Colored overlays enhance visual perceptual performance in children with Autism Spectrum Disorders

A.K. Ludlow*, A.J. Wilkins**, and P. Heaton***

*Corresponding author
Dr Amanda Ludlow
Department of Psychology
Anglia Ruskin University
Newmarket Road
Cambridge
CB1 1PT
Tel No: +44 (0)1223 363271 (ext. 2418)
Fax No: +44 (0)1223 417712
E-mail: a.ludlow@anglia.ac.uk

**University of Essex
Department of Psychology,
Wivenhoe Park, Colchester, CO4 3SQ

***Department of Psychology
Goldsmiths College,
University of London,
New Cross,
London, SE14 6NW

Running head: Use of colored overlays

Abstract: Children with Autism Spectrum Disorders (ASD), together with controls matched for age and ability participated in three experiments that assessed the therapeutic benefit of colored overlays. The findings from the first experiment showed that a significantly greater proportion of children with ASD, than controls, increased reading speed when using a colored overlay. This finding was replicated in the second experiment which also showed that therapeutic benefits were only observed when participants were instructed to select colors that improved textual clarity and not when colors were selected on the basis simply of preference. In the final experiment, children were required to discriminate between pictorially presented objects with and without overlays self selected for improvements in clarity. Participants with ASD, both with and without concurrent intellectual impairment, showed significant gains in performance when using an overlay. The beneficial effects of color overlays and the implications of these results for current neuropsychological models of ASD are discussed.

Keywords: Autism Spectrum Disorders, Visual Stress, color filters, Magnocellular deficits, Cortical hypexcitability

Introduction

Since Kanner's (1943) original description of autism, sensory processing abnormalities have been widely reported in individuals with this disorder (DeMeyer, 1976; Filipek et al., 1999; Gillberg & Coleman, 1992; Mayes & Calhoun, 1999; O'Neil & Jones, 1997; Kern et al., 2006). Whilst such abnormalities have been reported in auditory, vestibular, touch, oral and multisensory modalities, as measured by the Sensory Profile (Dunn, 1999), the focus of the current study is on visual processing abnormalities and their potential remediation.

The visual processing abnormalities commonly reported in ASD include hyper-sensitivity to lights and colors (Myles, Cook, Miller, Rinner & Robbins, 2000; Olney 2000; Attwood, 1994) and experiences of visual distortion, which may, for example, alter the perceived dimensions of rooms (White & White, 1987; Attwood, 1994). Visual distortions can also result in difficulties writing on printed lines and maintaining appropriate spacing between letters and words (Myles et al., 2000). Whilst there is no clear consensus about the root cause of these difficulties it has been suggested that some individuals with autism suffer from a co-occurring disorder called visual stress (Wilkins, 1995; 2003).

Visual stress refers to perceptual distortions and discomfort, most notably when reading printed text. Williams, (1999) has suggested that the co-occurrence of autism and visual stress results in particularly dramatic symptoms characterised by fragmentary perception. There is increasing evidence suggesting that such effects can be ameliorated by the use of colored spectacles, optimally colored lights or transparent colored overlays (see Wilkins, 2002, for review).

It has been estimated that 20% of the population will read more than 5% faster when using a colored overlay (Evans & Joseph, 2002; Wilkins, 2003), although recent research has indicated that particular clinical subgroups benefit to a far greater extent (Wright, Wilkins & Zoukos, in press). To date only one scientific study has been carried out investigating the effect of colored overlays in children with autism (Ludlow, Wilkins & Heaton, 2006). In this study, 79% of the children with autism tested were able to read more than 5% faster with an overlay and increments of up to 50% in reading speed were observed.

The suggestion that colored overlays can have extraordinary beneficial effects is still greeted with scepticism among some researchers, many of whom question whether results showing significant improvements can be explained simply by motivational or placebo effects. Several studies carried out with typically developing children (TD) have shown no effect of motivational instructions, and have shown little benefit from a variety of placebo overlays with which they compared the overlays selected as improving textual clarity (Bouldoukian, Wilkins & Evans, 2002; Jeanes, et al., 1997; Wilkins & Lewis, 1999; Wilkins, Lewis, Smith & Rowland, 2001). However, children with ASD may have difficulties in understanding test instructions and also frequently exhibit strong color preferences (Howlin, 1996; White & White, 1987; Williams, 1999) that influence many aspects of their behaviour. It may then be the case that in such a test situation they will select colors that they prefer rather than those that improve textual clarity. .

Two theories that have attempted to explain the mechanisms underlying the beneficial effects of colored filters on reading are the magnocellular deficit theory (Kriss, 2002; Chase, 1996; Chase, Ashourzadeh, Kelly, Manfette & Kinsey, 2003) and the cortical hyperexcitability theory (Wilkins, 2003). The beneficial effects of colored filters in dyslexia and migraine can be explained within the context of the magnocellular theory in so far as it has been suggested that both disorders are associated with magnocellular deficits (dyslexia: Livingstone, Rosen, Drislane & Galburda, 1991; Stein & Walsh, 1997; migraine: McKendrick, Badcock & Vingrys, 2000). Individuals with ASD have also shown deficits in magnocellular functioning (Deruelle, Rondan, Greper & Tardif, 2004; Milne et al., 2002; Spencer et al., 2000). These abnormalities have been proposed to account for a local processing bias (Milne, Swettenham, Campbell & Coleman, 2004) outlined in current cognitive theories of autism, such as the Weak Central Coherence Theory (Deruelle et al, 2004; Milne et al., 2002; Spencer et al., 2002) and the Enhanced Perceptual Functioning theory (Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert & Burack, 2006). However, research has failed to establish that sufferers of visual stress show abnormal magnocellular function (Evans et al., 1996; Simmers, Bex, Smith & Wilkins, 2001).

The cortical hypexcitability theory (Wilkins 2003) postulates that the effects of overlays occur because different colors can cause a shift in the major locus of activation away from hyperexcitable areas of the visual cortex to areas that are less hyperexcitable. The individual's cue for optimal overlay choice is his/her perception of reduced perceptual distortion in response to the specific overlay/s selected. The theory is supported by the finding that individuals with a range of central nervous system disorders associated with an increased risk of seizures, benefit from color filters. Amongst these disorders are photosensitive epilepsy (Wilkins et al., 1999), autism (Ludlow et al., 2006), migraine (Harle Shepherd & Evans 2006; Wilkins et al., 2002) head injury (Jackowski, Sturr, Taub & Turk, 1996) and multiple sclerosis (Wright Wilkins & Zoukos, in press). Findings from fMRI studies investigating hyperexcitability in migraine support this suggestion (Huang, Cooper, Satana, Kaufman & Cao, 2003; Huang, Wilkins & Cao, 2004). The high risk of epilepsy in patients with ASD is consistent with the vulnerability of GABAergic interneurons to developmental errors, and the low hippocampal $GABA_A$ receptor binding and low platelet GABA levels in autism (Belmonte et al., 2004). Brain imaging studies have also provided strong evidence that abnormalities exist in the visual cortical network of individuals with ASD (Brambilla et al., 2003; Bailey et al., 1995; Carper, Moses, Tigue & Courchesne, 2002).

