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Color Perception in Children with Autism

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Abstract

This study examined whether color perception is atypical in children with autism. In Experiment 1, accuracy of color memory and search was compared for children with autism and typically developing children matched on age and non-verbal cognitive ability. Children with autism were significantly less accurate at color memory and search than controls. In experiment 2, chromatic discrimination and categorical perception of color were assessed using a target detection task. Children with autism were less accurate than controls at detecting chromatic targets when presented on chromatic backgrounds, although were equally as fast when target detection was accurate. The strength of categorical perception of color did not differ for the two groups. Implications for theories on perceptual development in autism are discussed.

Key words: Autism; color; perception; categorization.

Introduction

Research into the cognition and perception of persons with autism has found differences compared to control groups on a range of tasks and for a range of domains. For example, persons with autism have been shown to out perform control groups on the embedded figures task (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983), block design (Rumsey & Maberger, 1988; Shah & Frith, 1993); visual search (O’Riordan, 2004; O’Riordan, Plaisted, Driver & Baron-Cohen, 2001; Plaisted, O’Riordan & Baron-Cohen, 1998a); and the reproduction of impossible figures (Mottron, Belleville & Ménard, 1999). Enhanced perception and discrimination has also been shown for pitch processing, musical processing and processing of auditory stimuli (eg., Bonnel et al., 2003; Heaton, Hermelin & Pring, 1998; Mottron, Peretz & Ménard, 2000), visuo-spatial perception (Caron, Mottron, Rainville, Chouinard, 2004; Mitchell & Ropar, 2004) and discrimination of novel stimuli (Plaisted, O’Riordan & Baron-Cohen, 1998b), leading to theories that those with autism show superior visual discrimination (O’Riordan & Plaisted, 2001) or an enhanced perceptual functioning (eg., Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert & Burack, 2006) that may extend to a large number of perceptual domains (Mottron, Peretz and Ménard, 2000). However, an impaired perceptual ability in autism has been shown for some other domains such as motion (e.g., Spencer et al., 2000; Milne et al., 2002; but see also Bertrone, Mottron, Jelenic & Faubert: 2003, 2005.)

Here we investigate whether there are also differences in the color perception of those with and those without autism. Anecdotal evidence from parents, carers, teachers of persons with autism and persons with autism themselves suggests that those with autism may perceive color differently to typically developing children. For

example, a parent of a child with autism describes her child's color obsessions and sensitivity to color:

“he was given photocopied sheets of characters from the film and would colour these in, from memory, with complete accuracy.....George knew the colours by heart, and never made a mistake” (Moore, 2004, p.68).

“by and large he would eat only red food, and to this day he uses ketchup to mask unwelcome colours. I call his colour obsession ‘mild’ because I have heard of far more extreme cases” (Moore, 2004, p.153).

Despite many such accounts suggesting that color perception and cognition may be atypical in autism, there has been little experimental investigation of whether this is the case. Kovattana and Kraemer (1974) found that a non-verbal group of children with autism preferred to use color and size cues rather than form on a sorting task, whereas there was no cue dominance in control groups. However, Ungerer and Sigman (1987) found no significant differences in children's sorting by function, form or color when compared to a control group of typically developing children. There is also a suggestion that children with autism are advanced in their color naming (Schafer & Williams, 2007). In addition, there is some indirect evidence that there may be differences in attention to color. For example, Brian, Tipper, Weaver and Bryson (2003), when investigating inhibitory mechanisms in autism, found that color unexpectedly produced a facilitation effect in persons with autism but not controls. Brian et al. speculate that ‘in autism, stimulus features such as color may be encoded too readily, and thus are detected more easily than is typically the case’ (p.558). Greenaway and Plaisted (2005) find a similar effect on a cueing task, where invalid color cues resulted in greater costs for those with autism than controls.

