

Abnormal global processing along the magnocellular visual pathway in
autism: a possible mechanism for weak visuospatial coherence?

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Abstract

Frith and Happé (1994) argue that individuals with autism exhibit ‘weak central coherence’: an inability to integrate elements of information into coherent wholes. Some authors have speculated that a higher-level impairment might be present in the magnocellular visual pathway in autism, and furthermore, that this might account for weak central coherence, at least at the visuospatial level. We assessed the integrity of the magnocellular pathway in children diagnosed with an autism spectrum disorder (ASD), and in typically developing children using two visual tasks, one assessing lower-level magnocellular functioning (Flicker Contrast Sensitivity; FCS), the other (Global Dot Motion; GDM) examining functioning at higher levels of the cortical stream fed by the magnocellular pathway. Central coherence was tested using the Children’s Embedded Figures Test (CEFT). Relative to the typically developing children, the children with ASD had shorter CEFT latencies and higher GDM thresholds but equivalent FCS thresholds. Additionally, CEFT latencies were inversely related to GDM thresholds in the ASD group. These outcomes suggest that the elevated global motion thresholds in autism are the result of higher-level impairments in the cortical regions receiving predominant input from the magnocellular pathway. Visuospatial impairments in autism may be in the form of abnormal cooperative mechanisms in extra-striate cortical areas, which might contribute to differential performance when processing stimuli as Gestalts, including both dynamic (i.e., global motion perception) and static (i.e., disembedding performance) stimuli.

Keywords: autism spectrum disorder, weak central coherence, visual perception

There has been a recent resurgence of interest in the nonsocial symptoms present in autism. Individuals with autism often display preserved or superior skills in various areas, such as good visuospatial ability, excellent rote memory, and peaks as part of an uneven profile on scales of intelligence. These abilities, which lie in stark contrast to the impairments in socialisation and communication that more overtly characterise autism in everyday settings, are often left unexplained by prominent cognitive theories of autism.

One theory of autism is particularly intriguing as it attempts to explain these ‘islets of ability’ as well as the weaknesses inherent in the disorder. Frith and Happé (1994) argue that persons with autism exhibit a peculiar processing style they term ‘weak central coherence’, which leads to particular peaks and troughs in performance. Weak central coherence refers to an inability to integrate incoming stimuli, accompanied by an inherent bias towards processing the parts of stimuli. By contrast, typically developing individuals have a natural tendency to pull together disparate information to perceive stimuli as Gestalts (Frith & Happé, 1994).

There is a growing body of research to support a weak coherence bias in autism (see Happé, 1999, for a review). One of the most reliable findings is better performance by persons with autism compared with typically developing individuals on the Embedded Figures Test (EFT; Witkin, Oltman, Raskin, & Karp, 1971), which requires one to locate a shape hidden within a larger meaningful figure (see Figure 1; Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Purportedly, persons with autism are unimpeded by the Gestalt-inducing nature of the complex figure, and are able to quickly disembed the figure to locate the hidden shape. Weak central coherence in autism has also been evidenced by heightened performance on the Block Design task

(due to a superior facility for segmentation of the design; Shah & Frith, 1993), and a local advantage on the Navon task (Plaisted, Swettenham, & Rees, 1999).

Stimuli on the Navon task are typically, large letters composed of smaller letters of the same or different kinds, and the task is to respond to the target letter which could appear at either the global or local level. Plaisted *et al.* (1999) found that the global form took precedence over processing the local elements for typically developing children, whilst children with autism showed a local advantage; they made fewer errors when processing local targets. However, when children were explicitly instructed to attend to either the global or local level, children with autism obtained a global precedence effect similar to their typically developing peers. Based upon these results, the authors argued that weak central coherence in autism is not due to an inability to integrate parts into wholes, but instead, might be a result of enhanced perception of local stimulus attributes. It has been shown that the global advantage seen in typical individuals on the Navon task is due to the faster availability of signals carried by channels sensitive to low spatial frequencies (Badcock, Whitworth, Badcock, & Lovegrove, 1990). Therefore, Plaisted *et al.* (1999) speculated that the underlying physiological mechanism for the local processing bias in autism might be abnormalities at a perceptual level (see also Mottron, Belleville, & Ménard, 1999). Specifically, they suggested that the bias might be due to increased sensitivity of those channels responsible for processing high spatial frequency information.

In the human visual system, visual input to the cortex is carried primarily by the retino-geniculo-cortical pathway (Merigan & Maunsell, 1993). This pathway can be subdivided into magnocellular, parvocellular and koniocellular streams (Hendry & Reid, 2000; Merigan & Maunsell, 1993). Segregation begins in the retina (Perry & Cowey, 1985), and is most obvious in the lateral geniculate nucleus (LGN), which is

composed of six layers, four consisting of small (parvo) cells and two composed of larger (magno) cells.¹ The magnocellular and parvocellular pathways remain largely segregated in the initial stages of the primary visual cortex (area V1; Merigan & Maunsell, 1993). In extrastriate cortical regions, the signals are mixed but magno cells provide prominent input to the dorsal stream of processing while parvo cells provide dominant input to the ventral stream (Livingstone & Hubel, 1988). The magnocellular pathway responds well to rapidly changing stimuli, such as flicker and motion, but is largely insensitive to wavelength differences. Conversely, the parvocellular pathway is optimised for encoding information about color/wavelength, and processes slower moving, and stationary stimuli (Merigan & Maunsell, 1993). Whilst the ranges of spatiotemporal information to which the pathways respond overlap considerably, the magnocellular pathway is the most sensitive to stimuli composed of low spatial frequencies and high temporal frequencies (Merigan, Byrne, & Maunsell, 1991), and the parvocellular pathway provides the best response to those composed of high spatial and low temporal frequencies (Merigan *et al.*, 1991).