Of particular interest in the present context is how these theories are able to account for particular colored overlay choice. Chase et al. (2003) found that reading is impaired with light of long wavelengths compared with shorter wavelengths. Yellow filters, in particular, have been found to be beneficial to children with reading problems (Ray, Fowler, & Stein, 2005), although not in the context of autism. According to proponents of the magnocellular theory, the yellow may boost magnocellular activity by eliminating inhibitory blue input to this pathway and boosting the red and green cone input to the magnocellular component of the visual system. Ray et al., found that wearing yellow filters increased motion sensitivity convergence and accommodation in many children with reading difficulties both short and long term (Ray, Fowler & Stein. 2005). However, blue overlays have also been found to convey benefits and many individuals wear blue filters for reading (Solan 1998; Williams, LeCluyse & Rock-Faucheux, 1992; Iovino, Fletcher, Breitmeyer & Foorman, 1998). It is speculated that these individuals have an abnormally large number of blue cones and that blue filters serve to reduce long wavelengths (Williams et al., 1992).

In contrast, the cortical excitability theory predicts that the location of areas of hyperactivation differ between individuals and this accounts for the wide range of colors self-selected by these individuals (Evans, 2001; Wilkins, 2003; Ludlow et al., 2006). The individual's consistency in choosing the most effective overlay over testing sessions and how individual and precise ophthalmic tints have to be to produce beneficial effects also provide strong evidence that the optimal color for an overlay is specific to each individual (Wilkins Sihra, & Nimmo-Smith, 2005).

The following experiments tested the hypothesis that children with autism would improve task performance at significantly higher levels than controls only when using self-selected colored overlays. Experiment 1 attempted to replicate earlier findings showing improved reading speed for single words (Ludlow, Wilkins & Heaton, 2006). Experiment 2 addressed the question of whether the colored overlay selected was simply based on color preference, and also compared performance on the rate of reading with yellow and blue overlays. The final experiment (Experiment 3) was the first to investigate the use of color overlays with low functioning children with ASD. Whilst all the participants included in Experiment 1 and 2 were able to read, Experiment 3 employed a matching-to- sample task that was developed for use with lower-functioning individuals who could not read.

Experiment 1: Testing the rate of reading with and without colored overlays; a replication

Participants

Eighteen boys with a diagnosis of autism spectrum disorders (ASD) participated in the study. They were aged between 9 years and 15 years 10 months (mean 12 years 6 months) and attended two schools for children with moderate learning disability. Control participants, sampled from a mainstream school and two schools for children with moderate learning disabilities, were matched individually to the children with ASD for chronological age and gender. As a reading test was used in the study, partiticipants were also matched for scores on the British Picture Vocabulary Scale (BPVS) (Dunn, Dunn, Whetton et al., 1997) a test of receptive vocabulary. The children's psychometric data are shown in Table 1.

Place Table 1 here

Materials

The *Rate of Reading Test* (Wilkins, Jeanes, Pumfrey & Laskier, 1996) and the *Intuitive Overlays* (Wilkins 1994) were used in the study. The Reading test consists of paragraphs of unrelated words. It is published in two versions that differ in typeface, size and spacing. In this study the larger text (14pt Geneva) was used. The Intuitive Overlays are colored plastic sheets. They are supplied in a teacher's pack and include two A5 size overlays of each of the following colors, rose, orange, yellow, lime green, mint green, aqua, blue, purple, pink and grey. The spectral reflectances are given by Wilkins (1994).

Procedure

In order to familiarise the children with the *Rate of Reading test*, they were presented with a short passage from the test and asked to read out loud for 30 seconds. Then, while they were still looking at the passage, they were asked the following four questions: (1)“Do the letters stay still or do they <u>move</u>?”; (2)“Are they clear or are they <u>blurred</u> (fuzzy, difficult to see)?”; (3)“Are the words <u>too close together</u> or far enough apart?”; (4) “Does it <u>hurt</u> your eyes to look at the page or is it ok?”; 5) “Is the page <u>too bright</u>, not bright enough, or just about right?”. A score of 1 was given for each symptom of visual stress (underlined above), whilst other responses scored 0. Children could receive a maximum score of 5. In past studies these questions have been effective in identifying symptoms that are generally slightly greater in those who show improvements in reading with overlays (Wilkins et al. 2001).

The children were then presented with two identical passages from the *Rate of Reading test* to compare when assessing which overlay made the text clearer. The colored overlays were assembled in a pile in the following order: Rose, Lime-Green, Blue, Pink, Yellow, Aqua, Purple, Orange, Mint-Green. This order was adopted in order to reduce the chances of complementary colors being placed next to each other. The top overlay (Rose) was placed to the left of the test page, covering one of the two passages of text. The children were shown the overlays individually and asked to choose which made the text clearest. When the side covered by the overlay was judged preferable to the uncovered side, the two sides of the overlay (matt and gloss) were compared in sequence, and the children were asked to select the best of the two. This side was used for the remainder of the overlays. A second overlay was placed beside the first so that both passages of text were now covered by overlays. The child was again asked which side was the clearest and felt most comfortable to look at. The process of removing the poorer overlay and leaving the best overlay in place was continued until all the overlays in the pile had been seen. When the child was unable to make a choice both colors were noted and one of the colors changed. The other color was placed at the bottom of the pile and reintroduced later. Provided the uncovered text was not preferred throughout, the best overlay was placed upon the page and the questions on visual stress symptoms were asked again.

The next stage of the procedure involved testing to see if double overlays (with stronger colors) made the text clearer than a single overlay. Stronger colors of the chosen hue were obtained by placing two overlays of the same or neighbouring chromaticity on top of each other (see: *Intuitive Overlays* instruction booklet). The best single overlay was compared with the three associated double overlays of similar color, and the child again eliminated its least preferred choice. If a double overlay was preferred, the questions concerning symptoms were repeated a third time.

The chosen single or double overlay was then placed over the second of the two passages on the test page and the other passage was covered with a blank white page. The children were asked to read the text aloud for one minute as quickly as possible and were timed using a stopwatch. The total number of words read in the correct order was noted. The overlay(s) were then removed and the children were asked to read the text again for one minute. The order in which the children received the overlay was randomised within groups so that some children read first with the overlay and others read first without the overlay.

Results

The means and standard deviations for reading rates with and without colored overlays are shown in Table 2 below. Only the words read both accurately and in the correct order were calculated with and without an overlay.

Place Table 2 here

A 2*2 ANOVA with Group (ASD/controls) as the between factor and condition (number of symptoms of visual stress reported with and without an overlay) revealed a significant effect of condition ($F(1,34)=7.2$, $p<0.05$) showing that both groups reported fewer symptoms of visual stress with an overlay. There was no significant effect of group ($F(1,34)=0.14$, n.s) and no significant interaction ($F(1,34)=0.29$, n.s).

A 2*2 ANOVA with Group (ASD/controls) as the between-group factor and condition (number of words read per minute with and without overlays) as the within-group factor revealed a significant main effect of condition ($F(1,34)=20.1$, $p<0.001$), a significant main effect of group ($F(1,34),=5.7$, $p<0.05$) and a significant group x condition interaction ($F(1,34)=29.7$, $p<0.001$).

This interaction was analysed using paired t-tests with Bonferroni adjustments. These showed that children with ASD read significantly more words per minute with than without an overlay ($t(17)=6.2$, $p<0.001$), whereas there was no significant difference across conditions for controls ($t(17)=0.8$, n.s.). The children with ASD read significantly faster than controls with ($t(34)=3.2$, $p<0.001$) but not without an overlay ($t(34)=1.6$, n.s). These effects are illustrated in Figure 1.