Therefore, although anecdotal evidence suggests that there may be some differences in the color perception of children with autism and typically developing

children, there has been little direct experimental investigation of this. There are theoretical reasons for addressing this issue — for example, it allows us to test whether enhanced perceptual functioning extends to other perceptual domains. There are also clinical and practical reasons for addressing this issue —gaining a better understanding of color perception and cognition in autism may give insight into color obsessions in autism and the way in which color may shape those with autisms’ world.

In the current study we investigated the color perception of children with autism in two experiments where children with high-functioning autism were compared to a group of typically developing children matched on age and non-verbal cognitive ability. In experiment 1, we assessed accuracy of color memory and color search. In experiment 2, we assessed accuracy and speed of chromatic discrimination using a target detection task. This experiment also investigated the strength of categorical influences on color perception by testing for categorical perception of color.

Experiment 1: Color Memory and Search in Children with Autism.

In Experiment 1 we assessed the hypothesis that color memory and color search is atypical in children with autism. Children with autism and typically developing children matched on age and non-verbal cognitive ability were compared on two tasks — a visual search task and a delayed matching-to-sample task. On the visual search task children were required to search a grid of colored squares (15 distractors, 1 target) and identify the ‘odd-one-out.’ On the delayed matching-to-sample task children were shown a colored stimulus (target) and after a delay were asked to identify the original stimulus (target) when paired with another colored stimulus (foil). Accuracy of target identification was assessed on both tasks. To be able to get

a measure of color perception rather than just perception generally, a comparison condition of stimuli differing in form was also included for both tasks.

As color naturally differs along three dimensions — hue (the ‘species’ or ‘ink’ of the color), saturation (colorfulness rather like richness) and lightness (roughly equivalent to the amount of light in the color / luminance), the colored stimulus pairs in the current experiment differed along all three dimensions. The colorimetric difference between stimulus pairs was made small enough (in CIE $L^*a^*b^*$, perceptual color space) that errors on both tasks were predicted. To be able to check that any differences in accuracy were not specific to one region of the color space, three sufficiently different regions of the color space were sampled (red, green, yellow). Only three regions of color space were sampled to ensure that the number of trials was manageable for the child participants. Stimulus pairs were taken from within each color region (eg., red1 & red2) so that verbal labeling of the colored target would not facilitate search (see Daoutis, Franklin, Riddett, Clifford & Davies, 2005) or recognition memory (see Franklin, Clifford, Williamson & Davies, 2005). The form stimuli were abstract line drawn shapes. Stimulus pairs differed on one element — with one line of one of the stimuli in the pair being slightly curved whilst the curve of the corresponding line in the other stimulus was more pronounced. The perceptual difference between the two stimuli in a stimulus pair was made small enough that errors on both tasks were predicted. To ensure that any differences in accuracy of form perception were not specific to one form, three different form stimulus pairs were used.

If enhanced perceptual functioning in autism extends to color then children with autism should be more accurate when detecting colored targets on search and memory tasks than typically developing children. If children with autism actually have

reduced perceptual color functioning compared to typically developing children then accuracy will be lower than the control group when detecting colored targets. If any differences are specific to color then no significant difference should be found between children with autism and typically developing children on accuracy of target identification for form.

Methods

Participants

Thirty-four children took part in the study, 20 with autism and 14 typically developing children (all males). Children were screened for color vision deficiencies using the Ishihara Color Vision Test (Ishihara, 1987). One child with autism failed to complete the test and was excluded from the study, resulting in a final sample of 19 children with autism. All children with autism were high functioning, attended schools for children with autism and had been diagnosed by clinicians according to the criteria of DSM – IV (APA, 1994). None of the children in either group had received a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). Typically developing children and children with autism were matched for non-verbal cognitive ability as assessed by Raven’s Coloured Progressive Matrices (Sets A, Ab and B, Raven, Court & Raven, 1990), ($t(31) = 0.10$, $p = 0.92$) and chronological age ($t(31) = 1.71$, $p = 0.1$), (see table 1).

