder degree that reflects familial relation to ASD (Bailey, et al., 1995; Bailey, et al., 1998; G. Dawson, et al., 2002; Piven, et al., 1997).

contrast sensitivity for chromatic gratings (L:C). A positive L:C ratio indicated higher contrast sensitivity to luminance than chromatic gratings i.e. higher functioning of the M pathway relative to the P pathway. There was a significant difference in L:C ratios between the infants at high risk of ASD, whose group mean L:C ratio was positive, and the infants at low risk of ASD, whose group mean L:C ratio was negative. The results indicate that the infants at high risk of ASD may have stronger M pathway functioning relative to P pathway functioning, while the infants at low risk of ASD may have stronger P pathway functioning relative to M pathway functioning. It was originally suggested that atypical visual perception in ASD may be explained by the balance in activity of the two visual channels responsible for processing low and high spatial frequencies (Milne, et al., 2002; Plaisted, et al., 1999). It is possible that how the M and P pathways interact with each other may be a more pertinent factor in the relationship between M and P pathway functioning and global motion perception in ASD, than just the absolute differences in M and P pathway functioning between groups. It remains to be established whether individuals with ASD show differences in the relative functioning of M versus P pathway compared to TD individuals, and whether atypical balance of M and P pathway functioning may play a role in atypical visual perception in ASD.

Other than the basic integrity of the M and P pathways and the balance of functioning of the M and P pathways, the extent to which M and P pathways contribute to the dorsal visual stream may also influence motion perception abilities. The MOT:DET ratio, which is a ratio of the contrast threshold required to discriminate direction-of-motion (MOT) and the contrast threshold required to detect presence of motion (DET), is an established way to quantify the contribution of the M pathway and the P pathway to cortical motion direction mechanisms in vision research (Derrington & Henning, 1993; Dobkins & Teller, 1996; Lindsey & Teller, 1990; Palmer, Mobley, & Teller, 1993). Discriminating direction-of-motion (MOT) i.e. local motion direction perception, requires processing by direction-selective neurons in the visual cortex (Movshon & Newsome, 1996; Snowden, Treue, & Andersen, 1992; Snowden, Treue, Erickson, & Andersen, 1991). Thus, MOT is a measure of the functioning of cortical motion direction mechanisms. The simple detection of motion (DET) in this paradigm is accomplishable by the sub-cortical M and P pathways which are not direction-selective, but are sensitive to luminance or chromatic contrast (Skottun & Skoyles, 2006). Thus DET is fundamentally a measure of M

and P pathway functioning. A MOT:DET ratio for discriminating direction-of-motion and detecting the same moving luminance grating, provides an index for the M pathway contribution to cortical motion direction mechanisms; A MOT:DET ratio for discriminating direction-of-motion and detecting the same moving chromatic gratings, provides an index for the P pathway contribution to cortical motion direction mechanisms.

Adult psychophysical studies have revealed MOT:DET ratios to be near 1.0 for luminance gratings, but closer to 2.0 – 4.0 for chromatic gratings, indicating stronger input of the M pathway than the P pathway to the cortical motion direction mechanisms than the P pathway in adults (Derrington & Henning, 1993; Dobkins & Teller, 1996; Lindsey & Teller, 1990; Palmer, et al., 1993). On the other hand, infants exhibit MOT:DET ratios that are comparable for luminance and chromatic gratings, suggesting that in early development M and P pathways provide equal input to the cortical motion direction mechanisms (Dobkins & Teller, 1996). Therefore, the infant and adult data indicate that the contribution of P pathway relative to M pathway for the cortical motion direction mechanisms decreases with development. Atypical development of this relationship between the sub-cortical pathways and the cortical motion direction mechanisms could be associated with motion perception deficits in ASD. Thus, in addition to the balance of M and P pathway functioning, the extent to which M and P pathways contribute to cortical motion direction mechanisms is another characteristic of the visual system that has yet been investigated in individuals with ASD.

In summary, previous research have revealed no evidence for atypical M pathway functioning, and equivocal evidence for impaired P pathway functioning, in individuals with ASD (Bertone, et al., 2005; Davis, et al., 2006; Pellicano, Gibson, et al., 2005). There is however some dispute with respect to whether the test stimuli used were appropriate for eliciting group differences in M pathway functioning (Plaisted & Davis, 2005). Furthermore, M and P pathway functioning have not been investigated with luminance and chromatically defined stimuli. Re-assessing M and P pathway functioning in ASD using luminance and chromatic stimuli may provide converging evidence for resolving the controversy on M and P pathway functioning in ASD. Two other aspects of the relationship between the sub-cortical visual pathways and the cortical visual system have also not been examined in ASD: the balance between M and P pathway functioning, and the extent to

which M and P pathways contribute to cortical motion direction mechanisms. This study therefore sought to address these issues and to provide a thorough examination of M and P pathway in ASD.

This study employed the MOT:DET paradigm for conducting a comprehensive investigation of M and P pathways in ASD, because the paradigm is capable of providing measures to examine i) the basic integrity of the M and P pathways, ii) the balance between M and P pathway functioning, and iii) the extent to which M and P pathways contribute to cortical motion direction mechanisms. Furthermore, data on contrast sensitivity of the participants to direction-of-motion discrimination (MOT) of luminance and chromatic gratings i.e. local motion direction perception would also be collected. Thus, the study would also examine iv) local motion direction perception in individuals with ASD.

The tasks were administered to adolescents with ASD, TD controls and also adolescents with siblings diagnosed with ASD (SIBS)[5]. The inclusion of SIBS was to make explicit, if any visual processing atypicalities found in participants with ASD, may also be present in individuals who have genetic similarities with individuals with ASD i.e. the broader autism phenotype.

[5] The broader autism phenotype was explored in this chapter with siblings of individuals with ASD, and not in the other studies in this thesis, as this study was done in collaboration with Professor Karen Dobkins at UCSD, whose research group has conducted studies with siblings of individuals with ASD.

5.2 Method

Participants

A total of 24 adolescents with ASD, 42 typically-developing (TD) adolescents, and 13 adolescents with siblings diagnosed with ASD (SIBS) were recruited for the study. Participants were recruited by advertising the study through community resources for parents with children affected by ASD, and also via the special education division and schools in the San Diego Unified School District. In addition, participants who had participated in previous studies from the lab were informed about the study and invited to participate. Informed consent from parents and participants were obtained at the start of each testing session. The study took 2-3 hours for each participant to complete. Participants were given USD10 for each hour spent on the research. The study protocol was approved by the UCSD Human Research Protection Program, which ensures that the federally registered Institutional Review Boards (IRB) policies are adhered to.

Parents were asked if their children had any vision issues e.g. short-sightedness, strabismus, and if there was a history of colour vision deficiencies in the family. All participants who contributed to the study were tested with the Ishihara colour deficiencies test (Ishihara, 1992) to ensure that they did not have undetected colour deficiencies. Adolescents with colour vision deficiencies and vision impairments were excluded from the study. All participants had normal or corrected to normal vision.

Psychometric Assessments

The Wechsler Abbreviated Scale of Intelligence (WASI) was administered to all participants to obtain measures of their cognitive ability. All four standardized sub-tests within the WASI were used in this study, in contrary to only two of the sub-tests being used in the previous chapters. The four standardized sub-tests assess expressive language, perceptual organization, abstract verbal reasoning and nonverbal fluid reasoning abilities. The two verbal sub-test scores can be converted into a verbal IQ score, and the two non-verbal sub-test scores can be converted into a performance IQ score. The four sub-tests when considered together yield a full scale IQ that provides a composite measure of the participant's intellectual ability.

Parents of all participants were asked to complete the *Lifetime* version of the Social Communication Questionnaire (SCQ) (Rutter, Bailey, Lord, & Berument, 2003) and the Social Reciprocity Scales (SRS) (Constantino, 2002). The Autism Diagnostic Observation Schedule (ADOS) was also administered to each participant with ASD to confirm clinical diagnoses, and each SIBS participant to confirm that the individuals did not meet the criteria for an ASD. The SCQ, SRS and the ADOS were described in greater detail in the Method section of chapter two.

Visual apparatus

The visual stimuli were presented on a high resolution RGB monitor (19.8" SONY GDM-F520 monitor, 100Hz frame rate, 1024x768 pixels at dot pitch of 0.22mm). The monitor was driven by a Microsoft Windows XP computer with Intel Pentium 4 processor. The Cambridge Research System's toolbox for MATLAB was used to create the visual stimuli and run the experimental paradigm. A 14 bit VSG2/3F digital video card was used to increase the range of the existing 8 bit computer graphics system and improve the display resolution. Gamma correction was performed to linearize the voltage/luminance relationship for the monitor display, using a PR-650 SpectraColorimeter (Photoresearch). At a viewing distance of 50 cm, the viewable portion of the monitor subtended 40.5 x 30.9 degrees visual angle.

Stimuli

The stimuli in these experiments were luminance (light/dark) and iso-luminant chromatic (red/green) sinusoidal gratings (mean luminance (L) = 23 cd/m^2, CIE 0.489 0.453) presented on a yellow background with the same luminance/chromaticity. The luminance (light/dark) sinusoidal gratings were produced by modulating the red and green phosphors in phase. The luminance contrast was controlled by varying the amplitude of the luminance sinusoid, which was produced from the summation of the red and green sinusoid. The luminance contrast (i.e., the luminance difference between the light and dark phases of the grating) is described in terms of Michelson contrast: $(L_{max} - L_{min})/(L_{max} + L_{min})$, where $L_{max} = L_{red} + L_{green}$, and $L_{min} = L_{red} - L_{green}$. Note that zero percent luminance contrast refers to a uniform field, which is indistinguishable from the background. The chromatic (red/green) sinusoidal gratings were produced by modulating

the red and green phosphors 180° out of phase. The chromatic gratings were displayed at equal luminance by setting the amplitudes of the red and the green sinusoids at the same values, and the chromatic contrast was controlled by varying the amplitude of the red and green sinusoids equally.

The gratings subtended 2.0 x 2.0° visual angle and were at a spatial frequency of 1.0cpd. They were horizontal gratings that could be moving up or down, at a drift temporal frequency of 5.5Hz. The stimuli parameters were selected to minimize the influence of chromatic aberration and possible spatial in-homogeneity of the display (Lindsey & Teller, 1990), and in expectation that they will replicate previous findings of large MOT:DET ratios in adults for chromatic gratings (Palmer, et al., 1993).

Psychophysical Paradigm

Participants were tested in a dark room and viewed the video monitor binocularly from a chin rest situated 50 cm away. Participants were instructed to maintain fixation on a small cross (length and width = 0.2 degrees) in the centre of the monitor. At the start of the session, participants first completed a motion minimization task to obtain their personal photometric iso-luminance setting for the chromatic gratings (Iso-luminance is defined as the phenomenon where two stimuli are observed to be of the same luminance by a human observer). This is because a chromatic grating displayed at equal luminance, may not be perceived as iso-luminant by a human observer. A human observer may need greater or smaller amplitude of the red sinusoid, relative to the green sinusoid, in order to see the output of both sinusoids in a grating as of the same luminance, and this setting for chromatic stimuli varies between individuals. Each participant's photometric iso-luminance setting was used to ensure that there is minimal detectable luminance information in chromatic gratings presented. The luminance contrast of the chromatic gratings is described in terms of a Michelson contrast: $(L_{red} - L_{green})/(L_{red} + L_{green})$. Participants were presented with a moving chromatic grating at the centre of the monitor, and were asked to adjust its luminance contrast in steps of 0.5% Michelson contrast (i.e. participants were changing the amplitude of either the red sinusoid or the green sinusoid differentially) until the apparent movement of the chromatic grating was the least prominent. Each participant made 10 photometric iso-luminance settings for 10 chromatic gratings. If the standard deviations for

their iso-luminance settings were above that of 1.0% luminance contrast, an adult mean iso-luminance setting obtained from 20 college students was used. Three participants with ASD, three TD participants and four SIBS participants used the adult mean iso-luminance setting for the chromatic gratings presented to them.

In the DET task, participants began each trial with a key press, after which a moving grating appeared at the centre of the monitor in one of two 250 ms intervals, separated by a 500 ms gap. The beginning of each of the two time intervals was accompanied by a beep. After each trial, participants reported whether the visual stimulus appeared during the first or second beep via key press, i.e. in a standard two-alternative forced choice manner. In the MOT task, participants also began each trial with a key press, after which a moving grating appeared at the centre of the monitor in for 250 ms. The beginning of the time interval was accompanied by a beep. After each trial, participants reported whether the visual stimulus appeared was moving up or down via key press, i.e. again in a standard two-alternative forced choice manner. Feedback was provided in which a beep sound of a different pitch indicated a correct response. Within each task, the luminance and chromatic gratings were presented randomly across trials, with 120 trials obtained for type of grating. The total number of trials was 480 (120 trials * 4) for luminance and chromatic gratings in the DET and the MOT tasks.

The contrast of luminance and chromatic gratings varied across trials in an adaptive staircase procedure. The contrast for subsequent trials of that type of grating varied in a 1 down/2 up procedure, based on the PEST method (see Taylor & Creelman, 1967). After a correct response, the subsequent contrast was decreased by one step size, and after an incorrect response, the subsequent contrast was increased by two step sizes. The maximum step size was 0.14 log units (1.38-fold change in contrast). The value of the step size was determined by an acceleration factor of 1.2 and a reversal factor of power of 1.1. Following either two correct or two incorrect responses, the step size was multiplied by the acceleration factor. Following a reversal in correctness, the stepsize was multiplied by (1/acceleration factor)^reversal power.

Data Selection

Three participants with ASD had difficulties differentiating the first time interval from the second time interval in the DET task, so their data were excluded. Data from two participants with ASD and three TD participants were also excluded as they had a performance IQ score of below 85 and there were doubts as to whether they understood the requirements of the psychophysical tasks. One SIBS participant met the ADOS cut-off for ASD so his data was also excluded from the final sample. Therefore, data from 19 participants with ASD, 39 TD participants and 12 SIBS participants contributed to the final sample. The ASD, TD and SIBS groups were matched on chronological age and performance IQ. Please see Table 5.1 for the participants' demographics.

Table 5.1 Group characteristics of participants with ASD, TD and SIBS participants.

	ASD (N=19)	TD (N=39)	SIBS (N=12)	F & p values
Sex	18 boys, 1 girl	22 boys, 17 girls	5 boys, 7 girls	
Vision Issues	12 Normal Vision 7 Corrected Vision	25 Normal Vision* 14 Corrected Vision	6 Normal Vision* 6 Corrected Vision	
Chronological Age (months)				
M	180	183	181	F(2,67)=0.193, p=0.825.
SD	21	14	21	
Range	148 – 215	144 – 212	156 – 215	
Verbal IQ				
M	98	109	106	F(2,67)=2.612, p=0.081
SD	23	15	10	
Range	55 – 133	77 – 133	86 – 123	
Performance IQ				
M	105	108	109	F(2,67)=0.746, p=0.478
SD	11	11	10	
Range	86 – 127	86 – 129	86 – 124	

Full Scale IQ				
M	101	109	108	F(2,67)=2.274, p=0.111
SD	16	12	10	
Range	70 – 125	79 – 133	93 – 124	
	ASD (N=19)	TD (N=39)	SIBS (N=12)	
SCQ Score[+]				
M	22	3	2	F(2,64)=120.3, p<0.001
SD	7	3	2	
Range	6 – 32	0 – 10	0 – 4	
SRS Score[+]				
M	93	53	58	F(2,64)=61.0, p<0.001
SD	19	8	12	
Range	61 – 121	39 – 89	44 – 86	
ADOS Total[++]				
M	9	0		t(df=19.8)=12.1, p<0.001
SD	3	1		
Range	4 – 16	0 – 1		

Note.