Place Figure 1 here

In previous studies (Wilkins, Lewis, Smith et al., 2001; Kriss & Evans, 2005) the criterion for clinically significant improvements in reading speed when using overlays has been set at 5%. Chi-square analysis confirmed that significantly more children from the ASD than from the control group (15/18 ASD and 3/18 controls) increased reading speed by more than 5% using an overlay.

The children selected a wide choice of color overlays for improving clarity of text. Consistent with previous results no one optimal color was selected for improving clarity of text (Ludlow et al., 2006). The double overlay of Mint Green was shown to be most frequently chosen (ASD, 39%; Controls 33%). The distribution of color choice is illustrated in Figure 2.

Place Figure 2 here

Discussion

There are large individual differences between children in reading rate: among children in mainstream education with similar reading age the scores can range over a factor of 3 (Wilkins et al., 2001). Here the differences between the groups with respect to mean reading speed are small given the within-group differences. The improvement in reading speed, expressed as a percentage has been shown in studies of children in mainstream education to be slightly larger among the children whose reading is slow (Wilkins et al., 2001). The slightly higher reading rate among the children with ASD therefore militates against the finding of a greater percentage improvement in reading speed.

Experiment 2: Comparing performance on rate of reading with the chosen overlay versus other colors.

Participants

16 children with ASD (4 girls, 12 boys) aged between 14 years 1 month 15yrs 10 (mean 14 years 8) were matched to children with mild learning difficulties (MLD) for, gender, age, verbal and non-verbal intelligence. None of these children had participated in Experiment 1. Psychometric data for these participants is shown in Table 3.

The children with ASD and their controls were recruited from three schools for children with moderate learning difficulties with autism units.

Place Table 3 here

Procedure

Children were shown the overlays and asked to make two selections. First they were asked to select the overlay they thought made the text clearest using an procedure identical to that used in Experiment 1. They were also asked to choose the overlay that they liked best. This was selected using the same procedure as in Experiment 1, but instead of comparing the overlays with text underneath, the overlays were placed over a plain white piece of paper. The order in which children chose their favourite overlay and the overlay that made the text clearest was randomised. All overlay colors were included when choosing the overlay for clarity and for color preference, so that the children had the opportunity to choose the same color on both occasions.

The rate of reading test was then administered. The procedure for the rate of reading was identical to that used in Experiment 1 except that on this occasion the children read (1) with the overlay chosen for clarity, (2) with the overlay chosen for preference, (3) with a yellow overlay, (4) with a blue overlay (if these had not been already selected) and (5) without an overlay. The overlay order was randomised.

Results

Figure 3 shows the percentage of the sample choosing each overlay color. No child from either group chose the same colored overlay for clarity and for color preference. Only two children, one from the ASD and one from the control group, selected a yellow overlay as improving the clarity of the text, and only two selected a blue overlay, again one from each group. For 6 of the 16 children with ASD and 11 of the 16 controls, the favourite overlay and the overlay chosen for clarity had neighbouring chromaticity. The most frequently overlay chosen for clarity (Mint green) and the most frequently chosen as favourite (Aqua) were the same for both the ASD and Control groups, although the consistency of choice, as shown in Figure 3, was marginally greater in the latter group.

Place Figure 3 here

The means and standard deviations of number of words read for both groups are shown in Table 4 below.

Place Table 4 here

An ANOVA was carried out on the data with group (autism/controls) as the between subjects factor and condition (number of words read with no overlay, overlay selected for clarity, overlay chosen as favourite, blue overlay and yellow overlay) as the within group factor. There was no significant main effect of group ($F(1,30)=0.04$, n.s), but a significant effect of condition ($F(4,120)=2.90$, $p<0.05$) and a significant group by condition interaction ($F(4,120)=3.1$, $p<0.05$).

A priori tests were carried out within groups across the overlay colors. For both groups the performance with an overlay chosen on the basis of clarity was superior to that with an overlay chosen on the basis of color preference ($t(15)=2.61$, $p<0.05$, autism group; $t(15)=3.41$, $p<0.05$), control group). *A priori* comparisons revealed a significant increment in reading speed with an overlay chosen for clarity compared to no overlay for the autism group ($t(15)=2.25$, $p<0.05$), but not for the controls, ($t(15)=1.15$, n.s). The difference in the increment was significant $t(30)=2.29$, $p<0.05$ between groups. Relative to no overlay, there were no significant increments in reading speed with an overlay of the favourite color for the autism group ($t(15)=2.25$, $p<.05$), but for the control children there was a significant decrement, ($t(15)=2.53$, $p<.05$). Relative to no overlay there was no significant reading speed increment with a blue overlay ($t(15)=1.91$, ns, autism group; $t(15)=0.59$, ns, control group), or with a yellow overlay ($t(15)=1.75$, ns, autism group; $t(15)=1.76$, n.s., control group). This is illustrated in Figure 4.

Place Figure 4 here

Discussion

The overlay selected for clarity resulted in significantly better performance than the overlay selected on the basis of color preference and this was the same for both the ASD and control groups. As with Experiment 1, only the children with ASD read significantly faster with than without an overlay. In fact the overlay selected for clarity by the participants in the ASD group was the only overlay to show significant improvements compared to no overlay.

Interpretation is complicated by the fact that no significant differences were noted between number of words read with the overlay selected for clarity and the blue and yellow overlays. This will be discussed further.

Experiment 3: Detecting changes in visual stimuli with and without colored overlays in children with high and low functioning ability.

Participants

Twenty six children with ASD participated in the study. They were aged between 9 years 0 months and 15 years 10 months (mean 12 years and three months) and were recruited from 5 schools for children with moderate learning difficulties with autism units. The MLD controls were recruited from 4 schools for children with learning difficulties and the TD controls were recruited from 2 mainstream state schools. 13 of the participants with ASD and their matched controls had participated in Experiment 1. None of the participants from Experiment 2 also completed Experiment 3. As this task did not involve reading, participants were matched for chronological age and scores on Raven's Matrices (Raven, Court & Raven, 1992), a non-verbal intelligence test widely used is studies of ASD. Psychometric data for participants is shown in Table 5.

Place Table 5 here

Materials

The Intuitive Overlays (Wilkins, 1994) were again used. 70 pictures of everyday objects (Snodgrass & Vanderwart, 1980) with similar levels of detail and familiarity were selected for use in a matching-to-sample task. These were copied onto an A4 sheet of paper, seven times in a row with a 20 mm gap between the first pictures (target pictures) and the remaining pictures in the row (comparison pictures), which were evenly spaced with 10 mm gaps. Five of the six non-target pictures were altered so that a part of the pictures was either deleted, amended or shaded. An example of the stimuli used in the experiment is shown in Figure 1 below.

Place Figure 5 Here

In order to reduce practice effects, the position of the picture that was identical to the target was randomised within stimulus sets. The stimuli were arranged in two sets (A1 & 2, B1 & 2) and children completed one set with and one set without an overlay. The allocation was randomised within groups.

Procedure

The procedure for choosing an overlay was the same as used for the *Rate of Reading test*, except that the picture stimuli replaced the pages of text. In the test trials the children were instructed to find the picture that was identical to the target picture as quickly as possible. Accuracy scores and speed data were recorded and were summed across stimulus sets.