Plaisted and colleagues (1999) proposed that enhanced processing might be found on those pathways responsible for carrying high spatial frequency information (in particular, the parvocellular pathway) in autism. However, Badcock *et al.* (1990) found that removing low spatial frequencies from hierarchical stimuli did not result in a local precedence effect, rendering it unlikely that the local advantage on the Navon task in children with autism results from superior processing in the parvocellular pathway. Milne *et al.* (2002) have entertained an alternative proposal: that the preference for local processing in autism might reflect impairments in the pathway responsible for processing low spatial frequency information. Milne *et al.* (2002) tested this hypothesis by examining children's ability to perceive global motion, a

function that is mediated by inputs from the magnocellular pathway (Schiller, Logothetis, & Charles, 1990). Children were required to determine the overall direction of coherently moving dots, set amongst a background of randomly moving dots. Consistent with earlier findings (Spencer et al., 2000), Milne et al. (2002) found that high-functioning children with autism required a significantly higher percentage of dots to be moving coherently in order to be able to perceive global motion, compared with typically developing children of similar age and nonverbal ability. This led Milne et al. to suggest that persons with autism might exhibit a deficit in the magnocellular visual pathway. Given that more rapid processing of the global level of a stimulus would require faster transmission of low spatial frequency information (Badcock et al., 1990), Milne et al. (2002) further conjectured that a magnocellular pathway deficit might offer a physiological explanation of weak central coherence in autism.

This evidence clearly indicates that children with autism have difficulty detecting global, coherent motion. What is less clear, however, is whether this difficulty arises due to deficient processing of low spatial frequency information, as Milne et al. (2002) suppose. When Smith, Snowden, and A. B. Milne (1994) removed low spatial frequencies from global motion displays, they found that the perception of global motion remained intact, thus demonstrating that global motion perception is not reliant on low spatial frequency information. What then, might account for the elevated global motion thresholds in autism? The magnocellular pathway is best viewed as a system with progressively more complex processing occurring at higher levels – a deficit could arise at any location along this pathway. At the earliest levels, magno cells in the LGN (Merigan et al., 1991) and in area V1 (Schiller et al., 1990) are sensitive to flickering stimuli. At higher levels, single-cell recording studies have

shown that area MT/V5 is crucial for motion processing (Newsome & Paré, 1988), with neuronal firing rates in this region correlating strongly with perception of global motion (Britten, Shadlen, Newsome, & Movshon, 1992; Newsome, Britten, & Movshon, 1989). It is at this stage that local directional signals are combined to form a global percept, which involves additional cooperative mechanisms in the cortex (Edwards & Badcock, 1996).

Bertone, Mottron, Jelenic, and Faubert (2003) have recently investigated lower- and higher-level processing along the motion pathway in children with and without autism. They examined children's sensitivity to first-order (luminance-defined) and second-order (texture-defined) motion stimuli, the latter of which, they argue, requires more 'complex' perceptual processing. Children with autism performed more poorly than typically developing children on the second-order motion task, and Bertone *et al.* (2003) suggested that this reflected a specific deficit in the integration of 'complex' information at the global level. They further proposed that this deficit might not be restricted to the processing of dynamic stimuli, but might also include the processing of static stimuli (such as objects).

There may be two reasons to cast doubt on this view. Firstly, Derrington, Allen, and Delicato (2004) have suggested that attentional processes potentially confound performance on tasks assessing second-order motion, as, unlike first-order motion tasks, second-order motion stimuli, such as those used by Bertone *et al.* (2003), require feature tracking, and more extended processing over time. Impairments in attention have been reported in autism (e.g., Burack, 1994); therefore, poor attentional capacities may have adversely affected children's performance on the second-order motion task, leaving the implications of Bertone *et al.*'s findings somewhat uncertain. Secondly, when examining visual processing in children with

autism and typically developing children, Spencer *et al.* (2000) administered two threshold tasks: one tested global motion perception (tapping dorsal-stream functioning) and a second task tested perception of global form (tapping ventral-stream functioning; Braddick *et al.*, 2001). This second measure required children to detect concentric circles made up of short line segments set amid an array of randomly oriented line segments. Whilst Spencer *et al.* (2000) found that children with autism displayed elevated thresholds on the global motion task relative to comparison children, they nonetheless showed similar global form thresholds (see also Blake, Turner, Smoski, Pozdol, & Stone, 2003). This latter finding of intact global form perception in children with autism is inconsistent with Bertone *et al.*'s (2003) suggestion that an inability to integrate 'complex' information might have a negative impact on the perception of motion and form.

Instead, Spencer *et al.* (2000) interpreted their findings of poor global motion perception in autism in terms of a general deficiency in the dorsal-stream of processing. Braddick and colleagues (Atkinson, 2000; Braddick, Atkinson, & Wattam-Bell, 2003) argue that functioning within the ventral-stream develops more rapidly than dorsal-stream functioning, which might render the dorsal-stream more susceptible to impairment. Furthermore, they suggest that this vulnerability is not specific to autism, but rather, is characteristic of several neurodevelopmental disorders. In developmental dyslexia, researchers have reported impairments at both lower (in the form of a reduced sensitivity to flicker, e.g., Martin & Lovegrove, 1987) and higher levels of the magnocellular visual pathway (in the form of poor global motion perception, e.g., Hansen *et al.*, 2001). In addition, abnormally high global motion thresholds in combination with relatively normal global form thresholds have

been reported in Williams syndrome (Atkinson et al., 1997) and hemiplegia (Gunn et al., 2002).