[*] *1 TD participant and 1 SIB participant (both females) had a brother and a father with colour vision deficiencies. Both participants showed no colour vision deficiencies.*

[+] *SCQ and SRS questionnaires were not returned for 3 TD participants. Post-hoc Games Howell correction indicated that participants with ASD had significantly higher SCQ and SRS scores than the TD participants and the SIBS participants.*

[++] *1 SIB participant did not complete the ADOS assessment*

Of the participants with ASD, four had a diagnosis of Autistic disorder, nine had a diagnosis of Asperger's syndrome and six had a diagnosis of an ASD. The diagnoses were given by from a qualified clinical or educational professional based on the DSM-IV criteria (APA, 2004). One participant who had a diagnosis of Asperger's syndrome attained an ADOS total score of 6, and another participant who had a diagnosis of ASD attained an ADOS total score of 4, both of which were below the ADOS cut-off for ASD. Given that

both of these participants had an existing diagnosis of ASD given by a qualified professional these participants were not excluded from the analysis. Furthermore, the participant with Asperger's syndrome had a SRS score of 114, which was above the SRS published mean of 101.5 for PDD-NOS. Also, the participant with ASD had a SCQ score of 22 which was above the ASD cut-off score of 15 for the SCQ, and had a SRS score of 94 which within one standard deviation below the SRS published mean for PDD-NOS.

Obtaining Contrast Sensitivity Data

For each participant, at the end of the experiment, the 120 trials obtained for each type of grating for each task, were used to obtain a contrast threshold for that stimulus/task. This was performed by fitting a psychometric Gumbel function (Gumbel, 1958) to "percent correct vs. contrast" data, using maximum likelihood method (Johnson, Kotz, & Balakrisnan, 1995; Watson, 1979).

$$\Pr[X \le x] = \exp\left\{-e^{-(x-\varepsilon)/\theta}\right\}$$

The Gumbel function is an extreme value model, and is also known as a log-Weibull model. The better known Weibull function has a distribution that can be transformed into a Gumbel function by the formula: $Z = -\log(\varepsilon - X)$. While the Weibull function obtains limiting distributions of the least values, the Gumbel function obtains limiting distributions of the greatest values.

Contrast thresholds obtained from the experimental paradigm were in instrument contrast. The human visual system has 3 types of cone photoreceptors: *l*-cones are maximally sensitive to long wavelengths of light, *m*-cones to medium wavelengths and *s*-cones to short wavelengths. Instrument contrast describes the vector sum of the modulation of cone photoreceptors by the visual stimuli. Comparing luminance and chromatic contrast thresholds with instrument contrast metric is inappropriate because luminance gratings modulate *l*-cones and the *m*-cones similarly, while chromatic gratings modulate *l*-cones and the *m*-cones in opposite phases. The luminance and chromatic instrument contrast thresholds were therefore converted to cone contrast metric. Cone contrast describes the amplitude of the modulation of cone photoreceptors by the visual stimuli, and allows luminance and chromatic contrast thresholds to be expressed in comparable units. The

contrast threshold for luminance stimuli is equivalent in instrument or cone contrast metric, so the luminance contrast thresholds needed no alteration. Chromatic contrast thresholds were multiplied by a factor of 0.287 i.e. the maximum cone contrast produced by chromatic gratings in this experimental set-up, to convert the values to cone contrast metric.

Contrast *sensitivity* was calculated as the inverse of cone contrast threshold. Contrast sensitivity was then logged as logarithmic, but not linear, contrast sensitivity data conform to normal distributions. A total of four contrast sensitivity values were obtained: 1) contrast sensitivity for luminance gratings in the DET task (Lum-DET-Sens), 2) contrast sensitivity for chromatic gratings in the DET task (Chrom-DET-Sens), 3) contrast sensitivity for luminance gratings in the MOT task (Lum-MOT-Sens), and 4) contrast sensitivity for chromatic gratings in the MOT task (Chrom-MOT-Sens).

Variables derived from contrast sensitivity data

Luminance: Chromatic (L:C) ratios provide a metric for comparing relative functioning of M versus P pathway. The L:C ratios were computed by subtracting Chrom-DET-Sens from Lum-DET-Sens. A positive L:C ratio would indicate a higher contrast sensitivity to luminance gratings than chromatic gratings and vice versa for a negative L:C ratio.

MOT:DET ratios for luminance gratings were calculated by subtracting Lum-DET-Sens from Lum-MOT-Sens; and for chromatic gratings by subtracting Chrom-DET-Sens from Chrom-MOT-Sens. A further computation was performed to enable the comparison of relative contributions of M and P pathway functioning to motion direction perception. The MOT:DET ratio of luminance gratings was subtracted from the MOT:DET ratio of chromatic gratings to form a difference ratio (Diff-Ratio). A positive Diff-Ratio would indicate a higher MOT:DET ratio to chromatic gratings compared to that of luminance gratings, suggesting a stronger relative contribution of M versus P pathway input to motion direction perception; A Diff-Ratio close to zero would indicate similar MOT:DET ratios of chromatic gratings and luminance gratings, suggesting equal M and P pathway input to motion direction perception.

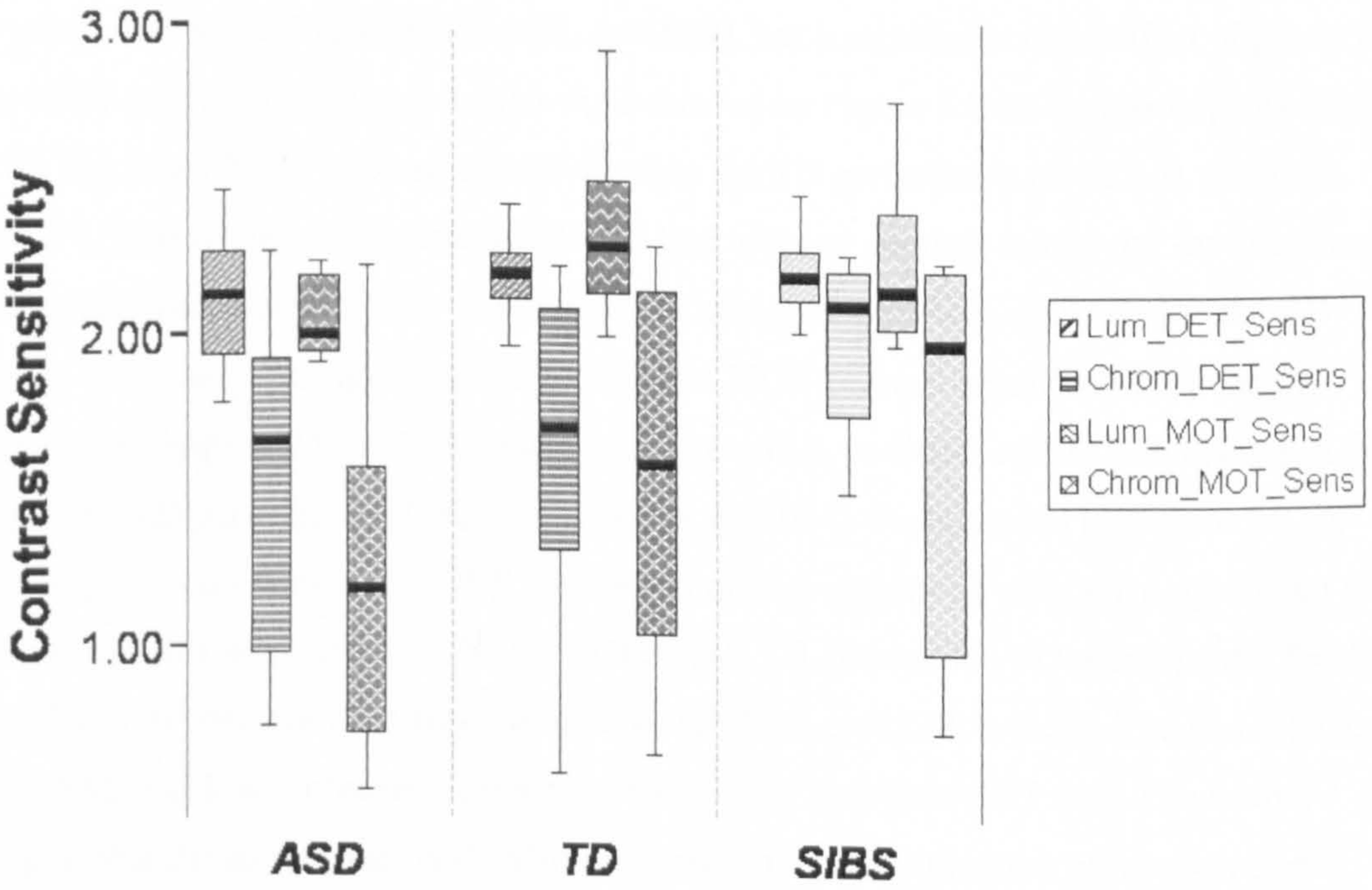
5.3 Results

The significance level is set at 0.05 for 2-tailed tests. Effects sizes, where appropriate, are measured as the Pearson's Correlation coefficient, r. Effects sizes are considered to be small, medium and large for the r-values: 0.10, 0.30 and 0.50 respectively (Field, 2005b).

Contrast Sensitivity Data

The contrast sensitivity data within each group (ASD, TD and SIBS) were screened for outliers, defined as scores that were +/- 3 standard deviations from the group mean, and no outliers were revealed. The dependent variables Lum-DET-Sens, Chrom-DET-Sens, Lum-MOT-Sens, and Chrom-MOT-Sens, violated assumptions of normality (Kolmogorov-Smirnov test: $p>0.003$) which is not usually the case (see Gunther & Dobkins, 2002), and assumptions of homogeneity of variance (Levene's test: $F(2,67)<3.99$, $p>0.023$). Figure 5.1 displays contrast sensitivity for each type of grating and task for each group.

Figure 5.1 Box-plot depicting contrast sensitivity to luminance and chromatic gratings for the DET and the MOT tasks for each group. Dark lines within the boxes indicate the median values, and error bars depict the inter-quartile range.

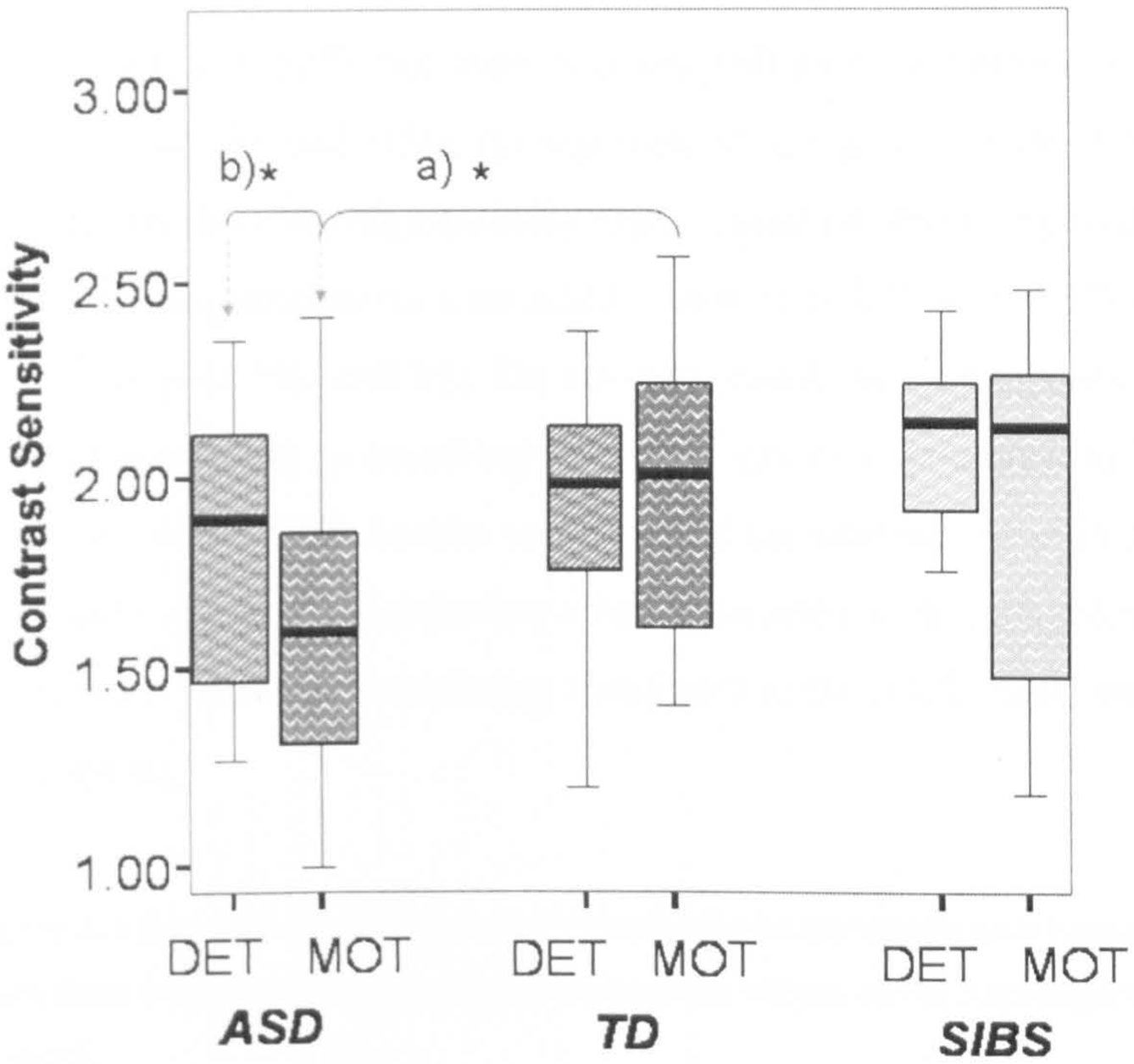


Do adolescents with ASD show deficits in local motion perception?

Lum-DET-Sens, Chrom-DET-Sens, Lum-MOT-Sens, and Chrom-MOT-Sens, were entered into a 2-within, 1-between, mixed measures ANOVA, with the within-subject factors as Task (2 levels: DET or MOT) and Stimuli (2 levels: luminance or chromatic) and between-subject factors of Group (3 levels: ASD, TD or SIBS), to establish if the participants with ASD displayed atypical contrast sensitivity to direction-of-motion discrimination of luminance and chromatic gratings, compared to the TD and SIBS participants, and relative to detection of motion of luminance and chromatic gratings. The ANOVA was used in the examination of interaction effects regardless of whether assumptions of normality or of homogeneity of variance were violated as it is known to be robust towards these violations (Field, 2005a). However, as a precaution, non-parametric post-hoc analyses were carried out to ensure that any significant results in the ANOVA were not artefacts of the violation of assumptions.

As shown in Figure 5.2 (pg 122), there was a significant interaction of task type and group on contrast sensitivity ($F(2,67)=3.28$, $p=0.044$, $r=0.30$). Non-parametric Kruskal Wallis tests applied separately to contrast sensitivity (collapsed over luminance and chromatic gratings) for the DET task and the MOT task revealed no significant main effect of group for the DET task ($H(2)=4.62$, $p=0.099$), but a significant main effect of group for the MOT task ($H(2)=8.23$, $p=0.016$). As indicated by Figure 5.2 a), the participants with ASD had lower MOT contrast sensitivity than the TD participants ($U=201.0$, $p=0.004$, $r=0.37$). That is, the participants with ASD had reduced contrast sensitivity for direction-of-motion discrimination of both luminance and chromatic gratings, compared to the TD group. There were no significant differences in MOT contrast sensitivity between the participants with ASD and SIBS participants ($U=67.0$, $p=0.059$, $r=0.34$), and between the SIBS and TD participants ($U=223.0$, $p=0.818$, $r=0.034$). As indicated by Figure 5.2 b), within group comparisons of DET and MOT contrast sensitivity were only significant for the participants with ASD ($T=39.0$, $p=0.023$, $r=0.37$), but not the TD participants ($T=348.0$, $p=0.566$, $r=0.066$) nor the SIBS participants ($T=23.0$, $p=0.233$, $r=0.26$). The participants with ASD had lower contrast sensitivity in the MOT task than DET task. The results suggest that the adolescents with ASD were poorer at discrimination of local motion direction when compared with TD adolescents.