Results

The means and standard deviation for the number of correct responses for the matching-to-sample task are shown in Table 6

Place Table 6 here

A 2*2 ANOVA was carried out on the data with group (ASD/controls) as the between subjects factor and condition (number of pictures correctly identified with and without overlays) as the within group factor. The analysis showed no significant main effect of group (F(1,50)=0.48, n.s.) or condition (F(1,50)=1.25, n.s.). There was no significant group by condition interaction (F(1,50)=0.03, n.s).

The means and standard deviations for time taken to complete the task are shown in Table 7 below.

Place Table 7 here

A 2*2 ANOVA was carried out. Group (autism/controls) was the between-subjects factor and condition (completion times with and without overlays) was the within-subjects factor. The analysis showed no significant main effect of condition (F(1,50)=0.01, n.s.) or group (F(1,50)=3.02, n.s.). However there was a significant group x condition interaction (F(1,50)=12.170, p<0.001) which is shown in Figure 6 below.

Place Figure 6 here

The significant interaction was analysed using both independent and paired t-tests. These showed no significant between-group difference (ASD/controls) when children completed the task without colored overlays ($t(50)=0.61$, n.s.), although children with ASD completed the task faster than controls with colored overlays ($t(50)=2.69$, $p<.05$). There was a significant difference in time to complete the task with and without an overlay for the ASD group ($t(25)=2.59$, $p<.05$) and for the controls ($t(25)=2.34$, $p<.05$).

In line with Experiment 1, a Chi-square analysis was carried out and showed that a significantly greater number of children with ASD than controls completed the task 5% faster with than without an overlay ($\chi^2=7.74$; df=1, $p<0.05$). Within the ASD group there were no significant differences in the number of high functioning and low functioning children with ASD who increased speed when using an overlay ($\chi^2=0.02$; df=1, n.s). There was also no intelligence dependent difference (TD/MLD) within the control group ($\chi^2=0.17$; df=1, n.s.).

For the ASD group, scores on the Raven's Matrices scores did not correlate significantly with time taken to complete the task with an overlay ($r=-0.07$, n.s.) or without an overlay ($r=-0.03$, n.s.). There was also no significant correlation between age and the time taken with an overlay ($r=-0.24$) or without an overlay ($r=-0.30$, n.s). For the controls there was no significant correlation between scores on Raven's Matrices scores and time taken with an overlay ($r=-0.01$ n.s) and without an overlay (r=-0.35, n.s.), although the correlation between age and time taken with an overlay was significant (r=-0.49, p<0.05).

Comparing performance across the experiments. It has been suggested that a therapeutic benefit from an overlay is identified when increases in reading speed are greater than 5% (Wilkins et al., 2001). Many of the children with autism exceeded this criterion, as shown in Table 8. In Experiments 1 and 2 significantly more children with autism than controls read more than 5% faster with an overlay (χ^2= 0.15.1; df=1, p<0.001).

Place Table 7 here

There were no significant group differences in the number of symptoms of visual stress reported with and without an overlay in Experiment 1 and 2. Data from the participants with autism showed a significant reduction in the number of symptoms of visual stress (scored out of 5) reported with an overlay (mean 0.13, SD 0.50) compared to without an overlay (Mean 1.56, SD 1.72), (t(33)=3.68, p<0.001). The same was true for the control group, with an overlay (Mean 0.21, SD 4.78); without an overlay (Mean 0.50. SD 0.89), though to a lesser extent (t(33)=2.05, p=0.048).

There was no significant correlation found in either of the two groups, between BPVS scores and the numbers of words read per minute with or without an overlay. Neither were there any significant correlations between age and the number of words read with and without an overlay in either group.

Twenty-six of the same children (13 ASD and 13 matched controls) participated in Experiments 1 and 3 and their choice of overlays was assessed twice. Of these, 10/13 children with autism and 9/13 control children chose the same overlay (for clarity) on both occasions 6 months apart.

Discussion

Experiment 3 replicated previous findings showing that children with ASD autism showed improvements in task speed without compromising accuracy when using a self-selected color overlay. Furthermore, Experiment 3 extends previous findings to show that children with autism and moderate learning difficulties who are unable to read also benefit from using self-selected color overlays. Interestingly, the proportion of children from both the ASD and the control groups showed remarkable consistency in respect of (1) the benefit from overlays across tasks and (2) the color overlay selected across tasks.

General Discussion

The findings from all three experiments provide further experimental support for the suggestion that colored overlays can benefit many children with Autism Spectrum Disorders. Importantly the gains observed in the current studies were significant only when overlays that improved clarity were selected and not when overlays were chosen on the basis of color preference.

The results showed that 74% of children with autism increased reading speed by 5% when using an overlay chosen for clarity and 38% read more than 25% faster. In comparison, only 23% of controls improved performance, and the improvement was less pronounced than in the ASD group, with only 6% showing more than a 25% increase. The proportion of children from both groups benefiting from colored overlays is identical to that previously reported in a study testing a different sample of children (Ludlow et al., 2006). The results from the controls replicate a previous study carried out with typical participants (Wilkins et al., 2001). Importantly, reading accuracy was not compromised by reading speed. Performance was measured in terms of the number of words read correctly and in the appropriate order.

Experiment 2 is the first reported study comparing reading performance across different colored overlays in children with ASD. Chase et al., (2003) and Ray et al., (2005), have suggested that only blue and yellow overlays will convey any benefit. However the findings from Experiment 2 showed that the children with ASD read faster with an overlay chosen for clarity than with no overlay, but did not show significant improvements in reading speed with blue or yellow overlays. It is of interest that only one child from each group (ASD and controls) actually chose a yellow and a blue overlay when asked to select the color that most improved the clarity of the presented text. However the sample tested in Experiment 2 is smaller and drawn from different populations to the samples tested in the studies by Chase et al., (2003) and Ray et al., (2005).

In Experiment 3, the autism and control groups showed a similar pattern of performance with neither group improving in levels of accuracy in the overlay condition. However, performance levels were high and it may have been the case that group differences would have emerged on a more difficult task. The test used in the experiment had been designed for use with children with more severe learning difficulties who were unable to be tested using measures of reading. Therefore, an important aspect of the study was the investigation of visual discrimination performance on a task that could be undertaken by low-functioning children. The analysis of the task completion time data showed no significant differences between groups without an overlay but the children with autism were significantly faster at completing the task when using an overlay relative to controls. However, the post-hoc comparisons between conditions within groups were not significant, and the interaction effect appeared to reflect both poorer performance in the overlay condition for controls as well as better performance in the autism group on the overlay condition. Another key finding was that a much greater proportion of children with autism completed the task faster with overlays: 62% in comparison to 23% of controls. Chi-square analyses showed that the difference between the groups was statistically significant and that the effect was independent of intellectual status.