INSERT TABLE 1 HERE

Stimuli

Color set. There were three colored stimulus pairs: red1 & red2; yellow1 & yellow2; green1 & green2. The stimuli of each pair differed in hue, brightness and saturation. For example red1 and red 2 were different hues and were also different in levels of brightness and saturation. The separation size of stimuli in a pair in CIE

($L^*a^*b^*$) perceptual color space ranged from $12\Delta E$ – $14\Delta E$, (see table 2 for the Y, x, y and $L^*a^*b^*$ co-ordinates of stimuli).

INSERT TABLE 2 HERE

Form set. There were three form stimulus pairs. These were abstract line drawn shapes modified from Pick (1965). The stimuli of each pair differed on one element — for one stimulus in the pair one line was curved and for the other stimulus in the pair the curve of the corresponding line was more pronounced (see figure 1 for examples of stimulus pairs.)

INSERT FIGURE 1 HERE

Stimuli filled a one inch square, and were presented on a grey ($Y=127$, $x=0.31$, $y=0.30$) background. For the visual search task 16 stimuli were presented in a grid arrangement. Fifteen stimuli were the same (distractors) and there was one different stimulus (target). There were four search grids for each stimulus pair with each stimulus in the pair appearing as both the target and the distractor. The location of the target was randomised across search grids.

Procedures

Each participant completed both the visual search task and the delayed matching-to-sample task, with the order of task counterbalanced for each sample. The tasks were conducted under Illuminant C (simulated natural daylight), $temp=6500K$.

Visual search task. Children were presented with a practise search grid and were told to ‘point to the one that is different to all the other ones’. Once it was clear that the children understood the task the children completed twelve color grids and twelve shape grids in a randomised order. The child’s response was recorded as either incorrect or correct.

Delayed matching-to-sample task. Children were presented with a stimulus (target) and were told to remember it. After a five second delay the stimulus was covered with grey card. Following a further five second delay a stimulus identical to the target and the other stimulus in the stimulus pair (foil) were presented. Children were asked to ‘point to the one that is the same as the one you just saw’. There were four trials for each stimulus pair and each stimulus appeared twice as the target and twice as the foil. Children were given a practice and once it was clear that the children understood the task the children completed twelve color trials and twelve shape trials in a randomized order. The child’s response was recorded as either incorrect or correct.

Results

The percentage of correct responses for the color trials and the form trials on the delayed matching-to-sample and visual search tasks was calculated. A three-way mixed ANOVA with the repeated measures factors of Domain (color/form) and Task (delayed matching-to-sample/visual search) and an independent groups factor of Group (children with autism/controls) was conducted on the accuracy percentages.

There was a significant main effect of Domain, with 85.7% [$SD=8.8$] correct for color trials and 91.8% [$SD=6.5$] correct for form trials, [$F(1,31) = 16.8, p<.001, \eta_p^2=0.35$]. Key to the research question, there was a significant interaction of Domain and Group, [$F(1, 31), = 6.2, p <.05, \eta_p^2 = 0.17$]. Figure 2 shows the mean percentage accuracy for each group for color and form. All other main effects and interactions were not significant [largest $F=2.6$, smallest $p=0.12$].

INSERT FIGURE 2 HERE

Post hoc *t* tests (Bonferroni corrected significance level $p < .025$) revealed a significant difference in accuracy between children with autism and controls for color, [$t(31) = 2.7, p < .025$], but not for form, [$t(31) = 0.13, p = 0.90$].

A two-way mixed ANOVA with the repeated measures factor of Color region (red/green/yellow) and the independent groups factor of Group (children with autism/controls) was conducted on percentage accuracy. There was a significant difference in accuracy for green [mean=81.6, SD= 1.3], yellow [mean=81.6, SD=12.9] and red [mean=92.3, SD=15.5], [$F(2,62) = 9.5, p < .001, \eta_p^2 = 0.23$], with lower accuracy for green and yellow stimuli compared to red [$p < .005$]. As identified in the previous ANOVA, there was a significant difference in accuracy of children with autism and typically developing children, [$F(1,31) = 8.74, MSE = 218, p < .01, \eta_p^2 = 0.22$]. However, there was no significant interaction between Color region and Group, [$F(2,62) = 1.0, p = 0.37$].