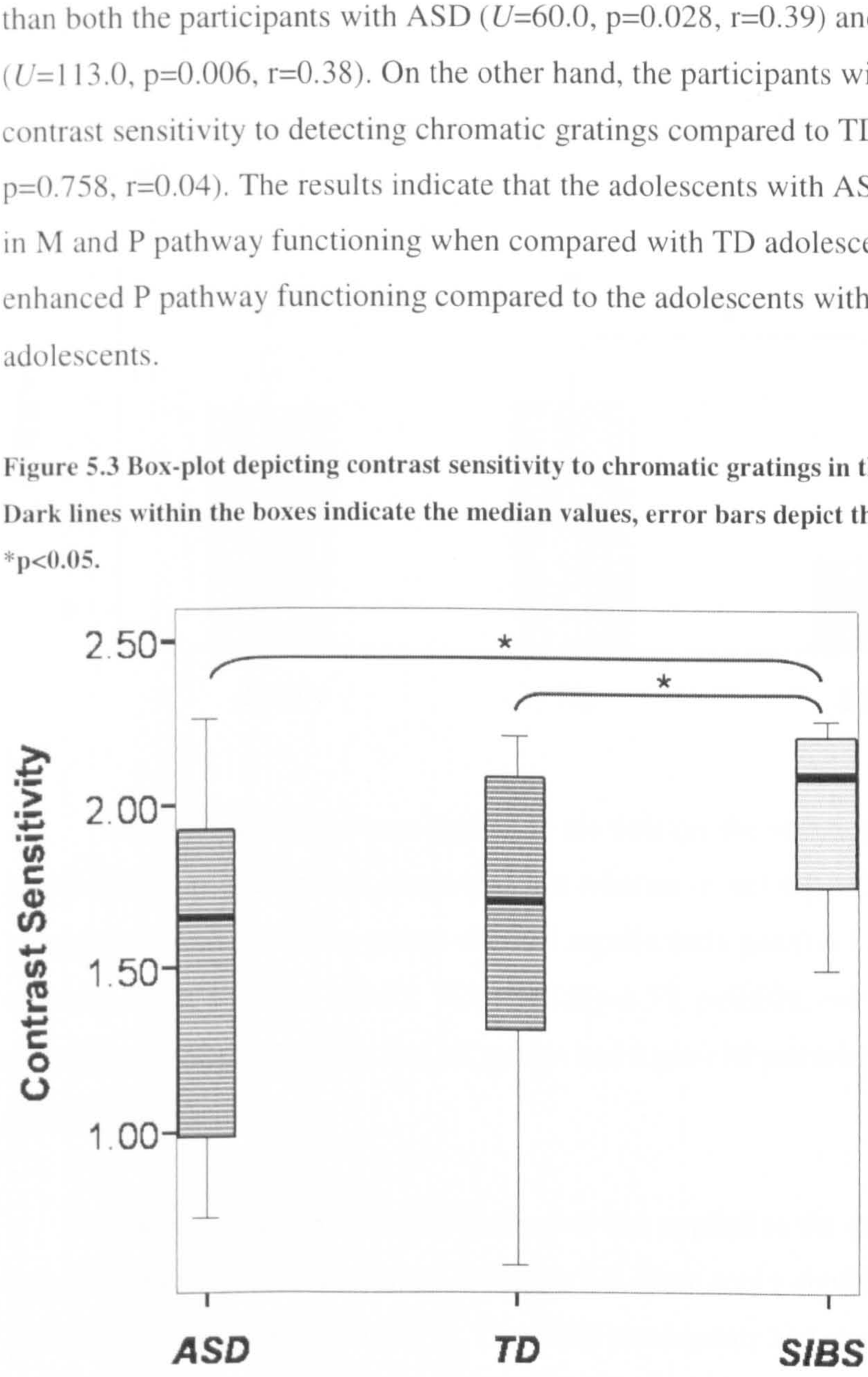
Figure 5.2 Box-plot depicting contrast sensitivity for DET and MOT task collapsed over luminance and chromatic gratings in each group. Dark lines within the boxes indicate the median values, error bars depict the inter-quartile range and *p<0.05.



Do adolescents with ASD show atypicalities in absolute M and P pathway sensitivities?

Non-parametric Kruskal Wallis tests were applied separately to Lum-DET-Sens and Chrom-DET-Sens. There was no significant main effect of group for Lum-DET-Sens ($H(2)=1.28$, p=0.527), but there was a significant main effect of group for Chrom-DET-Sens ($H(2)=7.49$, p=0.024). As represented in Figure 5.3, the effect was driven by the SIBS participants showing significantly higher contrast sensitivity to detecting chromatic gratings than both the participants with ASD ($U=60.0$, p=0.028, r=0.39) and the TD participants ($U=113.0$, p=0.006, r=0.38). On the other hand, the participants with ASD showed typical contrast sensitivity to detecting chromatic gratings compared to TD participants ($U=351.5$, p=0.758, r=0.04). The results indicate that the adolescents with ASD showed no difference in M and P pathway functioning when compared with TD adolescents. The SIBS displayed enhanced P pathway functioning compared to the adolescents with ASD and TD adolescents.

Figure 5.3 Box-plot depicting contrast sensitivity to chromatic gratings in the DET task for each group. Dark lines within the boxes indicate the median values, error bars depict the inter-quartile range and *p<0.05.

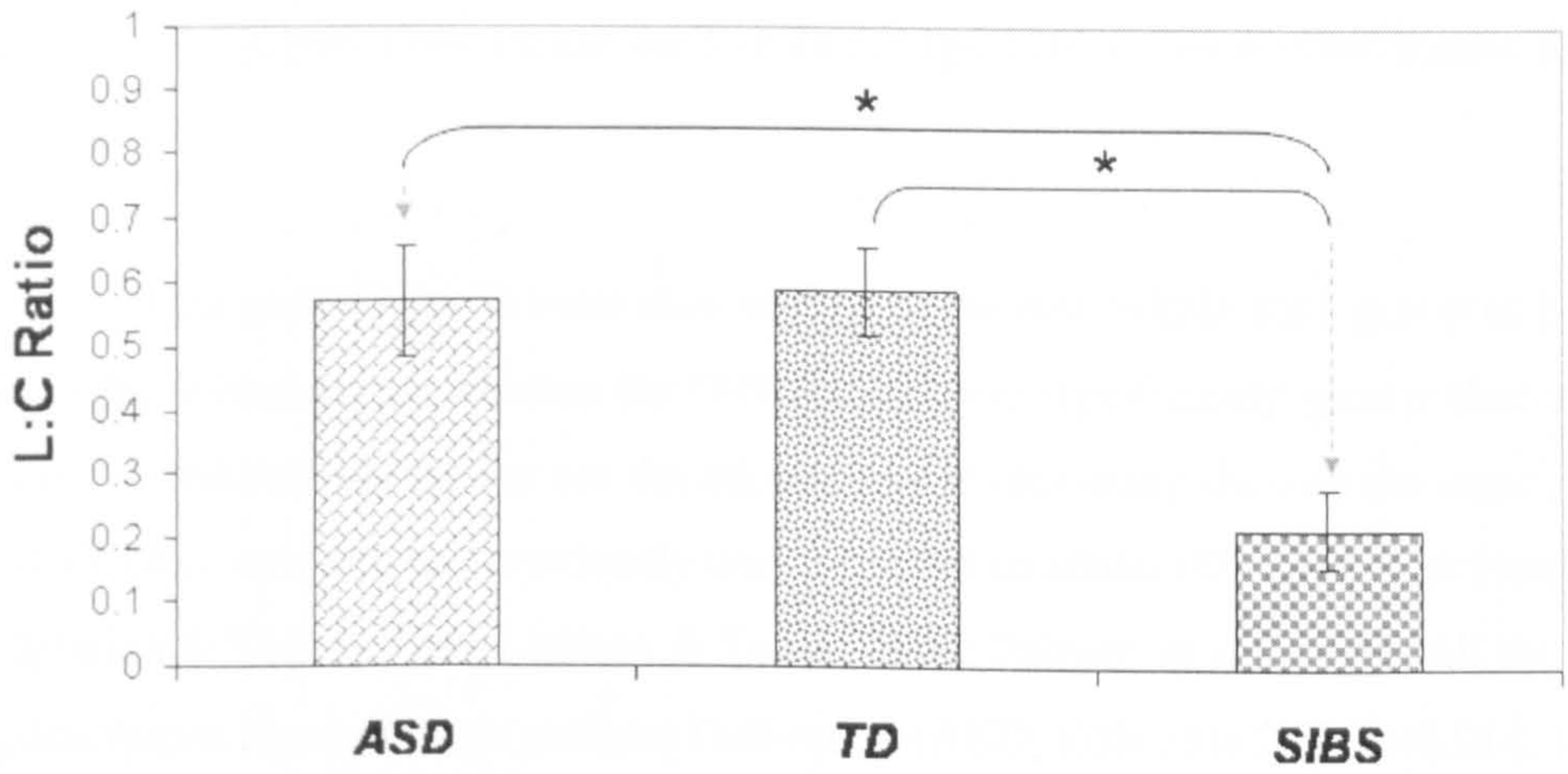


Variables derived from Contrast Sensitivity Data

Do adolescents with ASD show atypicalities in relative functioning of M versus P pathways?

The dependent variable L:C ratio did not violate assumptions of normality (Kolmogorov-Smirnov test: $p>0.098$) but violated assumptions of homogeneity of variance (Levene's test: $F(2,67)<3.19$, $p>0.048$). Please see Figure 5.4 for mean L:C ratios for each group.

Figure 5.4 Bar Graph illustrating mean L:C ratios for each group. Error bars denote standard error of means. *p<0.5



One-sample t-tests were applied to the data (as the within group data had a normal distribution) for each group, in order to test whether or not the L:C ratios were significantly greater than zero. All three groups showed significantly positive L:C ratios (ASD: $t(df=18)=6.41$, $p<0.001$, $r=0.83$, TD: $t(df=38)=8.57$, $p<0.001$. $r=0.66$, SIBS: $t(df=11)=3.51$, $p=0.005$, $r=0.53$), indicating that all groups had higher M pathway sensitivity than P pathway sensitivity.

A non-parametric Kruskal Wallis test was applied to the data to assess between-group differences. As represented in Figure 5.4, there was a significant main effect of group on L:C ratio ($H(2)=8.68$, $p=0.013$). The SIBS participants had significantly less positive L:C ratios than the participants with ASD ($U=54.0$, $p=0.014$, $r=0.44$) and the TD

participants (U=105.0, p=0.003, r=0.40), but the participants with ASD did not differ from TD participants on L:C ratios (U=368.0, p=0.974, r=0.005).

The results suggest that adolescents from all groups showed greater relative functioning of M versus P pathway functioning. However the SIBS showed lower relative functioning of M versus P pathway than the ASD and the TD adolescents.

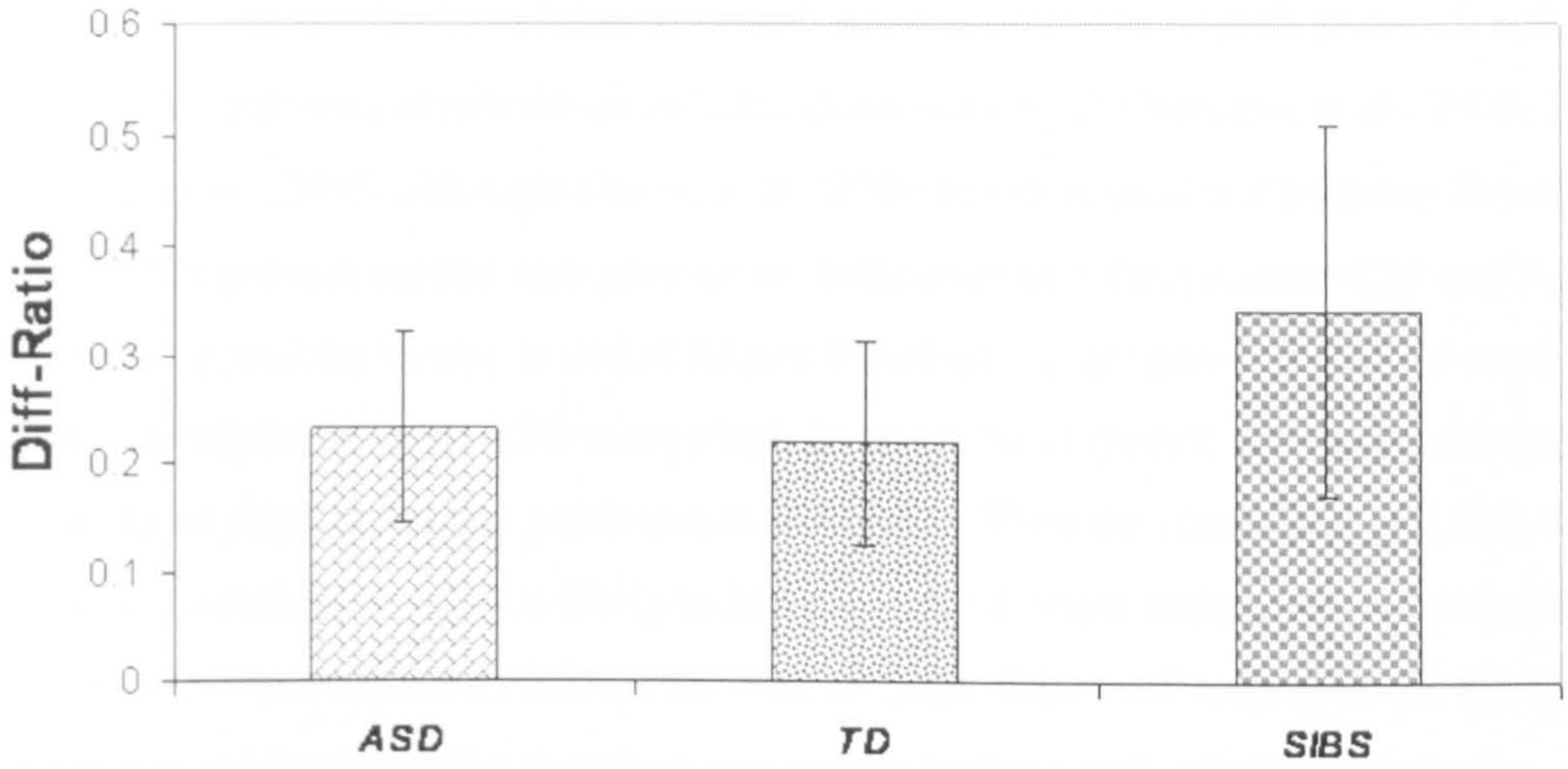
Do adolescents with ASD show atypicalities in the extent to which M and P pathways contribute to motion direction perception?

The dependent variable Diff-Ratios did not violate assumptions of normality (Kolmogorov-Smirnov test: p>0.200) or homogeneity of variance (Levene's test: F(2,67)<1.77, p>0.179). Please see Figure 5.5 (pg 126) for mean Diff-Ratios for each group.

One-sample t-tests were also applied to the data within each group of participants, in order to investigate whether the Diff-Ratios were significantly greater than zero. This was to establish whether or not the adolescents in this study showed the same pattern of MOT:DET ratios as has previously been reported in adults (Derrington & Henning, 1993; Dobkins & Teller, 1996; Lindsey & Teller, 1990; Palmer, et al., 1993). All three groups of participants showed more positive Diff-ratios (ASD: t(df=18)=2.71, p=0.014, r=0.54, TD: t(df=38)=2.31, p=0.027. r=0.35, SIBS: t(df=11)=2.02, p=0.068, r=0.52). The one-sample t-test for the SIBS participant was only near significant (p=0.068), but the large effect size (r=0.52) suggested that it was a reliable observation in the SIBS participants.

A one-way ANOVA was used to analyze the data and no significant group differences were found (F(2,67)=0.232, p=0.794, r=0.08). The results suggest that adolescents from all groups displayed the typical profile in the DET and MOT tasks i.e. a greater input from the M, compared with the P pathway to cortical motion direction mechanisms. The adolescents with ASD did not differ from TD adolescents or adolescents with siblings diagnosed with ASD on the extent to which M and P pathways contribute to cortical motion direction mechanisms.

Figure 5.5 Bar Graph illustrates mean Diff-Ratios for each group. Error bars denote standard error of means.



5.4 Discussion

The results for the adolescents with ASD are consistent with previous null findings of M and P pathway atypicalities in individuals with ASD (Bertone, et al., 2005; Pellicano, Gibson, et al., 2005, although Davis, et al., 2006 found impaired P pathway functioning in ASD). The present results also provide no indication that the balance of M and P pathway functioning and the extent to which M and P pathway contributes to cortical motion direction mechanisms in ASD is atypical. Even so, local motion direction perception was found to be impaired in the participants with ASD. Thus the results suggest that atypical motion perception in ASD is likely to have a cortical origin rather than a sub-cortical origin. The results for the adolescents with siblings diagnosed with ASD on the other hand suggest intact local motion direction perception in these individuals, and also no atypicalities in the extent to which the M and P pathway contribute to cortical motion processes. As with the adolescents with ASD and the TD adolescents, these siblings of individuals with ASD displayed higher relative functioning of M versus P pathways i.e. positive L:C ratios. However, they demonstrated enhanced P pathway functioning and significantly lower relative functioning of M versus P pathways, compared to TD adolescents and the adolescents with ASD. This may be the first study to date that revealed a trait that is common in individuals with ASD and TD controls, but different in siblings of individuals with ASD.