Whilst Braddick et al. (2003) interpret the elevated global motion thresholds in autism in terms of a general ‘dorsal-stream vulnerability’, Bertone et al. (2003) propose that the high thresholds arise due to specific higher-level impairments in the magnocellular pathway. The present study sought to disentangle these two competing explanations by assessing the integrity of the magnocellular pathway at both lower and higher levels. We examined children’s performance on two adaptive psychophysical measures: a Flicker Contrast Sensitivity (FCS) task, which assessed early visual processing, and a Global Dot Motion (GDM) task (similar to that used by Milne et al., 2002), which tapped visual processing in higher cortical areas. If Braddick et al. (2003) are correct in proposing that autism (like other specific developmental disabilities) is associated with a general impairment in the dorsal-stream, then children with ASD should obtain significantly higher threshold estimates than typically developing children on both visual processing tasks. Alternatively, if abnormal functioning in the magnocellular pathway in children with ASD is confined to higher-level integrative processing, as Bertone et al. (2003) suggest, then children with ASD might show no difficulties on the lower-level visual processing task (the FCS task), but perform significantly worse than typically developing children on the task assessing higher-level dorsal-stream functioning (the GDM task).

This study also examined the idea that an abnormality in the magnocellular pathway might be responsible for weak central coherence in autism (Bertone et al., 2003; Milne et al., 2002). There have been separate reports of elevated global motion thresholds (e.g., Milne et al., 2002; Spencer et al., 2000) and a local processing bias (e.g., on the EFT; Shah & Frith, 1983) in autism; however, as yet there has been no

direct investigation of these two task domains within the same study of autism. Certainly, the relationship between performances in these two domains is of critical significance to weak central coherence theory – Frith and Happé (1994) argue that superior local processing goes hand in hand with poor integrative processing in autism. Indeed, evidence of a reciprocal relationship in which poor global motion processing is associated with enhanced disembedding skill would be difficult to predict from other theoretical positions. Our own work (Pellicano, Maybery, & Durkin, in press) has failed to demonstrate evidence of a reciprocal relationship for performances on coherence measures expected to tap local and global processing. However, our previous research used a sample of typically developing children, and examination of this purported reciprocal relationship in a group of children with ASD would provide a more stringent evaluation of weak central coherence theory. As Milne *et al.* (2002) and Bertone *et al.* (2003) suggest, establishing an association between embedding skill and global motion perception would provide some empirical evidence for the putative mechanism for weak visuospatial coherence in autism.

To test this relationship, we also administered a common measure of central coherence, the children's version of the Embedded Figures Test (CEFT; Witkin *et al.*, 1971), where children were required to find hidden figures (e.g., a triangle) embedded in larger meaningful designs. Previous studies have reported that persons with autism are faster to locate the figure than typical individuals (Jolliffe & Baron-Cohen, 1997), and Frith and Happé (1994) argue that their good performance is achieved by resisting the tendency to perceive the Gestalt and focusing instead on the constituent parts. According to weak central coherence theory, we should expect an inverse relationship to emerge between performance on the GDM task and the CEFT in the ASD group; that is, short response latencies on the CEFT should be associated with elevated

global motion thresholds. On the contrary, we expected no significant association between scores on the FCS task and the CEFT, as the FCS task does not involve global processing.

Method

Participants

Twenty 8- to 12-year-old children with an ASD (18 boys) were recruited through an autism register, various pediatricians, intervention agencies, and speech pathologists. Fifteen children with ASD met DSM-IV criteria (APA, 1994) for Autistic Disorder and 5 were diagnosed with Pervasive Developmental Disorder – Not Otherwise Specified. These diagnoses were independently confirmed with the Autism Diagnostic Interview – Revised (Lord, Rutter, & Le Couteur, 1994; social interaction domain score: \underline{M} = 20.35, \underline{SD} = 6.18; communication domain score: \underline{M} = 16.20, \underline{SD} = 5.50; repetitive behaviours domain score: \underline{M} = 6.80, \underline{SD} = 2.02); children either met full criteria for autism (\underline{N} = 17) or scored above the cut-off in two of the three symptom domains (\underline{N} = 3).

Twenty 8- to 12-year-old typically developing children (18 boys) also participated, and were recruited from several schools in the metropolitan area. Parents of typically developing children completed the Social Communication Questionnaire (Berument, Rutter, Lord, Pickles, & Bailey, 2001), a reliable screening tool for autism. All typically developing children scored well below the cut-off of 15 specified by the authors (\underline{M} = 3.00, \underline{SD} = 2.67), ensuring that children in the comparison group did not show any significant level of autistic symptomatology. Children in both groups were excluded from participation if they had a diagnosis of any medical disorder (e.g., epilepsy) or other developmental disorder (e.g., ADHD), or if they

were taking any medication. Written informed consent was obtained from parents of all children, in accordance with the policies of the University's Ethics Committee.

Insert Table 1 about here

The groups were well-matched for chronological age, $t(38) = .98$, $p = .34$, gender, handedness, and nonverbal ability, $t(38) = .53$, $p = .60$, as measured by the Raven's Standard Progressive Matrices (RSPM; Raven, Court, & Raven, 1992; see Table 1). Children's verbal ability was also measured, using the Peabody Picture Vocabulary Test – Third Edition (PPVT-III; Dunn & Dunn, 1997) to ensure that their receptive language was at a level where they would be capable of comprehending task instructions.² The ASD group had significantly lower verbal ability than the comparison group, $t(38) = 2.7$, $p < .01$, consistent with communicative problems being part of the diagnostic criteria for ASDs. Notwithstanding, all children were considered high-functioning; that is, they obtained verbal and nonverbal IQ scores in the normal range, and all were attending mainstream schools.