Discussion

Experiment 1 assessed accuracy of color perception in children with autism using a visual search and delayed matching-to-sample task. Significant differences in the accuracy of both color memory and color search were found between children with autism and controls matched on non-verbal cognitive ability and age. Children with autism were significantly less accurate at identifying a colored target on the two tasks compared to controls. Importantly, this was found for all three color regions (red, green and yellow), suggesting that this pattern is not restricted to certain regions of the color space. Also importantly, there was no difference in accuracy between the two groups for the form condition, suggesting that the differences between the two groups were due to color and not due to more general differences in perception or cognition. Experiment 2 further investigated this effect using a task which is

intended to measure color discrimination more directly than the tasks in experiment 1. Experiment 2 also assessed the possibility that there are differences between children with autism and typically developing children in the strength of categorical influences on color perception.

Experiment 2: Chromatic Discrimination and Categorical Perception of Color

In Experiment 1 children with autism had less accurate color perception on two tasks compared to typically developing children. One aim of Experiment 2 was to see whether the findings of experiment 1 could be replicated using a target detection task. The target detection task was originally developed to assess color discrimination in infants (Franklin, Pilling & Davies, 2005), although it has since been modified for use with adult samples, and has been revealed to be a task that is sensitive to supra-threshold differences in color discrimination (e.g., Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies, 2007). The task involves the detection of a colored target when presented on a colored background, and as the target is defined purely by the chromatic difference of the target and the background, efficiency of target detection is related to the perceptual similarity of the target and background colors. Unlike the delayed matching-to-sample or visual search task, target detection simply involves the detection of a chromatically defined edge (rather than the memory or comparison of targets and distractors), therefore the task is thought to tap chromatic discrimination more directly than the other two tasks. If children with autism are also less accurate at identifying targets than typically developing children on this task, this would give further support to the hypothesis that children with autism have less accurate chromatic discrimination than typically developing children. As the task is computerized, the speed of target identification can also be recorded, which allows an

assessment of whether chromatic discrimination in autism is also slower as well as less accurate compared to typically developing children.

A second aim of the current experiment was to investigate the strength of categorical influences on color perception in children with autism. One way of investigating the activation and interaction of different levels of processing in autism has been to investigate categorization in autism. Such studies have assessed the influence or formation of category prototypes (Dunn, Gomes & Sebastian, 1996; Klinger & Dawson, 2001; Molseworth, Bowler & Hampton, 2005), and the strength of categorical influences on facial expressions (Teunisse & de Gelder, 2001) and ellipse width (Soulières, Mottron, Saumier & Larochelle, 2007). These studies have provided mixed support for the hypothesis that categorization in autism is atypical, and only two of these studies (Molesworth et al., 2005; Soulières et al., 2007) match groups on IQ. In the Molesworth, Bowler and Hampton (2005) study, those with autism formed artificial animal categories and prototypes to the same extent as those without autism. Soulières et al. (2007) investigated the ability of those with autism to categorize a continuum of ellipse widths into two categories and in addition assessed the influence that these categories had on discrimination. Although, those with autism showed typical classification curves (they divided the continuum in the same way as those without autism), the influence of this categorization on discrimination was shown to be weaker for those with autism than those without. Only those without autism showed a ‘categorical perception’ effect — facilitated discrimination of stimuli that cross a category boundary (between-category) compared to equivalently spaced stimuli from the same category (within-category), (see Harnad, 1987). As ‘categorical perception’ is also typically found for the domain of color (e.g., Bornstein & Korda, 1984), the second aim of the current experiment was to

assess whether the reduced categorical perception effect in autism found by Soulières et al. could be generalized to other perceptual domains. Therefore, here we test for categorical perception of color using the target detection task. The target detection task has previously been used to show categorical perception of color across the blue-green category boundary in adults (Drivonikou et al, 2007) and we test the same category boundary here.