In this discussion, the finding of local motion direction perception deficit in ASD in the context of previous research is first addressed, after which the implications of the finding of enhanced P pathway functioning and lower relative M versus P pathway functioning in siblings of individuals with ASD are considered.

The present finding of a local motion direction perception deficit in ASD is consistent with the notion that individuals with ASD have atypical motion perception, but inconsistent with findings from two previous studies that found intact local motion direction perception in ASD (Bertone, et al., 2003; Takarae, et al., 2008). Bertone et al (2003) utilized luminance gratings of spatial frequency 1.0cpd and a drift temporal frequency of 2.0Hz, and found no evidence of impairment in their sample of children with

autism (Bertone et al. 2003)[6]. Takarae et al (2008) employed luminance gratings of spatial frequency 0.67cpd and a speed of 1 degree per second i.e. drift temporal frequency of 0.67Hz[7], and found no evidence of local motion direction perception impairment in their sample of adolescents with autism and no language delay. The current study employed luminance and chromatic gratings of spatial frequency 1.0cpd and a drift temporal frequency of 5.5Hz, and found evidence of impairment in the adolescents with ASD. The local motion direction perception impairments in the adolescents with ASD in this study were significant for both luminance and chromatic stimuli, ruling out the possibility that it was only a reduction in contrast sensitivity for direction-of-motion discrimination of chromatic stimuli in the adolescents with ASD that was driving the effect. It is therefore suggested that the selected drift temporal frequency of the visual stimuli may be the crucial factor influencing whether local motion direction perception deficits are elicited in individuals with ASD. The drift temporal frequency of the visual stimuli in the current study (5.5Hz) is higher than that used in Bertone et al (2003)'s study (2.0Hz) (Bertone, et al., 2005) and that of Takarae et al (2008)'s study (0.67Hz)[8]. It could be that the higher the drift temporal frequency of a visual stimulus, the more difficulties individuals with ASD may have in perceiving the local motion direction, compared to TD individuals. Further investigation on local motion direction perception of stimuli with a fixed spatial frequency and a range of temporal frequency characteristics in individuals with ASD, is warranted.

It should be noted that Takarae et al (2008) also assessed adolescents with autism *and language delay*, and found local motion direction perception deficits in these individuals. Takarae et al (2008)'s results suggest that individuals with ASD with different histories of language development may show differential visual perceptual abilities. The current study did not obtain information on the early language development of the participants. However in light of this possible influencing factor, an additional statistical analysis was conducted (please see page 162 of the Appendix) by arbitrarily separating the participants with ASD into two sub-groups, one of higher verbal IQ and one of lower verbal

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[6] Bertone et al (2003) also had noise added to the luminance stimuli, which may also play a role in the inconsistency of their findings from the present results.

[7] The relationship between spatial frequency (sf), temporal frequency (tf) and speed (v) can be defined by the following equation: $v = tf / sf$.

[8] It is not clear if Takarae et al (2008) used sinusoidal or square-wave gratings. The use of square-wave gratings may have made a difference in the results obtained.

IQ. This was done on the basis that current verbal IQ may be a good approximation of early language development. The analysis revealed that both sub-groups of participants with ASD showed significantly reduced contrast sensitivity for direction-of-motion discrimination of luminance stimuli, but only the sub-group of participants with ASD with lower verbal IQ showed significantly reduced contrast sensitivity for direction-of-motion discrimination of chromatic stimuli. Nevertheless, that the participants with ASD in this study showed local motion direction perception deficits for luminance stimuli, which were the type of stimuli used in both Bertone et al (2003) and Takarae et al (2008)'s studies, regardless of their verbal IQ, suggests that the argument for an effect of temporal frequency on local motion direction perception in ASD still stands.

Following on the possibility that temporal frequency may be a crucial condition for whether local motion direction perception deficits are exhibited in individuals with ASD, it is suggested that there may be a similar effect of temporal frequency on global motion perception in individuals with ASD. Evidence of impaired global motion perception in ASD has come mainly from studies using random dot kinematograms (RDK), within which local motion signals have speeds ranging from 5.8 to 8.8 degrees per second which would correspond to very high temporal frequency values (Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000). A recent paper reported intact global motion direction perception in ASD using plaid stimuli, within which the component gratings had a low maximum speed of 2.4 degrees per second i.e. drift temporal frequency of 2.88Hz (Vandenbroucke, et al., 2008). Thus, it appears that individuals with ASD may have specific global motion perception impairment for visual stimuli with local motion signals of high drift temporal frequency.

The finding of impaired local motion direction perception for higher temporal frequency signals in ASD brings to attention a need to investigate global motion perception in ASD in terms of local and global visual integration. As described in chapter one, global motion stimuli such as RDK and motion Glass patterns perception require dot signals to be locally integrated across time for the local signal to be perceived, before those local signals can be globally integrated for the global pattern to be observed. It is possible that global motion perception atypicalities in ASD have an underlying impairment with local motion

direction perception for higher temporal frequency signals. Further research is therefore needed to unravel these mechanisms for atypical global motion perception in ASD.

The siblings of individuals with ASD in this study showed enhanced P pathway functioning and significantly lower relative functioning of M versus P pathways, compared to TD adolescents and the adolescents with ASD. As previously pointed out, research on first-degree relatives of individuals with ASD, have until now only reported ASD-like behaviours that are observed in both those diagnosed with an ASD and their family members i.e. the broader autism phenotype (Bailey, et al., 1995; Bailey, et al., 1998; G. Dawson, et al., 2002; de Jonge, et al., 2007; Piven, et al., 1997). This is the first study to reveal a trait that is similar between individuals with ASD and TD controls, but different in siblings of individuals with ASD compared to individuals with ASD and TD individuals. Enhanced P pathway functioning and the lower relative functioning of M versus P pathway in adolescents with siblings with ASD may reflect a mechanism in these individuals that provide with some 'immunity' against developing ASD.

The present results for the siblings of individuals with ASD are however not inline with McCleery et al (2007)'s finding of enhanced M pathway functioning and higher relative functioning of M versus P pathway. The adolescent siblings of individuals with ASD showed enhanced P pathway functioning, while the infant siblings of individuals with ASD have shown enhanced M pathway functioning. The infant siblings of individuals with ASD showed higher relative functioning of M versus P pathway than infant controls, while the adolescent siblings of individuals with ASD showed lower relative functioning of M versus P pathway than TD controls. These contradictory results may however be more easily interpreted if developmental changes in M and P pathway functioning in the TD individuals and the siblings of individuals with ASD are considered. The infant controls had lower functioning of the M pathway compared to the P pathway i.e. negative L:C ratios, and the adolescent controls demonstrated higher functioning of the M pathway compared to the P pathway i.e. positive L:C ratios. It was instead the siblings of individuals with ASD who showed consistently higher functioning of the M pathway compared to the P pathway i.e. positive L:C ratios from infancy to adolescence. These siblings of individuals with ASD then in their adolescence years show a lower L:C ratio than the TD adolescents and adolescents with ASD. This balance of M and P pathway functioning across development may therefore play a role, or is a by-product of some mechanism that

promotes 'immunity' against developing ASD in individuals with a genetic pre-disposition for the condition. Further investigation of this atypical balance of M versus P pathway functioning in siblings of individuals with ASD may place scientists en route to uncovering the neurobiological factors that prevent these individuals from developing ASD.

There is research suggesting that the balance of M and P pathway functioning changes at different stages in typical human development. Infants at 3 months old have been shown to have higher M to P pathway sensitivity, infants at 4 months old have been shown to have higher P to M pathway sensitivity, and adults have shown higher M to P pathway sensitivity (Dobkins, Anderson, & Lia, 1999). Future research would benefit from examining this relative functioning of M versus P pathway functioning in first-degree relatives of individuals with ASD across development i.e. from childhood to adulthood, as the data may reveal more about the nature of the mechanism.

Conclusions

The present findings indicate that adolescents with ASD have local motion direction perception deficits, but typical functioning of the sub-cortical M and P pathways. There is therefore evidence suggesting that motion perception atypicalities in ASD are likely to have a cortical origin rather than a sub-cortical origin. Siblings of individuals with ASD were found to have intact local motion perception, enhanced P pathway functioning and lower relative functioning of M versus P pathways, compared to TD controls and individuals with ASD. This finding of a trait that is common between individuals with ASD and TD individuals, but different in siblings of individuals with ASD, suggests the presence of an unknown mechanism that may be providing protection against developing ASD, for these individuals.

6 Chapter Six –

Spatial Contrast Sensitivity in Adolescents with Autism Spectrum Disorders

6.1 Introduction

Individuals with ASD have shown a perceptual bias towards processing local features of visual stimuli, as demonstrated by deficits in perception of faces (Boucher & Lewis, 1992; Davies, et al., 1994; de Gelder, et al., 1991; Deruelle, et al., 2004; Hobson, et al., 1988; Humphreys, et al., 2007; Klin, et al., 1999; Langdell, 1978; Tantam, et al., 1989), where faces are thought to be processed optimally using global strategies (Tanaka & Farah, 1993; Young, et al., 1987), and superior performance on visuo-spatial tasks such as the embedded figure tasks and visual search tasks (Jarrold, et al., 2005; Jolliffe & Baron-Cohen, 1997; O'Riordan, et al., 2001; Pellicano, Gibson, et al., 2005; Plaisted, et al., 1998; Ropar & Mitchell, 2001; Sang, et al., 2006; Shah & Frith, 1983, for negative findings see Brian & Bryson, 1996; Burnette, et al., 2005; Ozonoff, et al., 1991), where both tasks are thought to require attention to local detail.

Empirical evidence suggests that the local features of visual stimuli are conveyed by high spatial frequency information, and that the global structures dominate in low spatial frequency information (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Boeschoten, Kemner, Kenemans, & van Engeland, 2005; Han, Yund, & Woods, 2003; Hughes, Fendrich, & Reuter-Lorenz, 1990; Hughes, Nozawa, & Kitterle, 1996; Lagasse, 1993; Shulman, Sullivan, Gish, & Sakoda, 1986). It has therefore been proposed that the local feature bias in ASD individuals reflects an enhanced sensitivity to high spatial frequencies and/or a diminished sensitivity to low spatial frequencies (Behrmann, Thomas, & Humphreys, 2006; Boeschoten, Kenemans, van Engeland, & Kemner, 2007b; Kemner & van Engeland, 2006; Milne, et al., 2002; Plaisted, et al., 1999). Several studies have attempted to investigate spatial frequency visual mechanisms in ASD, with some studies designed to address the speculation directly, and others providing relevant data which were obtained prior to investigating some other aspect of visual processing in ASD.

One approach to study high spatial frequency visual mechanisms is to measure visual acuity, defined as the smallest spatial detail that an observer can perceive. At least three known studies have compared visual acuity between individuals with ASD and TD

controls (Ashwin, Ashwin, Rhydderch, Howells, & Baron-Cohen, 2009; de Jonge, et al., 2007; Milne, Griffiths, Buckley, & Scope, 2009). In one study, participants with ASD and TD participants were assessed on visual acuity with a Landholt-C chart (de Jonge, et al., 2007). The Landholt-C chart is a clinical measure in which test stimuli were C-shapes where the gap could appear in one of four positions (left/right/up/down), and participants were to report the position of the gap. The C-shapes decreased in size and consequently in gap size, and a visual acuity measure was obtained from determining the smallest C-shape that the participant could correctly detect a gap for. de Jonge et al (2007) reported no differences in visual acuity between ASD and TD individuals (de Jonge, et al., 2007). Likewise, Milne et al (2009), using the Crowded LogMAR test (Keeler Ophthalmic Instruments), where participants name letters that decreased in size off a series of test cards, reported no group differences in visual acuity (Milne, Griffiths, et al., 2009). These clinical screening tests of visual acuity are however considered quick assessments and are not very rigorous. Subtle group differences (if any) might therefore have been missed. In support of this possibility, another study that employed the Landholt-C test stimuli/task to test visual acuity, yet used a more thorough staircase procedure within a computerized set-up (i.e., the Freiburg Visual Acuity and Contrast Test, FrACT), reported that participants with ASD had significantly higher visual acuity i.e. superior high spatial frequency mechanisms, than TD individuals (Ashwin, et al., 2009). In the staircase procedure, the C-shapes decreased in size with each correct answer, and increased in size with each incorrect answer. This adaptive procedure allows test stimuli to be presented close to a participant's visual acuity, enabling faster and more accurate measure of visual acuity. Visual acuity was measured in Snellen metric, where the average visual acuity of 20:20, indicates an ability to see visual detail at 20 feet what an average person can accurately see at 20 feet. The participants with ASD were found to have significantly higher visual acuity (mean = 20:7) than the TD participants (mean = 20:13). Ashwin et al (2009)'s results have however been criticised as unsound (Bach & Dakin, submitted). It was suggested that spatial resolution of the visual display at the reported viewing distance of 60cm may not have been sufficient to enable measurement of the reported visual acuity values. The size of the C-shapes would cover less than 1 pixel of the display, so it would have been impossible for the participants to detect the position of the gap. Even so, should Ashwin et al (2009)'s findings be replicable, investigations of visual acuity do not address predictions about the lower spatial frequency visual mechanisms in ASD.

Another approach to study spatial frequency visual mechanisms is to measure contrast sensitivity across a range of spatial frequencies. Three different studies that used clinical screening charts reported no difference in contrast sensitivity between Participants with ASD and TD controls at any spatial frequency tested (de Jonge, et al., 2007: tested children, adolescents and adults with Vistech wall charts at 1.5, 3, 6, 12 and 18 cpd; Milne & Buckley, submitted & Milne, Scope, et al., 2009: tested children and adolescents with the CSV-1000 at 3, 6, 12 or 18 cpd). The Vistech wall chart consists of rows of circular sinusoidal grating patches at selected spatial frequencies. The contrast of the gratings within each row decreases from left to right by a fixed step size of 0.12 log units. The orientation of the gratings could be vertical, tilted to the left or to the right. Participants were asked to discriminate the orientation of the gratings. Similarly, the CSV-1000 consists of four panels of circular sinusoidal grating patches at the selected spatial frequencies. The left most grating is of the maximum contrast and is the prototype of the target stimuli participants are to detect in comparison to a second blank patch within the subsequent eight columns on the right. The gratings in each panel decreased in contrast at a step size of 0.17 log unit for the first three columns, and then at a step size of 0.15 log units for columns four to eight, from left to right. Participants are asked to indicate which of the two patches in the column contained the target grating. In both tests, the last correct response of a consecutive series of correct responses was recorded as the contrast threshold which is converted to contrast sensitivity by 1/contrast threshold, for each spatial frequency value.

The clinical screening tests of contrast sensitivity, used in the studies described in the previous paragraph, are however considered quick assessments, and subtle group differences in spatial contrast sensitivity between individuals with ASD and TD individuals might have been missed. The Vistech wall chart and the CSV-1000 were developed for monitoring spatial frequency contrast sensitivity of clinical patients whose conditions e.g. glaucoma, cataracts, result in huge deteriorations in visual abilities. Thus, these clinical tools can only be at best, crude measures of differences in spatial frequency contrast sensitivity between individuals with ASD and TD controls whose visual abilities appear to be within the normal range. Furthermore, there are a very small number of trials (<10) for each spatial frequency, relatively large step sizes (Vistech: 0.12 log units, CSV-1000: 0.15-0.17 log units) in contrast between test stimuli, and only one decision to be made at each contrast of each spatial frequency grating, in both tasks (Pesudovs, Hazel, Doran, & Elliott,

2004). Previous research even found the Vistech wall chart to have low test-retest reliability for charting the progress of refractive or cataract surgery patients (Pesudovs, et al., 2004).