Apparatus

For the visual tasks, stimuli were displayed using a VSG2/3 framestore (Cambridge Research Systems), in conjunction with a Sony Trinitron GDM-20SE1 monitor (using simple 8bit greyscale). Children sat 100 cm from the screen in an otherwise darkened room.

Stimuli

Global Dot Motion (GDM) task. A total of 100 bright dots (47.4 cd/m^2), each subtending 0.11° , were randomly distributed on a black background ($<1 \text{ cd/m}^2$) on the 388 x 292 mm screen ($18.16 \times 13.60^\circ$). A variable proportion of these dots moved

coherently (signal), either upwards or downwards (selected randomly for each trial), amongst the remaining randomly moving dots (noise). Stimuli were presented as 20-frame sequences, with each frame lasting 30 ms. The spatial step size for each dot was 0.19° . To ensure that children could not reliably follow the trajectory of a single signal dot, the dots carrying the coherent signal were randomly chosen on each animation frame.³

Flicker Contrast Sensitivity (FCS) task. This task was adapted from Evans, Drasdo, and Richards (1994). The target stimulus was a Gaussian blob (standard deviation = 3.15°), which flickered sinusoidally at a temporal frequency of 10 Hz in centre-screen for 1 s.⁴ This stimulus was paired with a zero contrast version of the flickering stimulus, which had the same mean luminance (20 cd/m^2). A field of matched space-averaged luminance occupied the rest of the screen.

Children's Embedded Figures Test (CEFT; Witkin et al., 1971). The first stimulus set uses a cardboard triangle and 17 laminated cards depicting coloured meaningful figures (see Figure 1), for 4 demonstration, 2 practice, and 11 test trials. The second set uses a cardboard house and 19 laminated cards, for 4 demonstration, 1 practice, and 14 test trials.

Insert Figure 1 about here

Procedure

Global Dot Motion task. Using a cover story involving a dog rounding up sheep (the dots) in a paddock, children were asked to indicate the direction of motion (up or down) by pressing the appropriate button on a button box, guessing if necessary. Audio feedback was provided to indicate performance accuracy. A two-

alternative forced-choice (2AFC) procedure was used to estimate the threshold. The staircase began with 20 dots moving coherently and the signal level was adjusted using a PEST procedure (Taylor & Creelman, 1967), converging on the 75% correct level. The threshold reflected the number of coherently moving dots required to perceive global motion, and was calculated by averaging all points following the fourth reversal (McArthur & Hogben, 2001). Each child completed 10 practice trials followed by 2 blocks of 60 test trials.

Flicker Contrast Sensitivity task. A temporal 2AFC procedure was used to estimate the threshold. Each trial began with the presentation of a central fixation cross. Two intervals (each 1000 ms) were presented, signalled by tones, and were separated by a second screen with a fixation cross. The flickering target stimulus was presented during one of the intervals (selected at random), and after the second tone, the child was required to report, using a button box, which interval had contained the stimulus. The task began at a relatively easy contrast level (5%), and a PEST procedure was used to estimate the threshold at the 75% performance level. After 10 practice trials, children completed 2 blocks of 60 test trials. The threshold (percentage of contrast needed to detect flicker) was transformed to a contrast sensitivity score (1/contrast threshold).

Children's Embedded Figures Test. Children were first asked to name the complex picture, and then to locate the hidden figure (triangle or house) embedded in the picture as quickly as possible. Response latencies (in seconds) were recorded for successful trials.⁵

General Procedure

Children were tested individually. Participants received one of the visual tasks to begin, and the remaining visual task at the end of the session, with the order of the

two counterbalanced within each group. The CEFT, RSPM and PPVT were presented in a random order in the intervening period.

Results

Preliminary Analyses

Significant correlation coefficients were found for threshold estimates for the two blocks of trials for the GDM task, $r = .81$, $p < .001$, and the FCS task, $r = .56$, $p < .001$, revealing adequate levels of reliability. Split-half reliabilities (with Spearman-Brown correction) calculated for mean times for odd and even trials on the CEFT, also yielded high reliability coefficients: triangle set, $r = .81$, $p < .001$; house set, $r = .86$, $p < .001$.

Group differences

Figure 2a shows the mean performance of the two groups on the GDM task. The larger range of GDM thresholds within the clinical group made parametric tests inappropriate, and therefore nonparametric tests were used. In line with Milne *et al.* (2002), children with ASD exhibited significantly higher global motion thresholds than typically developing children (Mann-Whitney $U = 87.00$ $p < .005$); that is, children with ASD needed, on average, 22.40% (95% CI: 15.95 – 28.85) of the dots to be moving in the same direction in order to detect the direction of motion, compared with typically developing children who required only 11.10% (95% CI: 9.35 – 12.85) of the dots to be moving coherently.

Notably, there was wide variation in global motion thresholds in the ASD group. Nonetheless, only a small number of children with ASD fell into the normal range of threshold estimates (see Figure 3 for a plot of individual scores). Spearman rank correlation coefficients were calculated within each group to assess whether

general and developmental differences in chronological age, nonverbal ability and verbal ability were associated with performance on the GDM task. No significant correlations emerged. We further examined whether the wide range in threshold estimates may be related to heterogeneity in the ASD group. To do this, we repeated the analysis but this time excluded children who had a clinical diagnosis of PDD-NOS ($N = 5$). Although the mean global motion threshold estimate was slightly reduced in the ‘pure’ autism group ($M = 20.27\%$, 95% CI: 13.47 – 27.08), differences between clinical and comparison groups remained significant, Mann-Whitney $U = 75.00$ $p < .01$.