Whilst the findings from the studies showed that colored overlays improve task performance in a high proportion of children with ASD, the question of why this should be the case remains unresolved. Here, as in the previously cited study by Ludlow et al., (2006), there was nothing to suggest that the individuals benefiting from colored overlays differed in age, nonverbal ability or verbal ability. It was interesting that in the earlier study (Ludlow et al., 2006), levels of visual stress symptoms reported did not discriminate children who showed significantly improved performance with overlays. However in Experiments 1 and 2, children from both groups reported significantly fewer symptoms of visual stress with than without an overlay. It is surprising, given that the two groups reported similar numbers of visual stress symptoms, that the beneficial effects of overlays was not more comparable across groups. Given that the ASD participants showed increased benefits from overlays, relative to controls, it may be the case that the number of visual stress symptoms they reported underestimated the extent of these difficulties. Self-reports may not be the most effective method of eliciting information from children with autism, particularly where there is co-occurring intellectual impairment. An important goal for future research is therefore to establish appropriate screening methods for children with ASD who experience visual distortion.

Wilkins (2003) has proposed that visual stress with distorted perception, reported in autism and other disorders affecting the central nervous system, occur when a spread of activation within the cortex causes cells to fire inappropriately. His theory predicts that the locus of hyper-excitability varies across individuals, and only specific color filters can change the distribution of firing appropriately. The present findings show that children with autism choose a narrower selection of colors to improve clarity than matched controls (7 different color chosen by ASD compared to controls' 9), and that these selected colors not only differ from their favourite color, but more importantly, are the only colors that significantly increase reading speed.

The assumption that the cortex is hyperexcitable in autism is plausible given research showing abnormalities of cortical networks (Brambilla et al., 2003; Minshew, Meyer & Goldstein, 2002; Bailey et al., 1995; Carper et al,. 2002) and reduced co-ordination and communication between cortical areas (Just, Cherkassky, Keller & Minshew, 2004) in individuals with this disorder. Also high incidences of paroxysmal EEG discharges are frequently reported in children with autism (Hashimoto et al., 2001; Deonna & Roulet, 2006). However links between these research findings and cortical hyperexcitability have yet to be precisely outlined. Much has yet to be learned about the specific behavioural consequences of atypical brain development in ASD.

Research studies showing impaired function of the magnocellular pathway in groups of individuals with dyslexia (Galaburda 1993; Iovino et al., 1998;), migraine (McKendrick et al, 2004) and autism (Milne et al., 2002; Spencer et al., 2000), and studies showing that colored spectacles, filters and overlays provide therapeutic benefits for individuals with these disorders (Wilkins 2003) provide links between the different neurophysiological accounts of visual disturbance presented in the introduction. Although there are a higher proportion of dyslexic individuals who report symptoms of visual stress, many who suffer from these conditions do not benefit from the use of overlays (Kriss, 2002) and no study has yet identified any specific magnocellular abnormality in visual stress (Evans et al., 1996; Simmers et al., 2001). Supporters of magnocellular theory have implied that specific colors such as yellow and blue, that change the balance of input into the magnocellular pathway, enhance reading (Ray et al., 2005; Solan, 1998; Williams et al., 1992). However the present findings failed to show a significant reading advantage for these specific overlay colors, as magnocellular theory might predict.

Taken together the findings from the studies show that the use of colored overlays results in increased speed in response to both written and pictorial stimuli without compromised accuracy in many, though not all children with ASD. A substantial proportion of these children are believed to be susceptible to the types of visual disturbance associated with visual stress (Irlen, 1991; Wilkins, 2003; Williams, 1999) than would be expected, given current diagnostic criteria. Whilst it is clear that the complex pattern of difficulties characteristic of ASD cannot be solely attributed to abnormalities in visual perception, it is nevertheless likely to be the case that such difficulties will negatively impact on the functioning and well-being of affected individuals. The development of appropriate screening methods and the establishment of early screening timetables should therefore be a primary aim for researchers working in the area.

Whilst the present study provides further support for the use of colored overlays in children with ASD, there are still many outstanding questions about the etiology of the visual disturbances in ASD. It had been hypothesised that blue and yellow overlays would enhance input to the magnocellular system. However no significant benefits were seen compared to no overlay when the children used blue and yellow overlays and so the results provide limited support for the magnocelluar account. The cortical hyperexcitability theory predicts that therapeutic benefits will only occur when overlays are self-selected. This is because self-selected overlays cause a shift away from hyperexcitable areas. It therefore appears this theory offers a better explanation for the current findings. However, given the fairly small samples included in Experiment 2 and the fact that no significance difference was shown between the overlay chosen for clarity and blue and yellow, more research is clearly warranted.

Acknowledgements: We would like to thank all the children who participated in our studies.

Declaration of interest: The *Intuitive Overlays* were designed by AJW when he was employed by the British Medical Research Council. The MRC own the rights. AJW receives an “Award to Inventors” from the MRC, based on royalties on sales.

References

Attwood, T. (1994). *Why does Chris do that? Understanding and managing the often baffling behaviour of people with autism*. London: National Autistic Society Booklet

Bailey, A., Le Couteur, A., Gottesman, I., Bolton, P., Simonoff, E., Yuzda, E., and Rutter, M. (1995). Autism as a strongly genetic disorder: Evidence from a British twin study. *Psychological Medicine*, 25(1), 63-77.

Belmonte, M. K., Cook, E. H. Jr, Anderson, G. M., Rubestein, J. L., Greenough, W. T. , Beckel-Mitchener, A., Courchesne, E., Boulanger, L. M., Powell, S. B., Levitt, P. R., Perry, E. K., Jiang, Y. H., DeLorey, T. M., and Tierney, E. (2004). Autism as a disorder of neural information processing direction for research and targets for therapy. *Molecular Psychiatry*, 9(7), 646-663

Bouldoukian, J., Wilkins, A. J., and Evans, B.J.W. (2002). Randomised control trial of the effect of colored overlays on eth rate of reading of people with specific learning difficulties. *Ophthalmic and Physiological Optics*, 22, 156-165.

Brambilla, P., Hardan, A., Ucelli Di Nemi, S., Perez, J., Soares, J. C., Barale, F. (2003). Brain anatomy and development in autism: review of structural MRI studies. *Brain Research Bulletin*, 61, 557-569.

Carper, R. A., Moses, P., Tigue, Z. D., and Courchesne, E. (2002). Cerebral lobes in autism: early hyperplasia and abnormal age effects, *NeuroImage*, 16, 1038-1051.

Chase, C. H. (1996). A visual deficit model of developmental dyslexia. In C. H. Chase, G. D. Rosen and G. F. Sherman (Eds). *Developmental dyslexia: neural, cognitive and genetic mechanism. (pp 127-156).* Timonium MD: York Press.

Chase, C., Ashourzadeh, A., Kelly, C., Manfette, S., Kinsey, K. (2003). Can the magnocellular pathway read? Evidence from studies of color. *Vision Research,* 43, 1211-1222.

De Meyer, M.K. (1976). Motor, perceptual-motor and intellectual disabilities of autistic children. *In L. Wing (Ed.), Early Childhood Autism* (pp.169–193).

Deonna, T., & Roulet, E. (2006). Autism Spectrum Disorder: Evaluating a possible contributing or causal role of epilepsy. *Epilepsia*, 47(2), 79-82

Deruelle, C., Rondan, C., Gepner, B., Tardif, L. (2004). Spatial frequency and face processing in children with Autism and Asperger syndrome. *Journal of Autism and Developmental Disorders*, 34(2), 99-210

Dunn, L., Dunn, L., Whetton, C., & Burley, J. (1997). *The British Picture Vocabulary Scale.* NEFER-NELSON.

Dunn, W. (1999). *Sensory Profile*. San Antonio, TX: Psychological Corporation.