There is one study to date that has used a more rigorous research-based approach to assess contrast sensitivity across a range of spatial frequencies in ASD (Behrmann, Avidan, et al., 2006). Contrast sensitivity over a range of spatial frequencies (0.13, 0.42, 1.26, 4.19 and 12.6 cpd), were tested in individuals with ASD and TD controls using a staircase procedure. Consistent with the results from the clinical screening tests, no group differences at any spatial frequency tested were revealed (results from their two-factor ANOVAs showed no main effect of group and no interaction between group and spatial frequency). There are, however, a couple of limitations to their protocol, which could have led to negative findings. First, they used relatively few total trials per spatial frequency i.e. 20 trials, and their staircase used a fixed and somewhat large step size of 0.2 log units. These conditions can lead to rather noisy estimates of contrast threshold, making it difficult to notice small group differences. Second, because the maximum spatial frequency they tested i.e. 12.6 cpd was well below visual acuity for humans (which is about 30-40 cpd, see Kelly, 1977; Ridder, 2004; Robson, 1966; Virsu & Rovamo, 1979), the data from this study could not address differences between groups in visual acuity.

Therefore, the objective of this study is to investigate low and high spatial frequency visual mechanisms in ASD, using a rigorous approach. This goal was achieved in several ways. First, contrast sensitivity was measured over a larger range of spatial frequencies (0.5 to 20 cpd) than employed in previous studies. Second, contrast sensitivity was obtained using a staircase procedure that employed a *variable* step size, and presented 60 trials per spatial frequency, which allows for more precision than previous studies. Third, a contrast sensitivity function (CSF) was fitted for each participant, which allowed estimation of both visual acuity i.e. the highest perceivable spatial frequency, and contrast sensitivity at a very low (0.1 cpd) spatial frequency. In addition, for each participant, the CSF provided information about the spatial frequency producing the peak contrast sensitivity, and the contrast sensitivity at that peak.

6.2 Method

Participants

A total of 13 adolescents with ASD and 29 typically developing (TD) adolescents participated in the study. Data from three adolescents with ASD and four TD adolescents were excluded because their data did not fit the criteria for a good sCSF fit (see below). This resulted in a final sample of 10 adolescents with ASD and 25 TD adolescents.

Participants were recruited by advertising the study through community resources for parents with children affected by ASD, and also via the special education division and schools in the San Diego Unified School District. In addition, participants who participated in previous studies from the lab were notified about the study and invited to participate. Informed consent from parent and child were obtained at the start of each testing session. The study took 2-3 hours for each participant to complete. Participants were given USD10 for each hour spent on the research. The study protocol was approved by the UCSD Human Research Protection Program, which ensures that the federally registered Institutional Review Boards (IRB) policies are adhered to.

Of the participants with ASD, one had a diagnosis of Autism, seven had a diagnosis of Asperger's syndrome, and two had a diagnosis of an ASD. Diagnoses were given by clinical or educational professionals based on the DSM-IV criteria (APA, 2004).

Parents were asked if their children had any vision issues e.g. short-sightedness, strabismus, and if there was a history of colour vision deficiencies in the family. Two participants with ASD and two TD participants had diagnosed colour vision deficiencies. All participants were tested with the Ishihara colour deficiencies test (Ishihara, 1992), so no other participants had colour vision deficiencies that were not known of. All participants had normal or corrected to normal visual acuity.

Psychometric Assessments

The Wechsler Abbreviated Scale of Intelligence (WASI) was administered to all the participants to obtain measures of their cognitive abilities. All four sub-tests were administered and it yielded a full scale IQ score that provided a composite measure of the

participant's intelligence. Parents of all participants were asked to complete the *Lifetime* version of the Social Communication Questionnaire (SCQ) (Rutter, et al., 2003) and the Social Reciprocity Scales (SRS) (Constantino, 2002). The Autism Diagnostic Observation Schedule (ADOS) was administered to each participant with ASD to confirm the clinical diagnoses. The WASI, SCQ, SRS and ADOS were described in greater detail in the Method section of chapter two.

The participants with ASD and TD participants were matched on chronological age and performance IQ. Please see Table 6.1 for the group characteristics of the participants with ASD and the TD participants.

Table 6.1 Group characteristics of participants with ASD and TD participants.

	ASD (N=10)	TD (N=25)	t & p values
Sex	10 boys	14 boys, 11 girls	
Vision Issues	5 normal vision 3 corrected vision 2 color vision deficiencies*	15 normal vision 8 corrected vision 2 color vision deficiencies*	
Chronological Age (months)			
M	181	187	t(df=33)=0.985, p=0.332
SD	21	14	
Range	157 – 213	168 – 212	
Verbal IQ			
M	101	108	t(df=33)=1.06, p=0.295
SD	22	15	
Range	64 – 133	77 – 133	
Performance IQ			
M	104	108	t(df=33)=0.94, p=0.352
SD	13	13	
Range	76 – 121	74 – 127	
Full Scale IQ			

M	103	109	t(df=33)=1.21, p=0.233
SD	16	14	
Range	75 – 125	79 – 133	
SCQ Score[+]			
M	25	3	t(df=30)=13.7, p<0.001
SD	6	4	
Range	18 – 33	0 – 13	
SRS Score[+]			
M	104	52	t(df=30)=11.2, p<0.001
SD	21	5	
Range	77 – 133	39 – 64	
ADOS Total[++]			
M	8.5		
SD	3		
Range	4 – 14		

Note.

[*]*Statistical analyses were repeated with participants diagnosed with colour deficiencies excluded, and similar results of unremarkable low and high spatial frequency visual processing in the participants with ASD compared to TD controls were found.*

[+] *Parents of 3 TD participants did not return the SCQ and SRS.*

[++] *One participant who had a diagnosis of Autism/Asperger's attained an ADOS total score of 4, which was below the ADOS cut-off for ASD. Data from the participant with Autism/Asperger's was also not excluded as he had a SCQ score of 22 which was above the autism cut-off for the SCQ, and had a SRS score of 94 which within one standard deviation below the SRS published mean for PDD-NOS.*

Visual apparatus

The visual stimuli were presented on a high resolution RGB monitor (19.8" SONY GDM-F520 monitor, 100Hz frame rate, 1024x768 pixels at dot pitch of 0.22mm). The monitor was driven by a Microsoft Windows XP computer with Intel Pentium 4 processor. The Cambridge Research System's toolbox for MATLAB was used to create the visual stimuli and run the experimental paradigm. A 14 bit VSG2/3F digital video card was used to increase the range of the existing 8 bit computer graphics system and improve the display resolution. Gamma correction was performed to linearize the voltage/luminance relationship for the monitor display, using a PR-650 SpectraColorimeter (Photoresearch).

At a viewing distance of 100 cm, the viewable portion of the monitor subtended 23.1 x 16.7 degrees visual angle.

Stimuli

The stimuli in these experiments were luminance (light/dark) static Gabor patches (mean luminance (L)= 23 cd/m^2, CIE 0.489 0.453) presented on a background with the same luminance/chromaticity. Gabor patches were created by multiplying horizontally-oriented sinusoidal gratings that subtended 3.1° with a Gaussian circular envelope (sd = 0.5°). The luminance contrast (i.e., the luminance difference between the light and dark phases of the grating) is described in terms of Michelson contrast: ($L_{max} - L_{min}$)/($L_{max} + L_{min}$). Note that zero percent luminance contrast refers to a uniform field, which is indistinguishable from the background. To obtain a contrast sensitivity function, the gratings were presented at seven different spatial frequencies, i.e., cycles/degree (cpd): 0.5, 2, 4, 8, 12, 16, and 20.

Psychophysical Paradigm

Participants were tested in a dark room and viewed the video monitor binocularly from a chin rest situated 100 cm away. Participants were instructed to maintain fixation on a small cross (length and width = 0.2 degrees) in the center of the monitor. Participants began each trial with a key press, after which a Gabor stimulus appeared at the centre of the monitor in one of two 250 ms intervals, separated by a 500 ms gap. The beginning of each of the two time intervals was accompanied by a beep. After each trial, participants reported whether the visual stimulus appeared during the first or second beep via key press, i.e., in a standard two-alternative forced choice manner. Feedback was provided in which a beep sound of a different pitch indicated a correct response. The seven different spatial frequencies were presented randomly across trials, with 60 trials obtained for each frequency. The total number of trials was 420 (60 trials * 7 spatial frequencies).

Contrast varied across trials in an adaptive staircase procedure. Specifically, on the first trial a given spatial frequency was presented, its contrast was 90%. The contrast for subsequent trials of that spatial frequency varied in a 1 down/2 up procedure, based on the PEST method (see Taylor & Creelman, 1967). After a correct response, the subsequent contrast was decreased by one step size, and after an incorrect response, the subsequent

contrast was increased by two step sizes. The maximum step size was 0.14 log units (1.38-fold change in contrast). The value of the step size was determined by an acceleration factor of 1.2 and a reversal factor of power of 1.1. Following either two correct or two incorrect responses, the step size was multiplied by the acceleration factor. Following a reversal in correctness, the step size was multiplied by (1/acceleration factor)^reversal power. Note that the use of a variable step size allows more precision than a fixed step size.

Obtaining Contrast Sensitivity Functions

For each participant, at the end of the experiment, the 60 trials obtained for each spatial frequency were used to obtain a contrast threshold for that spatial frequency. This was performed by fitting a psychometric Gumbel function (Gumbel, 1958) to "percent correct vs. contrast" data, using maximum likelihood method (Johnson, et al., 1995; Watson, 1979).

$$\Pr[X \le x] = \exp\left\{-e^{-(x-\varepsilon)/\theta}\right\}$$

The Gumbel function is an extreme value model, and is also known as a log-Weibull model. The better known Weibull function has a distribution that can be transformed into a Gumbel function by the formula: $Z = -\log(\varepsilon - X)$. While the Weibull function obtains limiting distributions of the least values, the Gumbel function obtains limiting distributions of the greatest values.

Contrast *threshold* was defined as the contrast value yielding 75% correct performance. Contrast *sensitivity* was calculated as the inverse of contrast threshold. Logarithmic transformation for the contrast sensitivity values was applied, as logarithmic contrast sensitivity data are more likely to conform to a normal distribution than linear contrast sensitivity data.

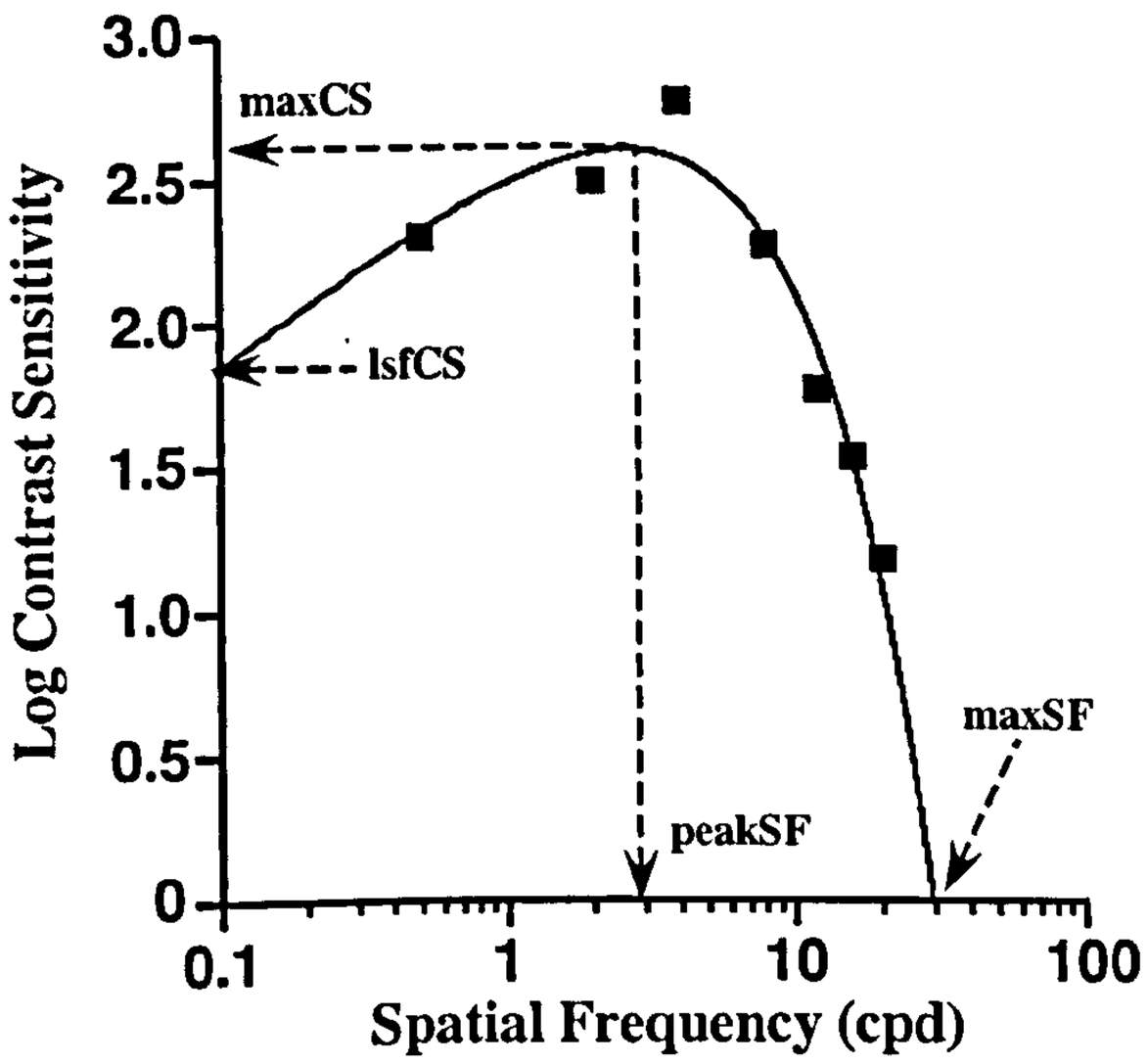
For each participant, the contrast sensitivities derived for the seven different spatial frequencies were fitted with a double exponential function to create a contrast sensitivity function (CSF), using an iterative minimization process as previously described (Dobkins, et al., 1999; Movshon & Kiorpes, 1988). The function is described as:

$$f(x) = -A + a(\varpi b)^d e^{-c\varpi b}$$

where ω is the spatial frequency, a allows vertical shifts of sensitivity, b allows lateral shifts in spatial frequency, c affects the high frequency fall-off and d affects the low frequency fall-off. (Note that –A is set to an arbitrarily large number just so the function extrapolates to the x-axis.)

After the functions were fit, four parameters of interest were derived: 1) the maximum perceivable spatial frequency (maxSF), i.e. where the curve extrapolates to the x-axis, which is considered visual acuity, 2) contrast sensitivity at a relatively low SF, i.e. 0.1 cpd (lsfCS), 3) the spatial frequency yielding the peak contrast sensitivity (peakSF), and 4) the peak contrast sensitivity at that peak (peakCS). The lsfCS is recognized to be an arbitrary low-end limit. However, this should suffice to capture contrast sensitivity to low spatial frequencies. Please see example data in Figure 6.1.

Figure 6.1 Example CSF Fit for an ASD participant.



The CSF was obtained with a double exponential fit to contrast sensitivity obtained for seven different spatial frequencies (filled squares). The value of the four parameters of the CSF (maxSF, lsfCS, peakSF, peakCS) are presented. The data show the expected bandpass shape of the CSF with a peak near 3 cpd.

Data from participants in the final sample had best error values not more than three standard deviations from the mean best error values of the combined sample, and also maxSF, peakSF, and peakCS, not more than two standard deviations from the means of the

combined sample. Three participants with ASD and four TD participants were excluded from the initial sample, based on these criteria. There was no significant difference in best error estimates between the participants with ASD and the TD participants ($t(df=33)=1.51$, $p=0.142$). Thus, the groups did not fare differently in terms of how the sCSF was fitted to the individual data points. Best error estimates were at mean = 0.16, S.D.= 0.07, for the ASD group and at mean=0.12, S.D.=0.06, for the TD participants.

6.3 Results

CSF Parameters

A multiple analysis of variance (MANOVA) was used to analyze the group difference in the combined effect of the four CSF parameters, with the parameter values entered as repeated measures and group entered as a between participants measure. The data satisfied Kolmogorov-Smirnov tests for normality and Levene's tests of homogeneity of variances between the two participant groups. Group means and standard deviations for the four parameters of the CSF (maxSF, lsfCS, peakSF, peakCS) are presented in Table 6.2. There was no significant group difference in the combined effect of the dependent variables (Wilk's Λ=0.948, F(4,30)=0.415, p=0.796). Also presented in Table 6.2, independent sample t-tests (2-tailed) revealed no group differences for any of the four parameters considered individually.