Average sensitivity scores are plotted for children’s performance on the FCS task in Figure 2b. Consistent with reports of intact low-level visual processing in autism (Bertone *et al.*, 2003), children with ASD were just as sensitive to flicker ($M = 131.30$, 95% CI: 120.04 – 142.56) as their typically developing peers ($M = 130.78$, 95% CI: 116.43 – 145.12), $t(38) = .06$, *ns*.

As predicted, children with ASD were much quicker to locate the hidden figure on the CEFT ($M = 2.73$ s, 95% CI: 2.17 – 3.27 s) than matched comparison children ($M = 7.17$ s, 95% CI: 6.55 – 7.78 s), $t(38) = 11.31$, $p < .001$ (see Figure 2c).⁶

Insert Figure 2 about here

We further examined the correlations between scores from the visual processing tasks and the CEFT for the ASD and typically developing groups separately. Spearman rank correlations revealed a significant negative relationship between global motion thresholds and mean time taken on the CEFT for children with

ASD, $r_s(20) = -.62, p < .005$ (see Figure 3). No other reliable relationships between task scores in either the clinical or comparison group were found (all $p_s > .05$).

 Insert Figure 3 about here

Discussion

The present study investigated the putative underlying mechanism of weak visuospatial coherence in autism. We contrasted two positions concerning the nature of the visual processing anomalies in autism: whether autism is characterised by a specific higher-level impairment in the magnocellular visual pathway (Bertone *et al.*, 2003) or alternatively, whether autism is the result of a more general ‘dorsal-stream vulnerability’ (Braddick *et al.*, 2003; Spencer *et al.*, 2000). We administered two tasks for which the magnocellular pathway would provide important input – one that required the perception of global motion (GDM task), and one that involved the detection of flicker (FCS task). Consistent with previous findings (Milne *et al.*, 2002; Spencer *et al.*, 2000), children with ASD were, on average, less able than typically developing children to perceive global motion amongst an array of randomly moving dots. However, children with ASD performed no differently from comparison children on the FCS task, suggesting that there is no early impairment in the contrast sensitivity of the magnocellular pathway in ASD. In line with weak central coherence theory, children with ASD were faster than typical children at locating hidden figures on the CEFT. Furthermore, performance on this central coherence task was inversely related to global motion perception in the ASD group.

Since the children with ASD performed poorly on only one of the tasks tapping magnocellular functioning, it is unlikely that children with ASD have a

general impairment on this pathway. These results, then, require an elaboration of Braddick *et al.*'s (2003) view that several neurodevelopmental disorders (e.g., autism, dyslexia, Williams syndrome) exhibit abnormalities in the dorsal stream of processing. When we examine closely the visual processing anomalies associated with these disorders, we do find dissociations. For example, whilst we found no evidence of early visual deficits in ASD (as indicated by preserved detection of flicker), other researchers have provided evidence of reduced sensitivity to flicker in developmental dyslexia (Martin & Lovegrove, 1987), in addition to poor perception of global motion. Therefore, the proposal that dorsal-stream vulnerability characterises a range of developmental disorders would require further elaboration before it could explain the specific pattern of impaired and intact performance by children with ASD on the magnocellular tasks.

Nonetheless, the ASD group did demonstrate a reduced ability to perceive global motion when compared with a group of typically developing children, as other researchers have found (Milne *et al.*, 2002; Spencer *et al.*, 2000). There are several possible reasons for the elevated global motion thresholds in the ASD group. Firstly, the ASD and typically developing groups did differ significantly in terms of level of verbal ability; low verbal ability may have influenced children's performance on the GDM task, particularly in the ASD group. However, correlations between verbal ability (and indeed, chronological age and nonverbal ability) and global motion thresholds were nonsignificant in this group. Secondly, group differences on the GDM task were characterized by wide variation in threshold estimates for children with ASD, a result that has also been found in the field of dyslexia. The majority of our sample of children with ASD had a diagnosis of autism, whilst a handful of children had been diagnosed with PDD-NOS (a less severe ASD); indeed,

heterogeneity within the ASD group itself may have contributed to the large spread of threshold estimates. However, removing those children with PDD-NOS from the analysis failed to change any of the crucial results.

Thirdly, some dyslexia researchers (e.g., Roach, Edwards, & Hogben, 2004) argue that children's elevated global motion thresholds might not be due to poor global motion perception per se, but instead might be due to general task-completion difficulties (for example, individual differences in attention or decision-making skills). Indeed, Stuart, McNally, and Castles (2001) simulated the effects of poor concentration on threshold estimates by adaptive psychophysical methods, and found that this would yield elevated threshold estimates. More recently, Roach *et al.* (2004) simulated the effects of random errors (inattentive trials) on a typical psychophysical task and also found that such errors can potentially exaggerate threshold estimates. Children with ASD have been shown to have impaired attentional capacities (Burack, 1994), and it is plausible that inattention, or other general, nonsensory difficulties, may well explain the poor performance of the ASD group on the GDM task. It is unclear, however, how these nonsensory difficulties would have affected threshold estimates on the global motion task alone, as such differences should have affected performance across all tasks. Instead, performance was similar across groups on the FCS task, which also used an adaptive threshold estimation method. Moreover, children with autism performed better than typically developing children on the CEFT. Therefore, whilst it may be the case for children with dyslexia, it is unlikely that task-completion difficulties explain the variation in GDM scores in children with ASD, and therefore the significant differences between clinical and comparison groups.