Evans, B. J. W. (2001). *Dyslexia and Vision*. London: Whurr Publication.

Evans, B. J. W & Joseph, F (2002). The effect of colored filters on the rate of reading in an adult student population. *Ophthalmic and Physiological Optics*, 22, 535-545.

Evans, B.J.W.,Wilkins, A.J., Brown, J., Busby, A., Wingfield, A., Jeanes, R., & Bald, J. (1996). A preliminary investigation into atetiology of Meares-Irlen Syndrome. *Ophthalmic and Physiological Optics*, 164, 286-296.

Filipek, P. A., Accardo, O. J., Baranek, G. T., Cook Jr., E. H., Dawson, G., Gordon, B., Gravel, J. S., Johnson, C. P.L., Kallen, R. J., Levy, S. E., Minshew, N. J., Prizant, B. M., Rapin, I., Rogers, S. J., Stone, W. I., Teplin, S., Tuchman, R. F., and Volkmar, F. R. (1999). *Journal of Autism and Developmental Disorders*, 29(6), 439-484.

Galaburda, A. M. (1993). *Dyslexia and Development.* Harvard University Press. Cambridge. MA.

Gillberg, C., and Coleman, M. (1992). *The Biology of the Autistic Syndromes (2nd edition).* MacKeith Press.

Harle, D.E., Shepherd, A.J. and Evans, B.J.W. (2006). Visual stimuli are common triggers of migraine and are associated with pattern glare. *Headache,* 46(9), 1431-40.

Hashimoto, T., Sasaki, M., Sugai, K., Hunaoka, S., Fukumizu, M., Kato, T. (2001). Paroxysmal discharges on EEG to young autistic patients are frequent in frontal regions. *The Journal of Medical Investigation*, 48(3-4),175-180.

Howlin, P. (1996). A Visit to the Light and Sound Therapy Centre. Pamplet. London. National Autistic Society.

Huang, J., Cooper, T. G., Satana, D., Kaufman, D. I., and Cao, Y. (2003). Visual distortion associated with hyper visual neuronal activity in migraine. *Headache*, 43(6): 664-671.

Huang, J., Wilkins, A. J., and Cao, Y. (2004). *International Society for Magnetic Resonance in Medicine Proceedings*.

Intutitive Colored overlays. (1995). Colored Overlays for people with reading difficulty and visual discomfort. *I.O.O. Marketing Limited*,

Iovino, I., Fletcher, J. M., Breitmeyer, B. G., and Foreman, B. R. (1998). Colored overlays for visual perceptual deficit in children with reading difficulties and attention deficit/hyperactivity disorder are they differentially effective? *Journal of Clinical and Experimental Neuropsychology*, 20(6), 791-806.

Irlen, H. (1991). *Reading by colors.* New York. NY. Avery Publishing group Inc.

Jackowski, M. M., Sturr, J. F., Taub, H.A., & Turk, M. A. (1996). Photophobia in patients with traumatic brain injury: Uses of light-filtering lenses to enhance contrast sensitivity and reading rate. *Neurorehabilitation*, 6, 193-201.

Jeanes, R., Busby, A., Martin, J., Lewis, E., Stevenson, N., Pointon, D., and Wilkins, A.J (1997). Prolonged use of colored overlays for classroom reading. *British Journal of Psychology*, 88, 531-548.

Just, M. A., Cherkassky, V., Keller, T. A., Minshew, N. J., (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. *Brain*, 127, 1811-1821.

Kanner, L. (1943). Autistic disturbance of affective contact. *Nervous Child*, 2, 217-50.

Kern, J. K., Trivedi, M. H., Garver, R., Grannemann, B. D., Andrews, A. A., Souka, J. S., Johnson, D. G., Mehta, J. A., & Schroeder, J. L.(2006). The pattern of sensory processing abnormalities in autism. *Autism*, 10, 484-494.

Kriss, I. (2002). An investigation of the effects of colored overlays on reading in dyslexics and controls. BSc Thesis, Manchester Metropolitan University UK.

Kriss, I., & Evans, B. J.W. (2005). The relationship between dyslexia and Meares-Irlen syndrome. *Journal of Research in Reading*, 28(3), 350-364.

Livingstone, M. S., Rosen, G. D. Drislane, F. W., & Galaburda, A. M. (1991). Physiological anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Science,* 88, 7943-7947.

Ludlow, A., Wilkins, A. J., and Heaton, P. (2006). The effect of colored overlays on reading ability in children with autism. *Journal of Autism and Developmental Disorders,* 36(4), 507-516.

McKendrick, A., Badcock, D.R. & Vingrys, A.J. (2000). Visual deficits in migraine sufferers: what do the methods tell us? *Journal of the Optical Society of America, A, Optics Image Science and Vision,* 17(5), 836-45.

Mayes, S. D., and Calhoun, S. L. (1999). Symptoms of autism in young children and correspondence with DSM. *Infants and Young Children*, 12(2), 90-97.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., and Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry,* 43, 255-263.

Milne, E., Swettenham, J., Campbell, R., and Coleman, M. (2004). *Degree of global/local processing is related to coherent motion detection.* Paper presented at the International Meeting for Autism Research, Sacramento, CA.

Minshew, N. J., Meyer, J., and Goldstein, G. (2002). Abstract reasoning in autism: A dissociation between concept formation and concept identification. *Neuropsychology*, 16, 327-334.

Mottron, L., & Burack, J. (2001). Enhanced perceptual functioning in the development of persons with autism. In J. Burack, T. Charman, N. Yirmiya and P. R. Zelazo (Eds.), *The Development of Autism: Perspectives from Theory and Research* (pp. 131-148). Mahwah, NJ: Erlbaum.

Mottron, L., Dawson, M., Soulieres, I., Hubert, B., Burack, J. (2006). Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, 36(1): 27-43.

Myles, B. S., Cook, K. T., Miller, N.E ., Rinner, L., Robbins, L. A. (2000). *Asperger syndrome and sensory issues: Practical solutions for making sense of the world*. Shawnee Mission, Kansas, US: Autism Asperger Publishing co

Olney, M. F. (2000). Working with Autism and other social-communication disorders. *The Journal of Rehabilitation*, 66(4), 51-56.

O'Neil, M., and Jones, R. S. P. (1997). Sensory–perceptual abnormalities in autism: a case for more research. *Journal of Autism and Developmental Disorders*, 27(3), 283-293.

Raven, J.C.M., Court, J. H., and Raven, J. (1998). *Standard Progressive Matrices*. OUP: Oxford Psychologists Press.

Ray, N. J., Fowler, S and Stein, J. F. (2005). Yellow filters an improve magnocelullar function: Motion sensitivity convergence, accomodation and reading. *Annals of the New York Academy of Sciences*, 1039, 283-293.

Simmers, A.J., Bex, P. J., Smith, F. K. H., and Wilkins, A. J. (2001). Spatiotemporal visual function in tinted lens wearers *Invest. Ophthalmol. Vis. Sci*., 423, 879-884.

Snodgrass, J.G., & Vanderwart, M. (1980). A standardised set of 260 pictures: Norms to name agreement, image agreement, familiarity and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, 6, 174-215.

Solan, H. A. (1998). Influence of varying luminance and wavelength on comprehension and reading efficiency: a brief review of three studies. *Journal of Optometric Vision Development,* 29(3*),* 98-103.