If categorical perception (CP) of color is shown on the target detection task, target detection should be faster and/or more accurate when the target is shown on a different-category (between-category condition) than same-category (within-category condition) background, when between- and within-category stimulus chromatic separation sizes are equated. The difference in target detection time for within- and between-category conditions indicates the strength of the CP effect. Unlike other tasks (e.g., triadic judgment tasks) the task does not ask participants to make explicit judgments of whether the colors are ‘same’ or ‘different’, and unlike other tasks (such as delayed matching-to-sample tasks) the detection of the target is not aided by a verbal labeling strategy. This ensures that CP and any differences between those with autism and those without autism are likely to be due to perceptual processes.

Methods

Participants

Thirty children took part in the study, 16 with autism and 14 typically developing children (all males). Children were screened for color vision deficiencies using the Ishihara Color Vision Test (Ishihara, 1987). One child with autism who failed to complete the color vision test was excluded from the study, and one child was excluded for performing at chance, resulting in a final sample of 14 children with autism. All children with autism were high-functioning, attended schools for children

with autism and had been diagnosed by clinicians according to the criteria of DSM – IV (APA, 1994). None of the children in either group had received a diagnosis of ADHD. Typically developing children and children with autism were matched for non-verbal cognitive ability as assessed by Raven's Standard Progressive Matrices (Sets A, B, C, D, E, Raven, Court & Raven, 1992) [$t(26) = .912, p = .37$] and chronological age [$t(26) = 1.54, p = .14$], (see table 3).

Experimental Set-Up

Stimuli were presented on a 16" Vision Master pro-1314 monitor, and the chromaticity and luminance of the stimuli were verified with a Cambridge Research Systems (Rochester, U.K.) ColorCal instrument. Responses were made on a games pad. Participants were seated 50cm away and at eye-level to the monitor, and the experimental session was conducted in a darkened room.

Stimuli and Design

Categorical perception of color was tested for across the blue-green category boundary and within- and between-category chromatic separation sizes were equated using stimuli from a standardized color space that is frequently used in studies of color-CP (the Munsell Color Order System). Four stimuli were taken from the green-blue region of the Munsell color space, with adjacent stimuli separated by 2.5 Munsell hue units, and stimuli constant in saturation (Munsell chroma = 7) and lightness (Munsell value = 8). The stimuli straddled the well established blue-green category boundary (7.5BG) and there were three stimulus pairs: within-category green; between-category; within-category blue (see Figure 3). Table 4 gives the Y, x, y co-ordinates (CIE, 1931) of the four stimuli. The colored target (diameter 30mm, visual angle 3.5°) appeared in one of 12 un-marked locations in a ring around a central fixation cross. The colored target was shown on a colored background that

filled the entire screen. For each stimulus pair, the target appeared to the left or the right of the central fixation cross for an equal number of trials. There were 16 trials for each stimulus pair, with each stimulus in the pair appearing for an equal number of trials as the target and the background. This resulted in 48 trials and these were presented in a randomised order. Before the onset of each trial, the white central fixation cross presented on a black background was shown for 1000ms, followed by the background and target. The target was shown for 250ms and the background remained until the participant had made their response.

Procedures

Participants were told that the aim of the task was to judge whether a circle appears on the left or the right of the screen. They were instructed to look at the cross in the middle of the screen and that they should press the left button if the circle appears on the left, and the right button if the circle appears on the right. They were given a practise session of 24 trials and after these trials if it was clear that the task instructions were understood, the 48 experimental trials were started. The experimental program recorded speed and accuracy of response.

Results

The mean percentage accuracy and the mean reaction time (ms) on accurate trials were calculated for within-category and between-category conditions, for children with autism and for controls. A two-way, mixed design ANOVA with an independent groups factor of Group (autism/controls) and a repeated measures factor of Category (within/between) was conducted on mean accuracy and also on mean reaction time on accurate trials.