Therefore, the most likely explanation for the elevated global motion thresholds in the ASD group relates to the additional cooperative processes in higher cortical areas necessary to perceive global, coherent motion. Behavioural evidence has been reported for a single motion pathway where global motion stimuli are processed in two stages (Edwards, Badcock, & Nishida, 1996). During the first stage, information about the local signals is extracted, which most likely occurs early in the visual pathway (area V1; Dow, 1974). It is not until higher up the motion pathway (area V5) that the integration of these local signals occurs (Britten *et al.*, 1992; Newsome & Paré, 1988). Current data suggest that early vision may be normal in ASD, and support the suggestion that the neural mechanisms required for integrating local motion signals to form a global motion percept might be compromised in ASD. This interpretation echoes previous suggestions (e.g., Bertone *et al.*, 2003), and provides corroborating evidence for abnormal cooperative processes in the magnocellular visual pathway in children with ASD.

Interestingly, children with autism have been shown to be impaired at perceiving global motion of another type – the perception of human activity. Blake *et al.*, 2003) presented children with and without autism with point-light displays portraying biological motion, such as a human walking. As in the global motion task used here, the individual dots in the point-light displays provide little information about the global direction of movement. It is only when the local signals are integrated that it is possible to perceive coherent motion. Perhaps the perception of both global motion and biological motion operate according to similar cooperative mechanisms in the cortex, which might be abnormal in autism. However, while the perception of global motion is associated with area MT/V5, Vaina, Solomon, Chowdhury, Sinha and Belliveau (2001) have demonstrated, using fMRI, that

activation following biological motion perception is distributed across several cortical areas serving both dorsal and ventral processing streams in typical individuals.

Further research will need to ascertain whether or not impaired grouping mechanisms in autism are responsible for poor performance on both types of motion tasks.

The present study also directly examined the claim that abnormalities in extrastriate motion areas may be responsible for weak visuospatial coherence in autism (Bertone *et al.*, 2003; Milne *et al.*, 2002). Our results provide strong empirical support for this conjecture: we found that performance on the GDM task was inversely related to children's efficiency on the CEFT in the ASD group, such that higher global motion thresholds were associated with faster times to find the hidden figure. The link between these measures is suggestive of the fact that abnormalities in global grouping processes in the dorsal cortical pathway (necessary to perceive global, coherent motion) might be responsible for producing the weak coherence bias in autism, at least at the visuospatial level. It is conceivable that poor global grouping processes in ASD might not be confined to the perception of dynamic stimuli *per se*, but could also extend to the perception of static stimuli. While the global motion task necessitates the perception of a coherent whole, the CEFT requires one to inhibit the Gestalt, focusing more on the individual elements. Therefore, poor global grouping could impede performance on the global motion task, as it could prevent the combination of local directional signals required for the perception of coherent motion. At the same time, abnormal integration processes could contribute to faster performance on the CEFT, as it could prevent one from 'seeing' the Gestalt, allowing one to quickly find the hidden shape.

This view is consistent with Bertone *et al.*'s (2003) speculations. This line of reasoning, however, rests largely on evidence of global grouping deficits in the dorsal

and ventral streams of processing in autism. Spencer *et al.*'s (2000) results argued against the notion that a deficit in integration extends to static stimuli after observing intact global form thresholds in a sample of individuals with autism (see also Blake *et al.*, 2003). Some recent arguments however, hold that performance on the global form tasks used by Spencer *et al.* (2000) and Blake *et al.* (2003), which had been thought to be processed in area V4, may instead be governed by low levels of the visual system, such as area V1 (Badcock & Clifford, *in press*; Field & Hayes, 2004; Gilbert, 1995). Field and Hayes (2004) review psychophysical and anatomical work showing that neurons in area V1 are able to integrate information beyond the neuron's receptive field by making use of long-range lateral connections. Therefore, detection of contours from individual line segments in global form tasks (where the angular deviation between line segments is small) may then be achieved by V1 neurons. According to our results, early vision appears to be intact in children with ASD, which would explain the preserved performance on the particular global form tasks used by Spencer *et al.* (2000) and Blake *et al.* (2003). However, this argument is somewhat contentious. Gallant, Braun, and Van Essen (1993) demonstrated that neurons in area V4 in the macaque monkey were stimulated in response to concentric patterns. Furthermore, Braddick, O'Brien, Wattam-Bell, Atkinson, and Turner (2000) found, using fMRI, that extrastriate cortical areas in the ventral stream of processing showed strong activation by global, coherent form in human participants. [*not sure what else to say here*] Certainly, the precise manner in which integration is impaired in autism warrants further investigation.

At a theoretical level, Frith and Happé (1994) purport that superior local processing sits alongside weaker integrative processing in autism. Some research groups have recently questioned this view, reporting evidence of intact global

processing in conjunction with superior local processing in autism (Mottron, Burack, Iarocci, Belleville, & Enns, 2003; Plaisted, Saksida, Alcántara, & Weisblatt, 2003). Indeed, our own work with typically developing children also failed to find evidence of a reciprocal relationship between local and global processing (Pellicano *et al.*, in press), leaving Frith and Happé's (1994) position somewhat uncertain. However, for the children with ASD in the present study, the inverse relationship between performance on the global motion task and time taken on the CEFT is in accord with predictions made by weak central coherence theory. Furthermore, although speculative, the idea of poor global grouping in autism is also congruent with Frith and Happé's (1994) notion of weak central coherence, and could provide further insight as to the neural underpinnings for integrating parts into wholes.