Spencer, J., O'Brian, J., Riggs, K., Braddick, O., Atkinson, J., and Wattam-Bell, J. (2000). Motion processing in autism: Evidence for a dorsal stream deficiency. *Neuroreport*, 11, 2765-2767.

Stein, J and Walsh, V., (1997). To see but not to read: the magnocellular theory of dyslexia. *Trends in Neuroscience, 20(4),* 147-152.

White, B. B., & White, M. S. (1987). Autism from the inside. *Medical Hypotheses, 24*, 223-229

Wilkins, A. J., (1994). Overlays for classroom and optometric use. *Ophthalmic and Physiological Optics, 14*(4), 97-99.

Wilkins, A. J., Jeanes, R, J., Pumfrey, P. D., & Laskier, M. (1996). Rate of Reading Test: Its reliability and its validity in the assessment of the effects of the colored overlay. *Ophthalmic and Physiological Optics*, 16, 491-497.

Wilkins, A. J., & Lewis, E. (1999). Colored overlays, text and texture. *Perception*, *28,* 641-650.

Wilkins, A. J., Lewis, E., Smith, F., & Rowland, E. (2001). Colored overlays and their benefits for reading. *Journal of Research in Reading, 181,* 10-23

Wilkins, A. J. (2002). Colored overlays and their effects on reading speed: a review. *Ophthalmic and Physiological Optics*, *22,* 448-454.

Wilkins, A, J. (2003). *Reading through color.* Chichester: Wiley.

Wilkins, A.J. (1995). *Visual Stress.* Oxford: Oxford University Press.

Wilkins, A.J., Sihra, N. & Nimmo-Smith, I. (2005). How precise do precision tints have to be and how many are necessary. *Ophthalmic and Physiological Optics,* 25, 269-276.

Williams, M.C., LeCluyse, K., & Rock-Faucheux, A. (1992). Effective interventions for reading disability. *Journal of the American Optometric Association,* 63(6), 411-417.

Williams, D. (1999). *Like Color to the Blind.* London: Jessica Kingsley Publishers Ltd.

Wright, B., Wilkins, A. J. Zoukos Y. (in press). Spectral filters can improve reading and visual search in patients with multiple sclerosis. *Journal of Neurology*.

Table 1: Mean (and standard deviation) of age, and scores on the British Picture Vocabulary Scale (BPVS) for 18 children with ASD and 18 controls

Group	Age	BPVS
ASD	12.3 (2.1)	64.5 (11.2)
Control	12.1 (1.9)	68.3 (11.3)

Table 2: Means (and standard deviations) of reading rates with and without colored overlays for 18 children with ASD and 18 controls.

Group	Number of symptoms		Words read per minute	
	With colored overlay	**without colored overlay**	**with colored overlay**	**without colored overlay**
ASD	0.06 (0.24)	0.39 (0.78)	96.9 (33.7)	83.8 (32.2)
Control	0.17 (0.28)	0.39 (0.61)	68.6 (17.4)	69.8 (19.8)

Table 3: Mean (and standard deviation) of age, and scores on the British Picture Vocabulary Scale (BPVS) for 16 children with ASD and 16 controls

Group	Age	Ravens	BPVS
ASD	**14.8 (8.1)**	**67.0 (5.3)**	**59.6 (5.3)**
Female (N=4)	15.1 (9.4)	67.5 (3.7)	64.3 (6.2)
Male (N=12)	14.7 (7.8)	66.8 (5.9)	58.0 (4.3)
Control	**14.9 (6.4)**	**65.1 (4.0)**	**62.7 (6.8)**
Female (N=4)	15.0 (6.1)	66.2 (5.4)	64.0 (8.8)
Male (N=12)	14.8 (6.1)	66.8 (5.9)	64.3 (6.2)

Table 4: Means (and standard deviations) of reading rates with an overlay chosen for clarity, an overlay chosen on the basis of preference and a blue and a yellow overlay. Data are for 16 children with autism and 16 controls.

Group	No overlay	Overlay			
		Color chosen for clarity	**Color chosen as favourite**	**Blue**	**Yellow**
ASD	57.8 (36.8)	72.3 (29.2)	65.4 (29.7)	69.3 (30.1)	70.3 (29.1)
Control	71.1 (20.8)	73.2 (23.2)	65.1 (18.2)	69.5 (18.2)	64.8 (15.3)

Table 5: Mean (and standard deviation) of age and IQ scores (Ravens Matrices) for 13 children with high functioning ASD (HFA, IQ>70) and 13 with low functioning ASD (LFA, IQ<70), and 13 controls with typical development (TD) and 13 with moderate learning difficulties (MLD)

Group	Age	IQ
ASD	12.3 (2.2)	75.8 (16.2)
HFA	12.2 (2.3)	89.6 (11.6)
LFA	12.4 (2.2)	61.9 (5.3)
Control	12.3 (2.1)	74.2 (15.3)
TD	12.1 (2.3)	86.0 (13.2)
MLD	12.4 (2.0)	62.4 (3.0)

Table 6 Mean (and standard deviations) for accuracy scores on the matching-to-sample task for 26 children with autism and 26 controls.

Group	With a colored overlay	Without a colored overlay
ASD	**26.8 (4.4)**	**26.4 (3.9)**
Control	**26.1 (3.3)**	**25.7 (3.2)**

***Maximum number correct =30**

Table 7: Means (and standard deviations) for time taken (seconds) to complete a matching-to-sample task for 26 children with autism and 26 controls.

Group	With colored overlay	Without colored overlay
ASD	112.9 (57.0)	135.7 (60.1)
Control	170.3 (92.6)	148.7 (89.6)

Table 8: Increases in speed of performance with colored overlays in Experiments 1 and 2 combined in Experiment 3.

% increase with an overlay	Number of children faster with overlay on Rate of Reading task (Experiments 1 and 2 combined)		Number of children faster with overlay on Matching-to-sample task (Experiment 3)	
	ASD	**Control**	**ASD**	**Control**
	N=34	N=34	N=26	N=26
>0%	25(74%)	9(26%)	16(61%)	6(23%)
5%>	25(74%)	7(20%)	16(61%)	6(23%)
25%>	13(38%)	2(6%)	6(23%)	1(4%)
50%>	4(12%)	0	4(15%)	0

Figure 1: Number of words read in a minute with and without an overlay

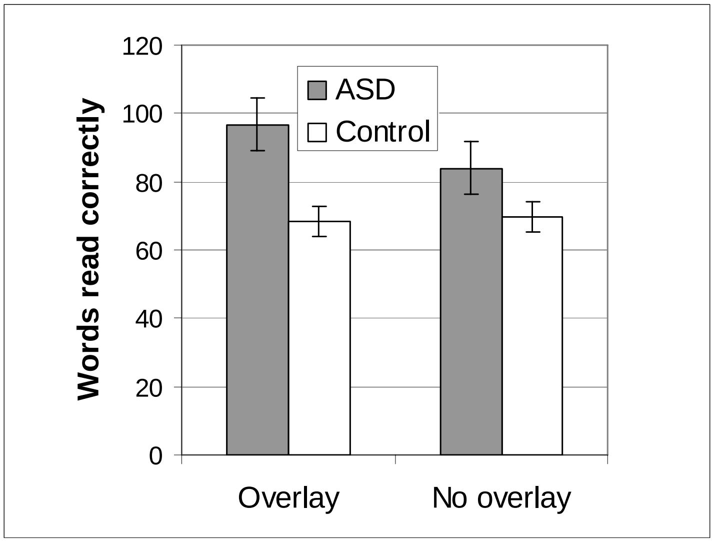

Figure 2: Distribution of overlay colors chosen.