Accuracy

Figure 4 shows the mean percentage accuracy for children with autism and for typically developing children, for within-category and between-category conditions.

INSERT FIGURE 4

As is apparent in figure 4, there was a significant main effect of Group, with less accurate target detection for children with autism [mean=62.17%, SD=13.56] than controls [mean=78.68%, SD=15.92], [$F(1,26)=8.72$, $MSE = 437.9$, $p<.01$, $\eta_p^2=0.25$]. All other main effects and interactions were not significant [largest $F=1.03$, smallest $p=0.32$]. One sample t-tests (test value = 50%) confirmed that both groups were significantly above chance: children with autism, [$t(13)=3.36$, $p<.01$]; controls, [$t(13)=6.74$, $p<.001$].

Reaction Time

Figure 5 gives the mean reaction time on correct trials for children with autism and typically developing children on within-category and between-category conditions.

INSERT FIGURE 5

There was a significant main effect of Category, with faster target detection for between-category [mean=1049ms, SD = 347] than within-category conditions [mean = 2257ms, SD = 837], [$F(1,26)=86.02$, $MSE= 237567$, $p<.001$, $\eta_p^2= 0.77$]. All other main effects and interactions were not significant [largest $F=2.39$, smallest $p=0.13$].

Accuracy / Reaction Time trade off

An ANCOVA with Group (autism / typically developing) and Category (within / between) as factors was conducted on mean percentage accuracy with reaction time as a covariate. Having reaction time as a covariate did not change the pattern of results: there was still a significant main effect of group [$F(1,25)=5.91$, $MSE = 94.5$, $p<.05$], and no other significant main effects or interactions [largest $F = .52$, smallest

$p=.48$]. An equivalent ANCOVA was conducted on reaction time with mean percentage accuracy as a covariate. Again, having mean percentage accuracy as a covariate did not change the pattern of results — there was still a significant main effect of category [$F(1,25)=86.44$, $MSE = 229090$, $p<.001$], and no other significant main effects or interactions [largest $F=.62$, smallest $p=.44$].

Discussion

Experiment 2 compared children with autism and typically developing children matched on age and non-verbal cognitive ability, in their accuracy and speed of color discrimination and the strength of categorical perception of color, using a target detection task. Children with autism were less accurate at target detection than those without autism. This lower accuracy for children with autism compared to the control group was found for both within-category and between-category targets and backgrounds. However, when children did accurately detect the colored target they were no slower than the control group in doing this. Categorical perception was not found for accuracy of target detection, but was found for speed of target detection, with faster detection of targets when presented on different- than same-category backgrounds. Both children with autism and the typically developing children showed categorical perception of color, and the strength of this category effect did not differ for the two groups of children.

The findings of Experiment 2 therefore replicate the finding in experiment 1 of less accurate color perception in those with autism compared to matched controls, and extend this finding to a task that measures chromatic discrimination more directly. The results also suggest that children with autism are not only less accurate at discriminating colors within a color category, but are also less accurate at between-category discriminations than typically developing children. That categorical

perception of color was found for the speed of target detection but not the accuracy is not unusual — CP is not always found on all measures and this pattern of CP affecting speed but not accuracy has been found previously (e.g., Franklin, Pilling & Davies, 2005). Despite the finding that children with autism have less accurate color perception than controls, these children have typical categorical perception of color. This suggests that the lack of categorical perception in children with autism, in Soulière et al.'s (2006) study of ellipse discrimination, does not generalise to the domain of color. One possible reason for this may be the difference in the nature of the categories being investigated. For example, the categories in Soulière et al.'s investigation were learnt during a classification task according to an arbitrary boundary. However, perceptual color categories, are likely to already be well learned and are more likely than Soulière et al.'s ellipse categories, to be at least partially biologically constrained. For example, color categories have universal prototypes (e.g., Regier, Kay & Cook, 2005), categorical perception of color is found in infants as young as four-months (e.g., Bornstein, Kessen & Weiskopf, 1976; Franklin & Davies, 2004; Franklin, Pilling & Davies, 2005), and an ERP study of color-CP has revealed category effects appearing as early 100-120ms on a visual oddball task (Holmes, Franklin, Clifford & Davies, 2007). Therefore, reduced categorical perception in autism may be limited to learned categories that are possibly mediated by more top-down mechanisms (Sowden & Schyns, 2006). Further research, testing for categorical perception in autism for other domains (e.g., orientation, Quinn, 2004) is needed to establish when categorization is atypical in autism. Gaining a better understanding of this may lead to a greater understanding of the activation and interaction of different levels of processing in autism.