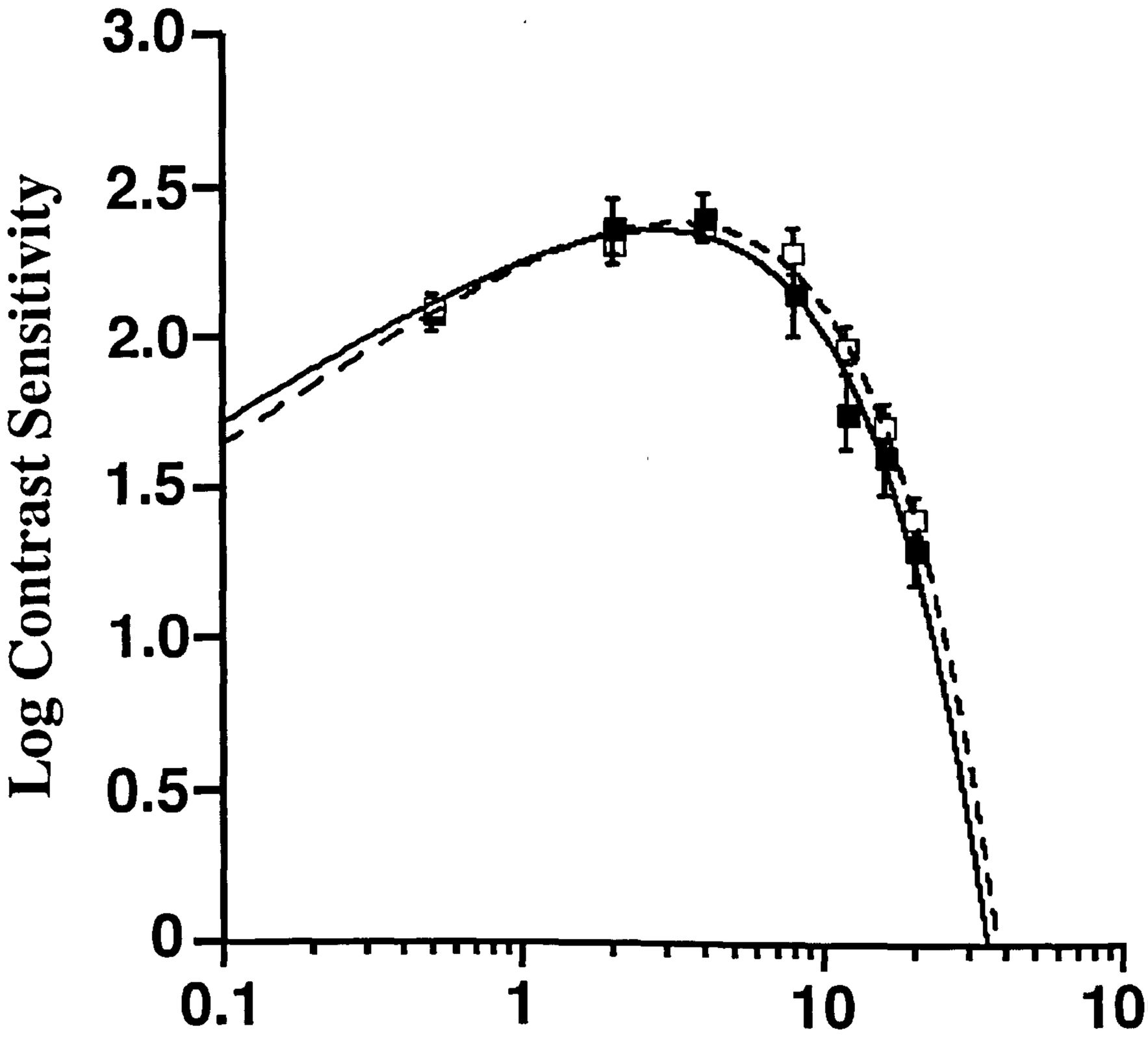
Table 6.2 Means and Standard Deviations (in parentheses) for four CSF parameters: maxSF, lsfCS, peakSF, and peakCS.

	ASD (N=10)	TD (N=25)	t- and p-values
maxSF	37 (11)	39 (8)	t(df=33)=0.749, p=0.459
lsfCS	1.7 (0.28)	1.6 (0.30)	t(df=33)=0.683, p=0.500
peakSF	2.8 (1.1)	3.2 (0.9)	t(df=33)=1.08, p=0.286
peakCS	2.4 (0.23)	2.4 (0.27)	t(df=33)=0.211, p=0.834

Group Mean CSF

To further demonstrate that there were no differences in CSF between the two participant groups, the group mean CSF for participants with ASD and TD participants were presented in Figure 6.2 (pg 144). These were created by first, averaging log contrast sensitivity values across participants for each of the seven spatial frequencies tested, and then fitting the double exponential function to these mean sensitivity values. Error bars denote standard errors of the means. Both data sets show the expected band-pass shape of the CSF, with a peak near 3 cpd (Robson, 1966; Virsu & Rovamo, 1979) and visual acuity near 40 cpd (Kelly, 1977; Ridder, 2004; Robson, 1966; Virsu & Rovamo, 1979). In addition, non-parametric Mann-Whitney tests for contrast sensitivity at each spatial frequency yielded no significant group differences at any spatial frequency (U>79.0, p>0.097 in all cases).

Figure 6.2 Group mean CSF for participants with ASD and TD participants.



ASD group (*bold line*) and the TD group (*dashed line*). Squares denote the group mean sensitivities for the seven different spatial frequencies (*ASD = filled squares, TD = open squares*), and error bars denote standard errors of the means.

6.4 Discussion

This study investigated low and high spatial frequency visual mechanisms in ASD using a rigorous psychophysical paradigm, and may be the first study to examine CSF in ASD. There was no evidence for any group differences, on measures of visual acuity (i.e., the highest perceivable spatial frequency), contrast sensitivity at a very low (0.1 cpd) spatial frequency, the spatial frequency producing the peak contrast sensitivity, and the contrast sensitivity at that peak. The following paragraphs will consider the present finding in the context of previous research, and discuss the implications of the current finding for higher level visual processes in individuals with ASD.

There are several previous studies that examined spatial frequency visual mechanisms in ASD (Ashwin, et al., 2009; Behrmann, Avidan, et al., 2006; de Jonge, et al., 2007; Milne & Buckley, submitted; Milne, Griffiths, et al., 2009; Milne, Scope, et al., 2009). Although it is argued that their approach was not as rigorous as that employed in this study, all the studies with one exception (Ashwin, et al., 2009) revealed findings that are inline with the present results i.e. showed no group differences in spatial frequency processing between the participants with ASD and TD controls. The results in the current study are also consistent with previous studies that assessed contrast sensitivity in ASD for luminance gratings at one or two spatial frequencies, which also varied in temporal frequency. Those studies have reported no group differences in contrast sensitivity for selected combinations of spatial and temporal frequencies (Bertone, et al., 2005; 0.5cpd/6Hz & 6.0cpd/1Hz, Pellicano, Gibson, et al., 2005; Gaussian blob flickering at 10Hz, Davis, et al., 2006: 0.5cpd/5 & 0.5cpd/12.5Hz, Koh, Milne, & Dobkins, in prep; 1.0cpd/5.5Hz which was described in chapter five), but one study did find reduced contrast sensitivity at 13.4cpd/2Hz in individuals with ASD compared to TD controls. The latter result still contradicts Ashwin et al (2009)'s finding of superior visual acuity in ASD (Ashwin, et al., 2009). The current literature therefore provides little support for atypicalities in spatial frequency visual mechanisms in ASD.

The present findings indicate individuals with ASD to have typical sensitivity to low and high spatial frequency information. However, psychophysical studies that assess spatial frequency contrast sensitivity only measure accuracy of participant's overt

responses, whereas ASD-TD differences in visual processing of spatial frequencies may lie with the neural processing strategies employed and the timing of those processes. This is a prospect studies that examined electrophysiological responses to stimuli of varying spatial frequencies in ASD, have sought to address (Boeschoten, Kenemans, van Engeland, & Kemner, 2007a; Milne, Scope, et al., 2009). In one study, participants with ASD showed a smaller increase in visual evoked potentials (VEP) for gratings of 6.0cpd compared to VEP for gratings of 0.75cpd, than TD controls (Boeschoten, et al., 2007a). In the same study, the participants with ASD also displayed a smaller difference in anatomical location of VEP sources for gratings of 6.0cpd and of 0.75cpd, while TD participants showed a distinct difference in anatomical location of VEP sources for the two spatial frequencies. In a another study, a similar pattern of results was found with alpha and gamma-band EEG power, whereby the participants with ASD showed a smaller increase in alpha and gamma-band EEG power for gratings at 0.5cpd, 1.0cpd, 4.0cpd, 8.0cpd, compared to TD participants (Milne, Scope, et al., 2009). Although electrophysiological responses are not a test of contrast sensitivity, these studies report decreased differential processing of low and high spatial frequencies in individuals with ASD compared to TD controls, which does suggest some atypical spatial frequency processing at the neuro-physiological level, in ASD.

Furthermore, atypical visual processing of spatial frequency in ASD may lie with how the spatial frequency information is used for higher level visual processes. The use of spatial frequency information in ASD has not been investigated for perception of non-social visual stimuli, but it has been investigated for perception of social visual stimuli such as faces. This has been done with face stimuli that have been low-pass filtered i.e. low spatial frequency information retained, or high-pass filtered i.e. high spatial frequency information retained. There is literature suggesting that identity recognition (Costen, Parker, & Craw, 1994, 1996; Fiorentini, Maffei, & Sandini, 1983; Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffaux & Rossion, 2006; Gold, Bennett, & Sekuler, 1999; Morrison & Schyns, 2001; Näsänen, 1999) and emotional recognition of faces in particular fearful facial expressions (Vlamings, Goffaux, & Kemner, 2009; Vuilleumier, Armony, Driver, & Dolan, 2003; Winston, Vuilleumier, & Dolan, 2003), may be dependent on low spatial frequency visual information.

There exists behavioural evidence providing support for the notion that individuals with ASD may utilize spatial frequency information for face perception, differently from TD individuals. Two studies measured perceptual discrimination of facial identity and emotion for low and high spatial frequency faces, and showed that while TD individuals rely more on low rather than high spatial frequency information, individuals with ASD showed greater reliance on high rather than low spatial frequency information (Deruelle, et al., 2004; Deruelle, Rondan, Salle-Collemiche, Bastard-Rosset, & Da Fonseca, 2008), In line with these findings, another study showed that individuals with ASD underperform TD individuals when face stimuli contain only low spatial frequencies (Katsyri, Saalasti, Tiippana, von Wendt, & Sams, 2008). An electrophysiological study also revealed participants with ASD to have less activation of frontal source locations of VEP to low spatial frequency faces than TD controls (Boeschoten, et al., 2007b). Individuals with ASD may not have atypicalities in sensitivity to low and high spatial frequency information, but there is substantial evidence suggesting that they may use spatial frequency information differently from TD individuals for higher level visual processes.

Conclusion

This study revealed no evidence for atypical sensitivity to low and high spatial frequency information in ASD. It is suggested that despite typical sensitivity to spatial frequency information, individuals with ASD may still show atypicalities with respect to the utilization of low and high spatial frequency information, as revealed by atypical electrophysiological responses to low and high spatial frequency information (Boeschoten, et al., 2007a; Milne, Scope, et al., 2009), and how low and high spatial frequency information may be used for higher perceptual tasks such as face perception (Deruelle, et al., 2004; Deruelle, et al., 2008; Katsyri, et al., 2008; Boeschoten, et al., 2007b).

7 Chapter Seven – Summary and General Conclusions

7.1 Main findings of the thesis

Contrary to speculations that global motion perception deficits in ASD may be a result of atypical visual inputs from the sub-cortical M and P pathways (Milne, et al., 2002; Plaisted, et al., 1999), the research in this thesis presents no evidence that sub-cortical visual pathway functioning is atypical in ASD. Chapter five assessed M and P pathways in adolescents with ASD and TD controls, using luminance and chromatically-defined gratings, which have not been used in previous tests of M and P pathway functioning (Bertone, et al., 2005; Davis, et al., 2006; Pellicano, Gibson, et al., 2005). It also used a smaller stimulus size than previous studies did, that was thought to be more appropriate for assessing M pathway functioning (as recommended by Plaisted & Davis, 2005). Additionally, it provided a comprehensive investigation of M and P pathway functioning in ASD by including measures of M and P pathway functioning not only of absolute M and P pathway functioning, but also of the balance of M versus P pathway functioning, and the extent to which M and P pathways contribute to motion direction perception. Consistent with previous research, the study found converging evidence that M and P pathway functioning is intact in individuals with ASD (Bertone, et al., 2005; Pellicano, Gibson, et al., 2005, although Davis, et al., 2006 found impaired P pathway functioning in ASD).

The finding of intact M and P pathway functioning in adolescents with ASD occurred in conjunction with the observation of impaired local motion direction perception in the adolescents with ASD. This result is inconsistent with findings from two previous studies that found intact local motion direction perception in ASD with stimuli at 2.0Hz (Bertone, et al., 2003) and 0.67Hz drift temporal frequencies (Takarae, et al., 2008). However, it is suggested that individuals with ASD may have specific local motion direction perception difficulties with stimuli of higher drift temporal frequencies i.e. at 5.5 Hz or higher. Motion direction perception requires the engagement of neural processes in the visual cortical region, as it has been established that discriminating direction-of-motion requires processing by direction-selective neurons in the visual cortex (Movshon & Newsome, 1996; Snowden, et al., 1992; Snowden, et al., 1991). Therefore the finding of typical M and P pathway functioning in the adolescents with ASD in conjunction with local motion direction perception deficits for stimuli at 5.5Hz, suggests that atypical lower level

visual perception in ASD is associated more with atypical cortical visual processes, rather than atypical sub-cortical visual processes.

In addition, chapter six provides indirect evidence suggesting that examples of atypical low level visual perception in ASD (e.g. Bertone, et al., 2003, 2005; Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000; Spencer & O'Brien, 2006) to have a cortical rather than a sub-cortical origin. Previous research (Behrmann, Avidan, et al., 2006; de Jonge, et al., 2007; Milne & Buckley, submitted; Milne, Griffiths, et al., 2009; Milne, Scope, et al., 2009, Ashwin, et al., 2009) was argued not to have employed as rigorous an approach for examining lower and high spatial frequency mechanisms in ASD as the current study did, as those studies did not use as wide a range of spatial frequencies (0.5 to 20 cycles/deg), did not use a staircase procedure with a variable step size, and did not fit a contrast sensitivity function that also enabled estimation of visual acuity and contrast sensitivity at a very low spatial frequency. Nevertheless, consistent with findings from those studies (Behrmann, Avidan, et al., 2006; de Jonge, et al., 2007; Milne & Buckley, submitted; Milne, Griffiths, et al., 2009; Milne, Scope, et al., 2009, except for Ashwin, et al., 2009) chapter six revealed no evidence for atypicalities in low and high spatial frequency detectors in adolescents with ASD. Detection of low and high spatial frequency information can be assumed to be a sub-cortical process as the M pathway is known to respond optimally to stimuli moving at high temporal frequencies and low spatial frequencies, and the P pathway to stationary or slow moving high spatial frequency stimuli (Merigan & Maunsell, 1993). Thus, chapter six's finding also suggests that atypical visual perception in ASD is unlikely to be associated with atypical sub-cortical visual processes. Previous literature suggests that there may be atypical cortical visual processes for low and high spatial frequency information, as atypical electrophysiological responses to low and high spatial frequency information were elicited in individuals with ASD (Boeschoten, et al., 2007a; Milne, Scope, et al., 2009), and individuals with ASD have shown differential use of low and high spatial frequency information for higher perceptual tasks such as face perception (Deruelle, et al., 2004; Deruelle, et al., 2008; Katsyri, et al., 2008; Boeschoten, et al., 2007b). Therefore atypical processing of spatial frequency information in ASD may arise at the cortical level, and has more to do with how the information is utilized, rather than the actual sensitivities to different spatial frequencies.