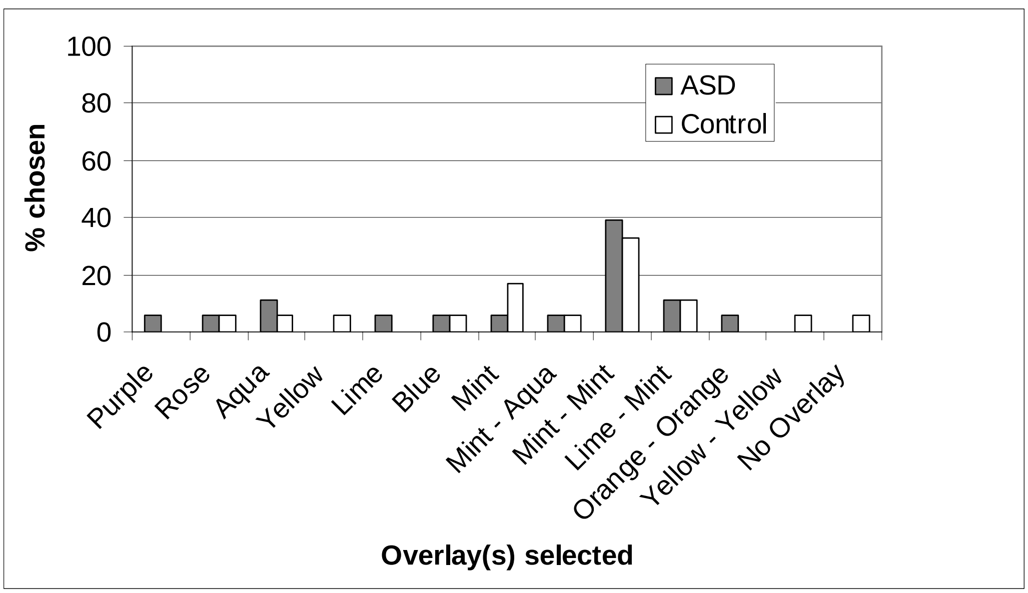

Figure 3: Distribution of colors chosen for clarity versus favourite.

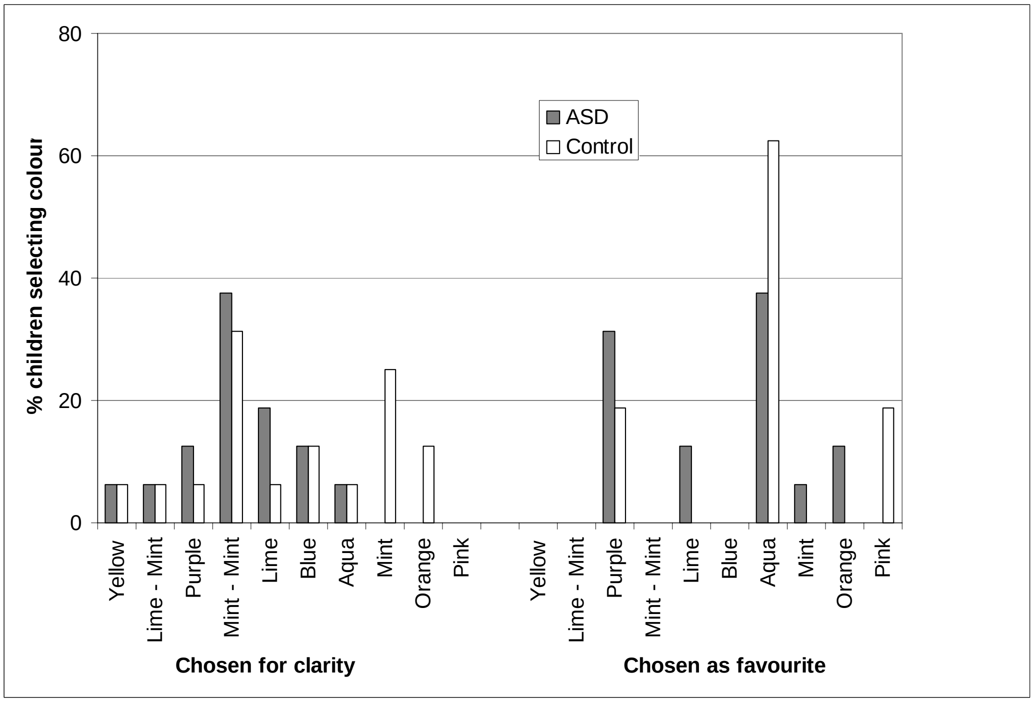

Figure 4: Number of words read per minute across the 5 overlay conditions.

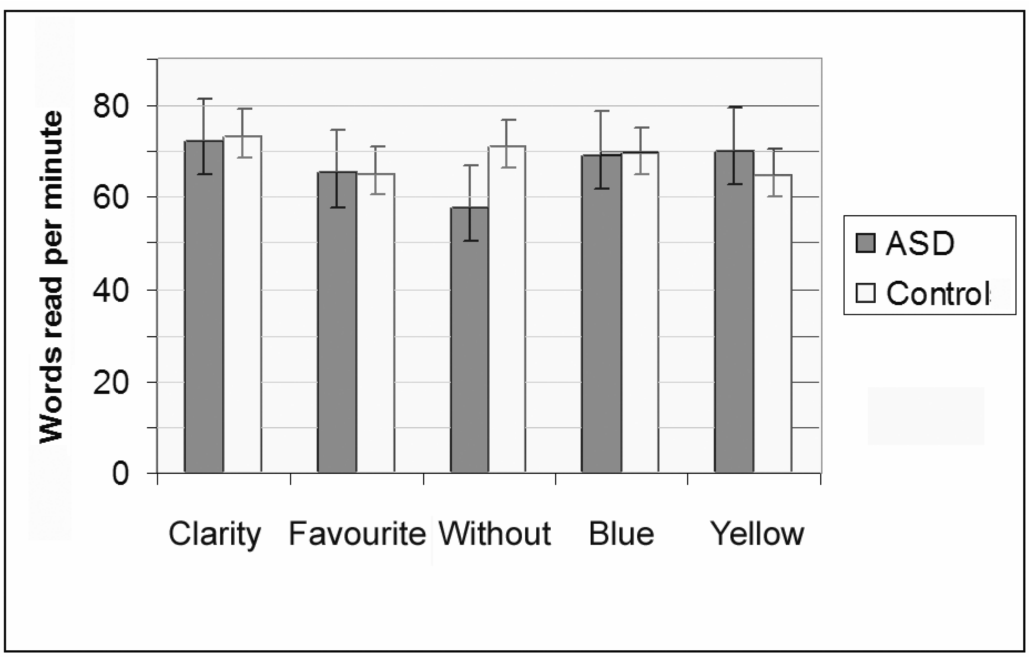

Figure 5: Examples of stimuli in the matching-to-sample task

Figure 6: Group by condition interaction for matching-to-sample task