General Discussion

On visual search, memory (Experiment 1) and target detection tasks (Experiment 2) children with autism were less accurate than typically developing children at detecting the differences between colors. The difference between high functioning children with autism and typically developing children in accuracy of color perception appears to be robust. For example, the effect is found on three different tasks tapping three different perceptual processes (color search, color memory, chromatic edge detection), in various areas of the color space (red, green, yellow in Experiment 1 and blue-green in Experiment 2), and when color varies along all three colorimetric dimensions (hue, lightness and saturation combined in Experiment 1) or when color varies just in hue (Experiment 2). Despite less accurate color perception, the strength of categorical influences on color perception does not appear to be atypical in autism and children with autism show categorical perception across the blue-green boundary to the same extent as the control group.

These findings of less accurate color perception appear to be at odds with anecdotal evidence of strong color obsessions in children with autism (e.g., Moore, 2004), and the suggestion that children with autism have advanced color naming (Schafer & Williams, 2007). However, there could be other potential explanations for why children with autism may have strong color obsessions or advanced color naming, which are based on social or conceptual rather than perceptual accounts. The findings also do not support the hypothesis that enhanced color perception can account for the color facilitation effect on a negative priming task for children with autism but not controls (Brian et al., 2005), and the greater cost of invalid color cues for those with autism than controls (Greenaway & Plaisted's 2005). Studies that explore more complex aspects of attention to color are needed to further investigate

the cause of these effects. The current experiments also do not provide evidence that ‘enhanced perceptual functioning’ or ‘reduced categorization’ in autism extends to the domain of color. This suggests that these phenomena may apply selectively to certain perceptual domains but not others.

So why do children with autism appear to be less accurate at color memory, search and chromatic target detection than controls? One potential explanation is that the difference arises from differences in the anatomical and functional organization of the brain in autism. How the human brain processes color is not fully understood and the precise areas that are involved are controversial (Engel & Fries, 2001). However, a generally accepted basic account of color processing holds that color vision starts in the retina, where activation of cones with photopigments sensitive to short (S), medium (M) and long (L) wavelengths of light leads to two opponent processes — a red-green axis (L-M) and a blue-yellow axis (S-(L+M)) (e.g., De Valois & De Valois, 1975). Then, in essence, Parvocellular and Koniocellular cells in the Lateral Geniculate Nucleus code for chromaticity, and Magnocellular cells for luminance, giving different pathways to the visual cortex (e.g., Lee, Pokorny, Smith, Martin, Valberg, 1990; Livingstone & Hubel, 1998, although see also Schiller & Logothetis 1990). Various areas of the visual cortex have been implicated in color vision, and color-selective neurons have been found in areas V1 and V2 (e.g., Livingstone & Hubel, 1984), V4 (e.g., Zeki, Watson, Lueck, Friston, Kennard & Frackowiak, 1991) / V8 (Hadjikhani, Liu, Dale, Cavanagh, Tootell, 1998). Following this, a network of many different brain areas is thought to be involved (e.g., Gulyas & Roland, 1994), mainly in the ventral occipito-temporal cortex (e.g., Beauchamp, Harby, Jennings & De Yoe, 1999), although some have argued that there is also some dorsal activation (Claeys, Duport, Comette, Suaert, Heche, De Schutter & Orban,