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Figure Captions

Figure 1. An illustration of a trial from the Children's Embedded Figures Test (CEFT). Children were required to locate the hidden triangle in the complex figure as quickly as possible.

Figure 2. Box plots showing (a) performance on the Global Dot Motion (GDM) task, (b) performance on the Flicker Contrast Sensitivity (FCS) task and (c) performance on the Children's Embedded Figures Test (CEFT) for children with ASD and typically developing children. The solid black lines bisecting each rectangle represent the medians of the distributions. The vertical rectangle for each group shows the distribution of the middle 50% scores, and the 'whiskers' attached to both ends of these rectangles extend out to include 100% of the data.

Figure 3. Scatterplot showing the relationship between performance on the GDM task and the CEFT for the ASD and comparison groups separately. Dotted line shows upper 95% confidence limit for the comparison group's performance on the GDM task.

Table 1. Participant characteristics

Measures		Children with ASD (<u>N</u> = 20)	Typical developing children (<u>N</u> = 20)
Age (yrs:mths)	Mean	9:6	9:9
	SD	1:4	1:1
	Range	8:1 – 12:0	8:0 – 11:9
RSPM (raw score)	Mean	40	41
	SD	5.3	5.9
	Range	30 - 49	29 - 48
PPVT-III (raw score)	Mean	118.8	137.1
	SD	25.7	16.4
	Range	83 - 169	100 - 159

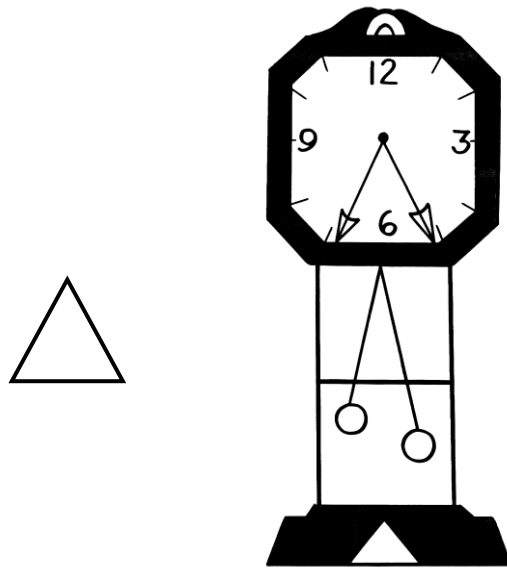
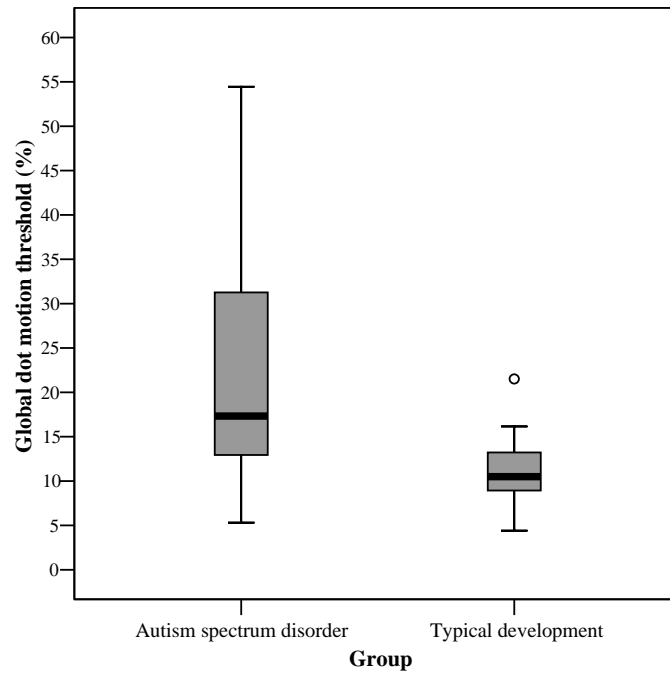
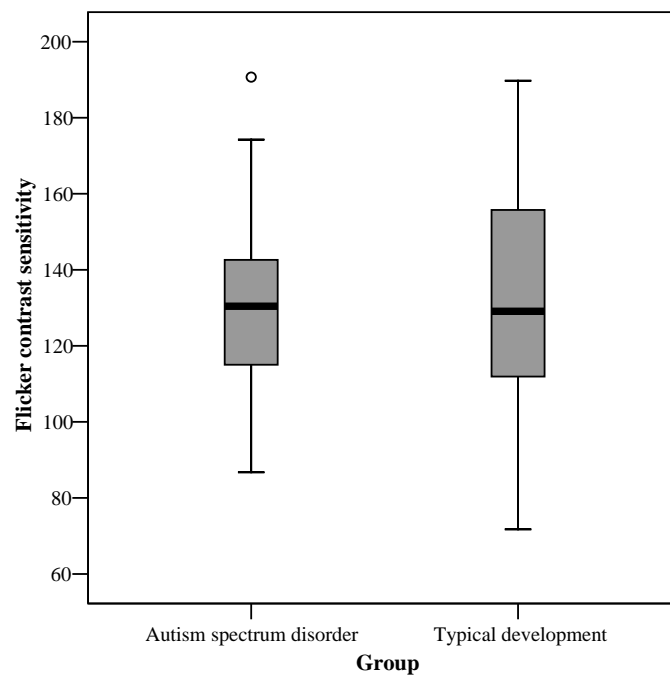


Figure 1.