That atypical visual perception in ASD has a cortical origin concurs with the findings from chapters three and four that revealed electrophysiological evidence for atypical visual cortical processes in ASD. Previous behavioural evidence have demonstrated individuals with ASD to show superior discrimination of orientation and intact discrimination of direction-of-motion of first order gratings, but deficits in perception of orientation and direction-of-motion of second order gratings (Bertone, et al., 2003, 2005). In contradiction to the "complexity" hypothesis arising from this research, which suggests that individuals with ASD have specific difficulties with visual stimuli requiring visuo-integrative processes, chapter three found no VEP evidence that visuo-integrative processes associated with perception of second order and hyperbolic gratings are atypical in the children with ASD. Instead, the children with ASD showed increased activity in the visual cortical region within the first 100-200ms of visual stimulation. It was suggested that this increased activity in the visual cortical region in ASD may reflect over-representation of local contrast signals in the visual cortex, which may be beneficial for perception of first order gratings, but may interfere with the integrative processes required for perception of second order gratings. Chapter four followed up on the finding of increased activity in the visual cortical region in the children with ASD, and demonstrated increased gamma power during the same time-frame in the children with ASD for parallel and first order gratings. Gamma power is thought to be indicative of neuro-connectivity within functional cortical regions (von Stein & Sarnthein, 2000), and parallel and first order gratings are thought to require engagement of the primary visual area V1 more so than V2 and the extra-striate visual areas (Larsson, et al., 2006). The results therefore suggest that there may be increased neuro-connectivity within the primary visual area V1, which is likely to be associated with over-representation of local contrast signals in the visual cortical region as primary visual area V1 is known for contrast detecting processes (Dumoulin, et al., 2003; Smith, et al., 1998). This interpretation is consistent with research indicating atypical neuro-connectivity to underlie ASD symptomology (Barnea-Goraly, et al., 2004; Belmonte, et al., 2004; Brock, et al., 2002; Casanova, et al., 2003; Castelli, et al., 2002; Gustafsson, 1997; McClelland, 2000; Rippon, et al., 2007; Rubenstein & Merzenich, 2003), although the majority of those investigations focused on brain regions implicated in social and language functioning, rather than the visual cortical region. In sum, atypical visual perception in ASD appears to have a cortical, rather than sub-cortical origin, and the

underlying mechanism of this atypical visual perception may be increased neuro-connectivity within primary visual area V1. Atypical neuro-connectivity in the visual cortical region may result in over-representation of local contrast signals in the visual cortex, promoting superior orientation perception of parallel first order gratings (Bertone, et al., 2005), but lead to downstream detrimental effects on the perception of stimuli requiring integration of those signals.

In line with chapter one's discussion on the EPF model (Mottron, et al., 2006) and WCC account of ASD (Happé & Frith, 2006), the atypical low level visual cortical processes described in the previous paragraph may be the mechanism underlying locally-biased perceptual style in ASD. However, whether these atypical low level visual cortical processes in individuals with ASD manifest at the higher perceptual level in visual cognitive tasks, such as the EFT and the BDT, can as chapter two suggests, be determined by cultural variability in attention and response processes. Chapter two investigated central coherence or field-dependence in children with ASD and TD children from Singapore and England on the CEFT, the Absolute FLT, the Relative FLT and the BDT. The CEFT and the Absolute FLT results revealed the expected WCC in the English children with ASD compared to their English TD peers, but stronger central coherence in the Singaporean children with ASD compared to their Singaporean TD peers. The results found evidence for a cultural influence on the ASD-TD difference in perceptual style and suggests that WCC in ASD may not be culturally universal. This finding provides strong justification for greater emphasis on research on low level visual perception in ASD, rather than the higher perceptual processes, for the objective of unravelling fundamental differences between individuals with ASD and TD individuals.

On a separate note, chapter five also presented data indicating siblings of individuals with ASD to have enhanced P pathway functioning and lower relative functioning of M versus P pathways, compared to TD controls and also the individuals with ASD. This is the first study to reveal a trait that is similar between individuals with ASD and TD controls, but different in siblings of individuals with ASD compared to individuals with ASD and TD individuals. The results contradict previous results that compared relative functioning of M versus P pathways in infants siblings of individuals with ASD and infant controls, and found the infant siblings to have enhanced M pathway functioning

and higher relative functioning of M versus P pathways (McCleery, et al., 2007). However, if the results from McCleery et al (2007) are considered together with the present results, it is observed that the infant controls had lower functioning of the M pathway compared to the P pathway, and the adolescent controls demonstrated higher functioning of the M pathway compared to the P pathway, while the siblings of individuals with ASD showed consistently higher functioning of the M pathway compared to the P pathway from infancy to adolescence. This balance of M and P pathway functioning across development may play a role, or is a by-product of some mechanism that promotes 'immunity' against developing ASD in individuals with a genetic pre-disposition for the condition. Further investigation of this atypical balance of M versus P pathway functioning in siblings of individuals with ASD may place scientists en route to uncovering the neurobiological factors that prevent these individuals from developing ASD.

7.2 Small sample sizes and sub-groups in ASD

A limitation of the research conducted in this thesis is that the sample sizes for the participants with ASD were relatively small (range of sample size for participants with ASD = 10 – 19). There is a possibility that any null findings or significant findings may be a result of sampling of individuals with ASD belonging to different sub-groups. Therefore, further replication of those findings is required to determine their reliability. It is fair to note however, that the sample sizes used here are not unusually small compared to many published studies in this area.

Also, due to the small sample size, the studies in this thesis did not separate the participants with ASD into sub-categories of ASD, such as Autistic disorder, Asperger's syndrome and PDD-NOS, and also did not attempt to perform sub-grouping of participants with ASD based on cognitive profiles (with the exception of the additional analysis conducted for data from chapter five, Appendix pg 162), for the purpose of group comparisons. There may be differences in visual perception between individuals of these ASD sub-categories/ groups. For example, individuals with Autistic disorder, but not Asperger's syndrome have been found to have impaired global form perception of Glass patterns (Spencer & O'Brien, 2006). Takarae et al (2008) also found no evidence of local motion direction perception impairment in participants with autism and no language delay, but found local motion direction perception impairment in participants with autism and

language delay. Furthermore, Caron et al (2006) only found superiority in BDT performance for participants with ASD who were identified to have BDT peaks in their cognitive profile, but not for participants with ASD with no BDT peaks in their cognitive profile, compared to TD participants. Provided that a large enough sample of participants with ASD are recruited, future studies may benefit from employing some form of sub-grouping, which will help identify characteristics of individuals with ASD that are associated with certain visual abilities or disabilities.

In addition to stratifying participants with ASD into sub-categories/groups, future research may also examine lower and higher level visual processes simultaneously in participants with ASD. This is because there is a possibility that sub-groups of individuals with ASD may show different performance profiles on various low and high level visual perceptual tasks. For example, it could be that individuals with ASD who show difficulties with face identity and emotion recognition are the same individuals who show WCC and atypical spatial contrast sensitivity functions; whereas individuals with ASD who do not show difficulties with face perception are the same individuals who do not show WCC and have unremarkable spatial contrast sensitivity functions. Likewise, it may be that individuals with ASD who display local motion direction perception difficulties are the same individuals who show deficits for global motion and form perception; and that it is individuals with ASD who do not display local motion direction perception difficulties, who do show deficits for global motion perception but not global form perception. Therefore, time-consuming as it may be, the best approach in ASD research may be to assess the same individuals with ASD and comparison groups on low and high level visual perceptual tasks, in order to determine associations between different visual abilities in ASD. Further effort can then be made to correlate those visual abilities with the social abilities of the participants, to aid in determining meaningful sub-groups of ASD with distinct behavioural and cognitive profiles.

7.3 Additional suggestions for future research

The conclusions made in section 7.1, that individuals with ASD have difficulties in perceiving 'complex' visual stimuli, including stimuli used in assessments of global motion perception, are based on the premise that individuals with ASD do have global motion perception deficits. However, as reviewed in chapter one, not all studies that have

investigated global motion perception using RDK in individuals with ASD have found impaired global motion perception in these individuals (for positive findings please see Davis, et al., 2006; Milne, et al., 2002; Pellicano, Gibson, et al., 2005; Spencer, et al., 2000, for negative findings please see de Jonge, et al., 2007; Del Viva, et al., 2006; Milne, et al., 2006; Takarae, et al., 2008). It was suggested that the choice of task i.e. detection of motion instead of discrimination of direction-of-motion, where the former is likely to be an easier task than the latter, and the use of shorter stimulus durations, where stimulus durations of less than 600ms make the global motion perception tasks as difficult for the TD participants as it is for the participants with ASD, may explain the null findings. There is however no empirical evidence supporting the conjecture that the two factors play a role in the discrepant findings. Thus, these potential confounding factors need to be examined in greater depth, for the reliability of findings of global motion perception deficits in ASD to be determined.

Also, global form perception deficits have only been elicited in ASD with Glass patterns (Spencer & O'Brien, 2006), and not line segment or gabor patch displays (Blake, et al., 2003; Milne, et al., 2006; Spencer, et al., 2000; Del Viva, et al., 2006; Kemner, et al., 2007). It was suggested that children with ASD may show greater difficulties with perceiving form in Glass patterns than in line segment and gabor patch displays, because Glass patterns require both local and global integration of the dots for the global form to be perceived, whereas the line segment displays and gabor patch displays only require global integration of the local signals. The notion that individuals with ASD have issues with local integration for global form perception of Glass patterns, is consistent with behavioural evidence that individuals with ASD show deficits in orientation perception of static second order gratings (Bertone, et al., 2005). Further investigation of global form perception in ASD, by comparing form perception in participants with ASD and TD controls for matched line segment displays, gabor patch displays and Glass patterns, is therefore recommended. The finding may clarify whether local and/or global integration atypicalities are implicated in form perception in ASD.

Last but not least, the suggestion that impaired local motion direction perception in ASD is specific for visual stimuli of high drift temporal frequencies i.e. at 5.5Hz and higher needs to be verified. Data on direction sensitivity to moving gratings in individuals with

ASD and TD controls, for a range of drift temporal frequencies, would be necessary. The figures would also be helpful for determining if global motion perception atypicalities in ASD have an underlying impairment with local motion direction perception for higher temporal frequency signals.

7.4 Concluding remarks

This thesis provides evidence that atypical visual perception in ASD has a cortical, rather than sub-cortical origin, and suggests that the aetiology of atypical visual perception may be increased neuro-connectivity within primary visual area V1. Atypical neuro-connectivity in the visual cortical region may result in over-representation of local contrast signals in the visual cortex, promoting superior orientation perception of parallel first order gratings (Bertone, et al., 2005), but lead to downstream detrimental effects on the perception of stimuli requiring integration of those signals. As suggested by the EPF model (Mottron, et al., 2006), atypical neuro-connectivity may be the low level visual mechanisms underlying locally-biased perceptual style in ASD. However, whether these atypical low level visual mechanisms in ASD actually manifest themselves at the higher perceptual level with visual cognitive tasks such as the CEFT/EFT, may be subject to external cultural influences.

All in all, this thesis' findings have demonstrated research on visual perception in ASD to have great potential for understanding the non-social behavioural traits of ASD, and to be a powerful avenue for examining the neurobiology of ASD. It is hoped that with further perseverance along this line of research, meaningful sub-types of ASD with different behavioural and cognitive profiles, and different underlying aetiology, will be revealed. Such knowledge would eventually provide strong theoretical bases for the formulation of reliable early diagnostic tools, and effective personalized medical and psychological interventions for individuals with ASD, and contribute towards creating "a world in which suffering because of Autism no longer exists" (G. Dawson, et al., 2009; page 2 of the executive summary).

Table 8.1 Published group studies on visual motion perception in ASD.

Reference	Task & stimuli	Participants (Group means)	Main Findings
	Random Dot Kinematogram		
Spencer, et al., 2000	Task: discriminate direction-of-motion i.e. locate a target strip (left or right) that is moving in opposite direction to rest of display. Dot speed: 5.8 deg/s Stimulus duration: until response made	23 ASD (7-11 years, no IQ details) 50 TD age-matched	ASD > TD motion coherence threshold
Milne, et al., 2002	Task: discriminate direction-of-motion i.e. are the dots moving left or right? Dot speed: 8.8 deg/s Stimulus duration: 1010 ms	25 ASD (12 years, Raven's raw score 41) 22 TD (age and NVA matched)	ASD > TD motion coherence threshold
Pellicano, Gibson, et al., 2005	Task: discriminate direction-of-motion i.e. are the dots moving up or down? Dot speed: 6.3 deg/s (spatial step size 0.19 deg per 30ms) Stimulus duration: 600ms (20 frame sequences of 30ms)	20 ASD (10 years, Raven's raw score 40) 20 TD (age and NVA matched)	ASD > TD motion coherence threshold

Davis, et al., 2006	Task: discriminate direction-of-motion i.e. are the dots moving left or right? Dot speed: 6.4 deg/s Stimulus duration: 220ms and 1000ms	9 ASD (12 years, WISC-III similarities score 13) 9 TD (age and VA matched)	ASD > TD motion coherence threshold for 1000ms but not 220ms stimulus
Milne, et al., 2006	Task: detection of motion i.e. locate panel that has dots moving in one direction Dot speed: 7.0 deg/s Stimulus duration: until response made	23 ASD (10 years Raven's score 95) 23 TD (age and NVA matched)	No group difference in motion coherence thresholds
de Jonge, et al., 2007	Task: detection of motion i.e. locate panel that has dots moving in one direction Dot speed: no details Stimulus duration: until response made	29 ASD (17 years, Wechsler Scales IQ 99) 32 TD (age and IQ matched)	No group difference in motion coherence thresholds
Del Viva, et al., 2006	Task: discriminate direction-of-motion i.e. contraction or expansion, rotation anti-clockwise or clock-wise, translation left or right Dot speed: 10.0 deg/s Stimulus duration: 160 ms	10 ASD (8 years, Wechsler scales verbal mental age 7 years) 12 TD (VA matched) 14 TD (age matched)	No group difference in motion coherence thresholds
Takarae, et al., 2008	Task: discriminate direction-of-motion i.e. are the dots moving left or right? Dot speed: 3.3 deg/s	36 ASD (15 years, Wechsler Scales IQ 104) 46 TD (age and IQ matched)	No group difference in motion coherence thresholds

	Stimulus duration: 300ms		
	Motion Glass Pattern		
Spencer & O'Brien, 2006	Task: detection of motion i.e. locate panel that has dots moving in a circular pattern Dot speed: 5.8 deg/s Stimulus duration: 250ms	15 Autism (14 years, BVPS IQ 97) 10 Asperger's syndrome (12 years, BVPS IQ 110) 15 TD (12 years, BVPS IQ 109)	Autism > TD motion coherence threshold No group difference between participants' with Asperger's syndrome and TD participants.
	Plaid Stimuli		
Vandenbroucke, et al., 2008	Task: indicate when a coherently moving plaid pattern is observed and when component moving plaid pattern is observed Spatial Frequency (component gratings): 0.9 – 3.0 cpd Drift Temporal frequency (component gratings): 1.44 – 2.88Hz	13 ASD (21 years, Wechsler Scale IQ 121) 27 TD (age and IQ matched)	No group differences in measures of perception of coherent motion and component motion observed
	First and/or Second order gratings		
Bertone, et al., 2003	Task: discriminate direction-of-motion of first and second order gratings i.e. translation left or right, contraction or expansion, rotation anti-clockwise or clock-wise Spatial Frequency: 1.0 cpd	12 ASD (12 years, normal intelligence) 12 TD (age-matched)	No group difference in contrast sensitivity to first order gratings ASD < TD in contrast sensitivity to second order gratings

	Drift temporal frequency: 2.0Hz		
Takarae, et al., 2008	Task: discriminate direction-of-motion of first order gratings i.e. is the grating moving left or right? Spatial Frequency: 0.67 cpd Drift temporal frequency: 0.67Hz	36 ASD (15 years, Wechsler Scales IQ 104) 46 TD (age and IQ matched)	No group difference in contrast sensitivity

Table 8.2 Published group studies on visual form perception in ASD.