2004). The pattern of results in the current study could arise from disruption to any one or more of these different biological and neurological processes. Further studies are needed to explore this. For example, a threshold discrimination task that measured just-noticeable differences using stimuli along blue-yellow and red-green cone excitation axes could indicate whether there are differences in one or both of the opponent processes for children with autism and typically developing children. Event-related potential studies may give an indication of whether there are any differences in the time course of color processing which may help to indicate the stage(s) at which color processing is disrupted. Likewise, fMRI studies of color processing in autism could highlight any differences in the pattern of neural activation involved in color processing. However, there could be explanations for the pattern of results in the current study other than a biological account. For example, less accurate color perception could arise from various conceptual, social or cultural factors (such as a restricted use of color in educational contexts). Therefore, further research which investigates the broader context of color for those with autism is also needed to explore these alternative accounts.

In conclusion, two experiments provide converging evidence that children with autism are less accurate at color perception than controls matched on age and non-verbal cognitive ability. This effect appears to be robust — it is found on three tasks that tap different aspects of color perception and it is found for various regions of the color space. Despite differences in accuracy of color perception, categorical perception of color appears to be intact in autism, with an equivalent amount of color categorization in children with autism compared to the controls. It is clear that there is a long way to go to fully understand the perception and cognition of color in

children with autism. Nevertheless this study represents an important first step to understanding how these children interact with and perceive the world of color.

Author Note

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Table 1. Chronological Age and Raven's Matrices raw scores for both samples, Experiment 1.

	Age			Ravens		
	Mean	SD	Range	Mean	SD	Range
Autistic (N=19)	10.9	1.7	7-13	29.5	5.9	15-36
Control (N=14)	9.8	2.2	7-13	29.7	4.2	19-35

Table 2. Y,x,y and L*a*b* co-ordinates of stimuli.

	Y	x	y	L*	a*	b*
Yellow1	128	0.46	0.46	82.35	0	76.71
Yellow2	148	0.46	0.48	87.23	-6.32	85.86
Red1	28.5	0.55	0.31	43.61	55.20	25.18
Red2	26.4	0.53	0.28	42.11	58.78	12.01
Green1	32.4	0.21	0.45	46.22	-59.18	10.82
Green2	34.1	0.19	0.39	47.29	-57.58	-1.26

Table 3. Chronological Age and Raven's Matrices raw scores for both samples, Experiment 2.

	Age			Ravens		
	Mean	SD	Range	Mean	SD	Range
Autistic (N=14)	11.93	0.73	11-13	36.29	7.91	14-45
Control (N=14)	12.29	0.47	12 -13	33.86	6.06	18-42

Table 4. Munsell codes, Y,x,y (CIE, 1931) and L*u*v* (CIE, 1976) co-ordinates of stimuli. White of monitor: Y=60.26, x=0.327, y=0.339.

Munsell Code	Y	x	y	L*	u*	v*
1.25B 7/8	25.95	0.222	0.294	71.60	-53.96	-37.94
8.75BG 7/8	25.95	0.226	0.310	71.60	-55.57	-28.44
6.25BG 7/8	25.95	0.232	0.326	71.60	-55.85	-19.22
3.75BG 7/8	25.95	0.240	0.342	71.60	-54.92	-10.24

Figure Captions

Figure 1. Examples of form stimulus pairs.

Figure 2. Percentage Accuracy (± 1 se) combined for visual search and delayed matching-to-sample tasks, on color and form discrimination for children with autism and typically developing children.

Figure 3. Between-category and within-category blue / green stimulus pairs. Stimulus pairs are separated by 2.5 Munsell hue units and all stimuli are at constant saturation and lightness (munsell chroma = 7, munsell value = 8). The dashed line indicates the category boundary.

Figure 4. Percentage accuracy (± 1 se) of target detection on within- and between-category trials, for children with autism and typically developing children

Figure 5. Reaction time (ms, ± 1 se) for accurate target detection on within- and between-category trials, for children with autism and typically developing children.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.