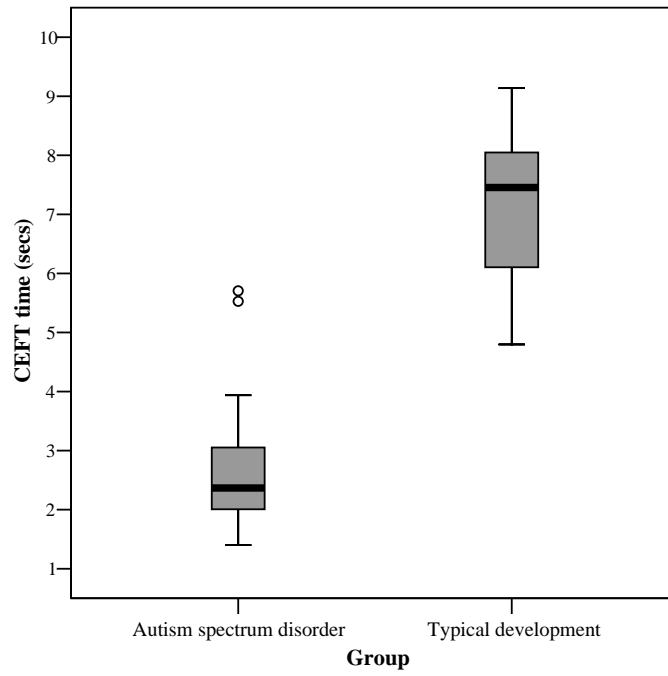


(a)



(b)

Figure 2.



(c)

Figure 2 cont.

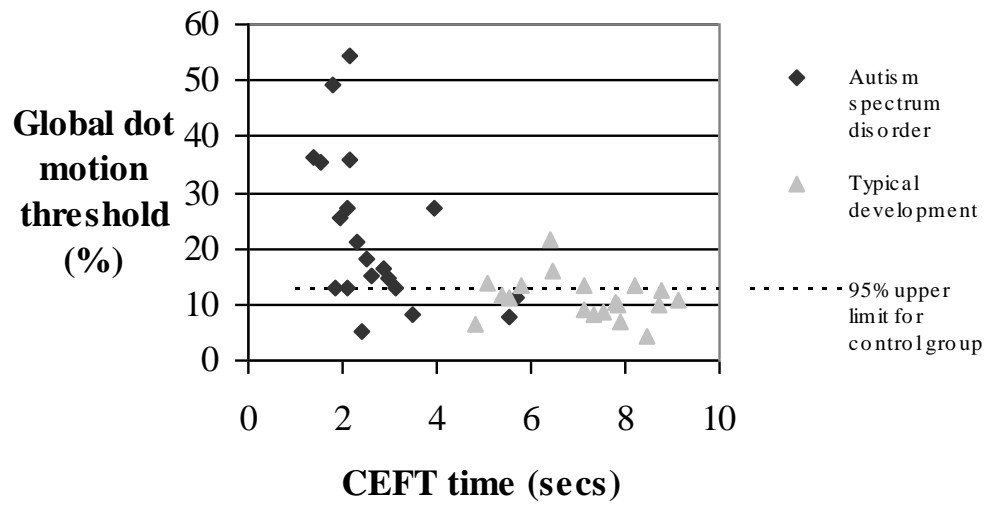


Figure 3.

Footnotes

1. The koniocellular pathway is formed from interlaminar neurones, is sensitive to blue-yellow chromatic signals and projects to striate cortex.
2. Separate measures of verbal ability and nonverbal ability were obtained, as several subtests within more frequently used full-scale measures of intelligence (such as the Block Design and Object Assembly subtests from the Wechsler scales) place similar demands on global-local processing to the central coherence measure (the CEFT) used in the present study.
3. In the task used by Milne et al. (2002), the coherently moving dots had a lifetime of 4 animation frames (224.4 ms). We enforced a more global processing requirement in the task described here, by randomly selecting which dots carried the coherent signal on every animation frame (30 ms). At a coherence threshold of 20%, there is only a 0.04 chance of a dot carrying this signal on two successive frames and a 0.008 chance over 3 frames, limiting the extent to which children can follow the local motion signal of a single dot for each trial. In normal observers this change has little impact (Scase, Braddick, & Raymond, 1996), but it might with children with autism who focus on the local elements of the display.
4. The luminance profile $L(x, y)$ is given by:

$$L(x, y) = L_m (1 + c \cdot e^{(-r^2 / \sigma)} \cdot \sin(2\pi ft))$$

where

$$r = \sqrt{(x - \mu_x)^2 + (y - \mu_y)^2}$$

and

μ_x = the x midpoint,

μ_y = the y midpoint,

c = the contrast,

σ = the standard deviation of the Gaussian,

f = the number of cycles of luminance change per second, and

t = time.

5. Time taken to find the hidden figure has been demonstrated to be a more sensitive measure than response accuracy (e.g., Jolliffe & Baron-Cohen, 1997). Our results showed no significant difference between the groups on CEFT accuracy, $t(38) = 1.23$, ns.
6. We also examined whether level of verbal ability contributed to children's performance on the tasks. The only significant relationship involving verbal ability was the CEFT-verbal ability correlation in the typically developing group, $r(20) = -.61$, $p < .005$, which is consistent with previous reports (Witkin et al., 1971).
7. We do note here that the CEFT and global motion tasks were not directly matched as 'ventral' and 'dorsal' stream tasks, as was the case in Spencer et al.'s (2000) study.