Reference	Task	Participants (Group means)	Main Findings
Spencer, et al., 2000	Line segment displays	23 ASD (7-11 years, no IQ details) 50 TD age-matched	No group difference in form coherence threshold
Blake, et al., 2003	Line segment displays	12 ASD (8-10 years) 9 TD (5-10years, mental age-matched)	No group difference in form coherence threshold
Milne, et al., 2006	Line segment displays	23 ASD (10 years, Raven's score 95) 23 TD (age and NVA matched)	No group difference in form coherence threshold
Del Viva, et al., 2006	Gabor patch displays	10 ASD (8 years, Wechsler scales verbal mental age 7 years) 12 TD (VA matched) 14 TD (age matched)	No group difference in form coherence threshold
Kemner, et al., 2007	Gabor patch displays	16 ASD (13 years, Wechsler Scale IQ 106) 17 TD (age and IQ matched)	No group difference in form coherence threshold
Spencer & O'Brien, 2006	Glass Pattern	15 Autism (14 years, BVPS IQ 97) 10 Asperger's syndrome (12 years, BVPS IQ 110) 15 TD (12 years, BVPS IQ 109)	Autism > TD form coherence threshold No group difference between participants' with Asperger's syndrome and TD participants.
Davis, et al., 2006	Noise stimuli	9 ASD (12 years, WISC-III similarities score 13)	No group difference in form coherence threshold

		9 TD (age and VA matched)	
Bertone, et al., 2005	First and Second order gratings Spatial frequency: 0.75 cpd Drift temporal frequency: 0Hz	13 ASD (21 years, Wechsler Scale IQ 100) 13 TD (age and IQ matched)	No group difference in contrast sensitivity to first order gratings ASD < TD in contrast sensitivity to second order gratings

Table 8.3 Group studies on cultural differences in EFT performance.

Reference	Task	Participants	Results	Main Findings
Kuhnen, et al., 2001	EFT	107 Russian adults 175 Malaysian adults 60 American adults 80 German adults	Russians < accuracy than Americans and Germans Malaysians < accuracy than Americans and Germans	Russians and Malaysians > field dependent than Americans and Germans
Ji, et al., 2000	EFT	42 East Asian adults (N=42) 56 American adults (N=56)	No group differences observed	No cultural differences in field dependence
Bagley, 1995	CEFT	50 Chinese nine to eleven year old females	Chinese children scored > CEFT norms for American children	Chinese children < field dependent than American children
Bagley et al, 1983, as cited in Bagley, 1995	CEFT	Japanese nine to eleven year old (no sample size details)	Japanese children scored > CEFT norms for American children	Japanese children < field dependent than American children

Table 8.4 Group studies on cultural differences in FLT performance.

Reference	Task	Participants	Results	Main Findings
Ji, et al., 2000	Rod and Frame task i.e. Absolute FLT	42 East Asian adults 56 American adults	East Asians < errors than Americans	East Asians > field dependent than Americans
Kitayama, et al., 2003	Absolute and Relative FLT	20 Japanese adults 20 American adults and 32 Japanese adults 40 American adults From two related studies	Japanese > absolute error than Americans on Absolute FLT Japanese < absolute errors than Americans on Relative FLT	Japanese > field dependent than Americans
Hedden, et al., 2008	Modified Absolute and Relative FLT (participants were asked to make judgements on whether the stimuli were congruent or incongruent to the absolute or the relative rule), while undergoing an fMRI scan	10 Chinese adults 10 American adults	No group difference on behavioural task Chinese > fMRI activation in frontal and parietal regions for Absolute FLT Americans < fMRI activation in frontal and parietal regions for Relative FLT	No cultural difference in field dependence but Chinese and Americans show differential activation of cortical regions responsible for higher cognitive processes for culturally not preferred tasks
Zhou, et al., 2008	Absolute and Relative FLT	20 Chinese adults 98 American adults	No group differences observed	No cultural difference in field dependence

Duffy et al, unpublished cited in Nisbett & Miyamoto, 2005	Absolute and Relative FLT	Japanese four year olds American four year olds Japanese five year olds American five year olds (no sample size details)	No group difference between Japanese and American four year olds American five year olds < absolute errors on the Absolute FLT than on the Relative task	Americans become < field dependent from five years of age

Table 8.5 Published ASD-related studies on M and P pathway functioning in ASD.

Reference	Task & stimuli	Participants (Group means)	Main Findings
Bertone, et al., 2005	Task: 2 temporal alternative forced choice task i.e. participants indicated if the flicker was in the first interval or the second interval Stimuli: luminance (light/dark) gratings at 0.5 cpd and 6Hz for the M condition, and 6cpd and 1 Hz for the P condition; the sinusoidal gratings were presented centrally in a circular region with diameter 10° visual angle, for 750ms	13 ASD (21 years, Wechsler Scale IQ 100) 13 TD (age and IQ matched)	No group difference in flicker contrast sensitivity for the M and P conditions
Pellicano, Gibson, et al., 2005	Task: 2 temporal alternative forced choice task Stimuli: Luminance Gaussian blob flickering at 10 Hz for the M condition; stimuli extended 6.3° visual angle and were presented for 1000ms	20 ASD (10 years, Raven's raw score 40) 20 TD (age and NVA matched)	No group difference in flicker contrast sensitivity for the M condition.
Davis, et al., 2006	Task: detection task i.e. participants indicated if a grating was present or not Stimuli: Luminance grating at 0.5cpd and 12.5Hz with a duration of 80ms for the M condition (an additional stimuli at 0.5cpd and 5Hz with duration of 200ms was also used), Luminance grating at 13.4cpd and 2Hz with	9 ASD (12 years, WISC-III similarities score 13) 9 TD (age and VA matched)	ASD showed lower contrast sensitivity for the P condition; no group difference in flicker contrast sensitivity for the M condition.

	duration of 493ms for the P condition; gratings were presented centrally with a Gaussian envelope extending 5.3° visual angle.		
McCleery, et al., 2007	Task: forced preferential looking (left or right) task Stimuli: luminance (light/dark) gratings for M condition, chromatic (red/green) gratings for P condition; the horizontal sinusoidal gratings subtend 11.1x11.1°, was presented at 0.27 cpd and 4.2Hz	13 6-month olds at risk of ASD 26 6-month olds not as risk of ASD	Infants at risk showed higher contrast sensitivity for the M condition, no group difference flicker contrast sensitivity for the P condition.

Re-examination of local motion direction perception in adolescents with ASD grouped by Verbal IQ

The participants with ASD (*N*=10) with verbal IQ within the top 50th percentile (range = 96 – 133) were placed in one sub-group. The remaining participants with ASD (*N*=9), who had lower verbal IQ scores (range = 55 – 95), were placed in another sub-group. Their contrast sensitivity to luminance and chromatic gratings, for the MOT (direction-of-motion discrimination) task, were compared to the TD controls (*N*=39).

The participants with ASD with high verbal IQ and the TD controls were matched on verbal IQ, performance IQ and Full Scale IQ. The participants with ASD with high verbal IQ showed significantly reduced contrast sensitivity to direction-of-motion of luminance gratings (t(df=47)=2.57, p=0.013, r=0.35), but did not show a significant difference for chromatic gratings (t(df=47)=0.878, p=0.384, r=0.13), when compared with the TD controls.

The participants with ASD with low verbal IQ and the TD controls were matched on performance IQ. The participants with ASD with low verbal IQ showed significantly reduced contrast sensitivity to direction-of-motion of luminance (t(df=46)=4.55, p<0.001, r=0.56) and chromatic gratings (t(df=46)=2.49, p=0.016, r=0.35), when compared to the TD controls.

In sum, contrary to Takarae et al (2008)'s findings, the results showed that the adolescents with ASD demonstrate local motion direction perception deficits for moving luminance stimuli regardless of their language abilities, although only the adolescents with ASD of lower verbal IQ revealed local motion direction perception deficits for moving chromatic stimuli. Please also see Figures 8.1 and 8.2 (pg 163) for scatter-plots of contrast sensitivity of participants with ASD with high verbal IQ, with low verbal IQ and TD controls to luminance and chromatic stimuli, in the MOT task.

Figure 8.1 Scatter-plot of contrast sensitivity to luminance gratings in the MOT task for each group.

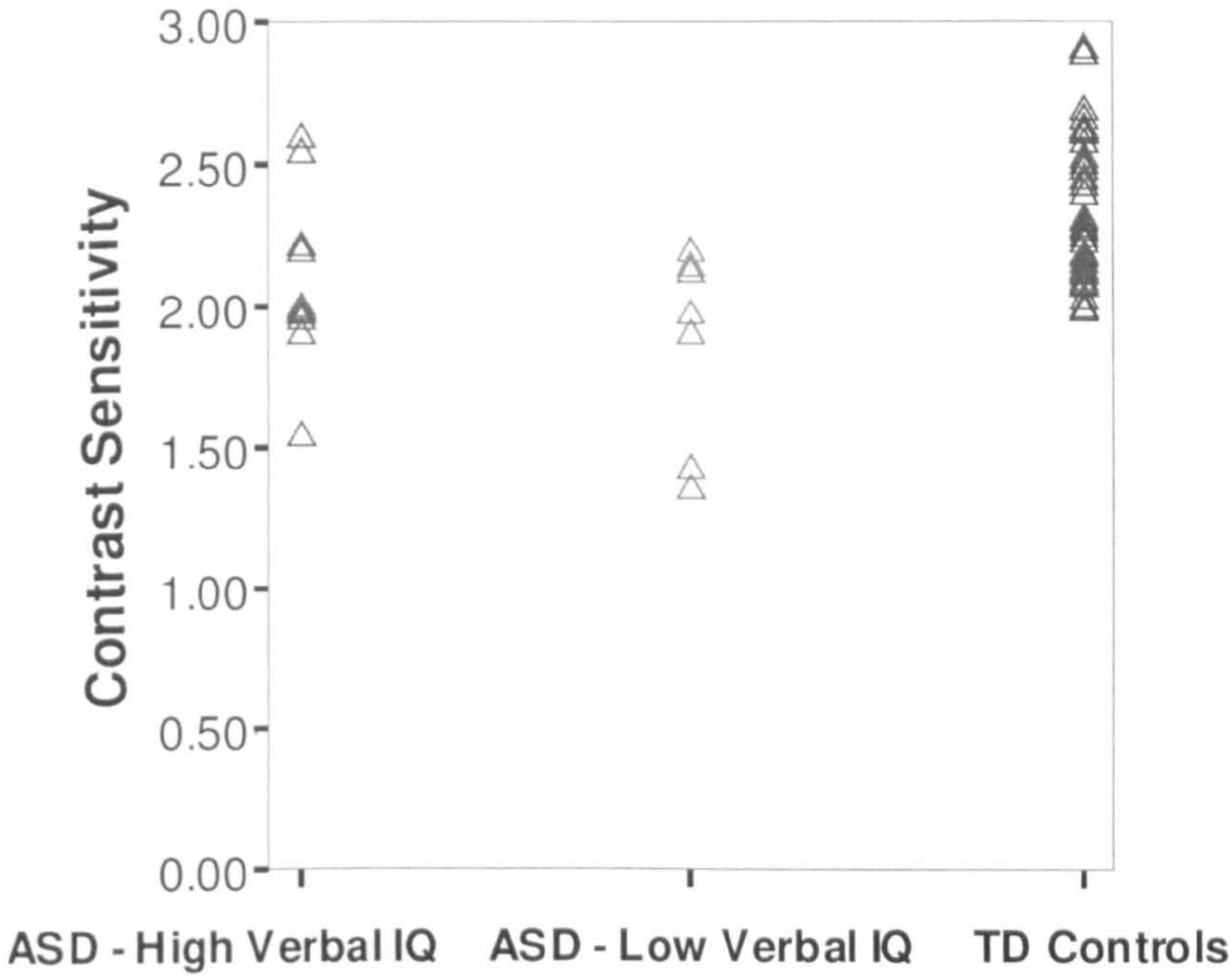
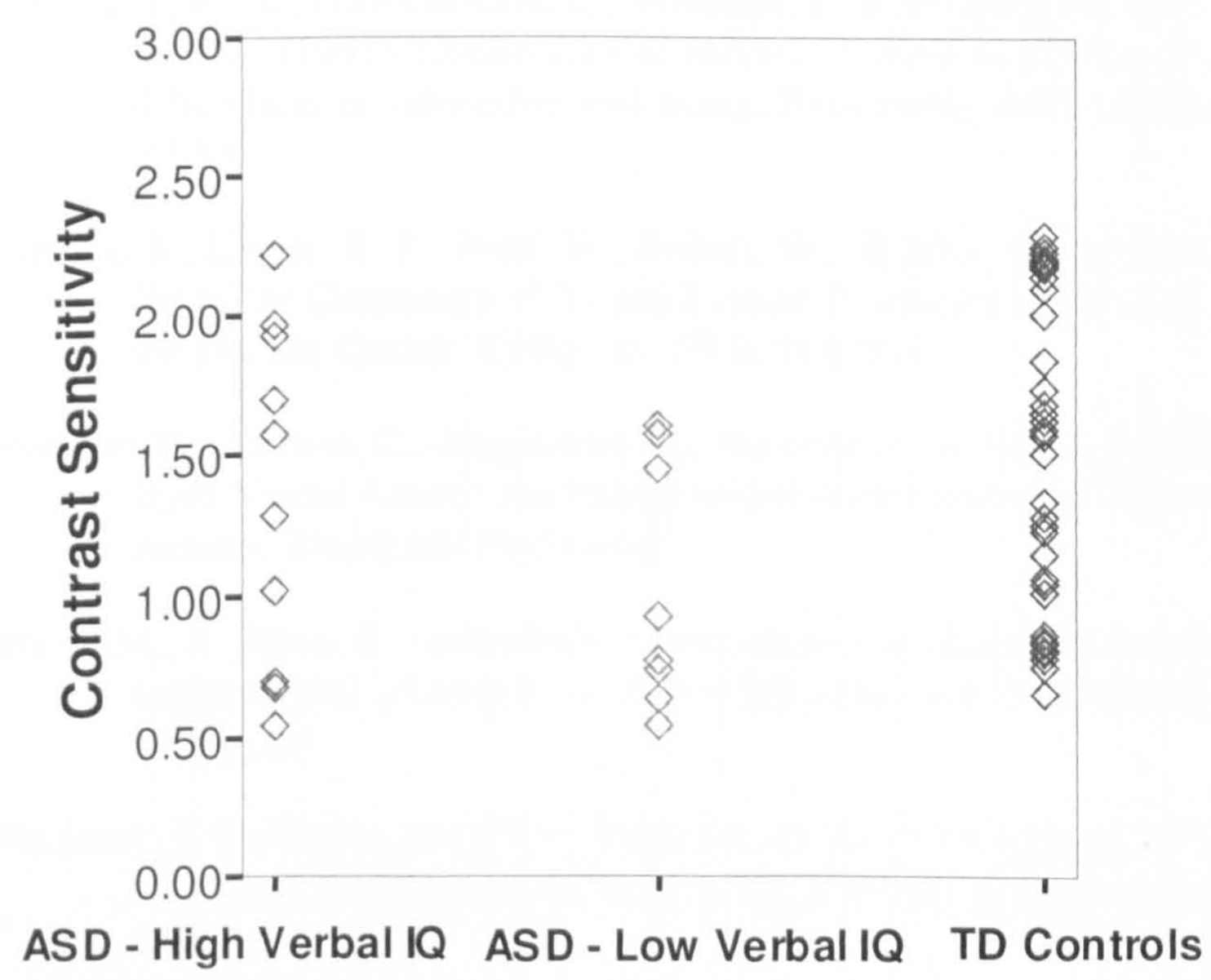


Figure 8.2 Scatter-plot of contrast sensitivity to chromatic gratings in the MOT task for each group.



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List of commonly used abbreviations

ASD	– Autism Spectrum Disorders
BDT	– Block Design Task
CEFT	– children's version of the embedded figures test
CSF	– contrast sensitivity function
DET	– motion detection
Diff-Ratio	– a metric for indicating the contribution of M and P pathway to motion direction perception.
EFT	– Embedded Figures Test
EPF	– Enhanced Perceptual Functioning
FLT	– Framed Line Test
L:C ratio	– a metric for comparing relative functioning of M versus P pathway
M	– Magnocellular
MOT	– discrimination of direction-of-motion
P	– Parvocellular
PC	– perceptual cohesiveness
PDD-NOS	– Pervasive Developmental Disorder Not-otherwise specified
RDK	– Random Dot Kinematograms
TD	– typically-developing
ToM	– Theory of Mind
VEP	– Visual Evoked Potential
WCC	– Weak Central Coherence