# The possible use of precision tinted lenses to improve social cognition in children with Autism Spectrum Disorders

Running head: Coloured Lenses and ASD

Ludlow, A.K.[a], Giannadou, A.[b], Franklin, A.[c], Allen, P.M.[d], Simmons, D.R.[e], Wilkins, A.J.[f]

[a]University of Hertfordshire, School of Psychology and Sports Sciences, College Lane, Hatfield, AL10 9AB

[b]University of Sheffield, Department of Psychology, 1 Vicar Lane, Sheffield S1 1HD e-mail: agiannadou1@sheffield.ac.uk

[c]University of Sussex, School of Psychology, Falmer, BN1 9QH e-mail: Anna.Franklin@sussex.ac.uk

[d] Anglia Ruskin University, Department of Vision and Hearing Sciences & Vision and Eye Research Unit, Cambridgeshire CB1 1PT email: peter.allen@anglia.ac.uk

[e]University of Glasgow, School of Psychology, 62 Hillhead Street, Glasgow G12 8QB e-mail: David.Simmons@glasgow.ac.uk

[f]University of Essex, Department of Psychology, Wivenhoe Park, Colchester CO4 3SQ e-mail: arnold@essex.ac.uk

Corresponding Author: Prof A Wilkins

University of Essex

Wivenhoe Park

Colchester, Essex

CO4 3SQ

UK

Arnold@essex.ac.uk

**Abstract**

A masked randomised control design compared the effectiveness of precision ophthalmic tints in improving the recognition of emotion in Autism Spectrum Disorders (ASD). Fourteen children aged 10-14 with ASD and 14 control children matched on verbal and non-verbal IQ, wore spectacles with coloured lenses to complete two tasks that involved the observation of coloured video sequences in which social interactions were depicted. On one occasion (randomly first or second) the coloured lenses provided light of a colour that the child had one month previously selected as optimal for the clarity of text. On the other occasion the lenses differed in CIE UCS chromaticity by 0.07. Performance in the ASD group was superior in both social interaction tasks with the lenses that provided the optimal colour of light.

Key words: Sensory disturbances; Emotion; ASD; Coloured lenses; Visual discomfort

## Introduction

Abnormalities in visual processing are amongst one of the most frequently reported sensory symptoms in children with Autism Spectrum Disorders (ASD, Mottron et al., 2007), and include experiences of visual distortion (Attwood, 1994; White & White, 1987), and hyper-sensitivity to lights and colors (Myles, Cook, Miller, Rinner, & Robbins, 2000; Olney, 2000). Children with ASD are four times more likely to read more quickly with an individually chosen coloured overlay than age- and intelligence-matched peers (Ludlow, Wilkins & Heaton, 2006, 2008). It is possible that discomfort from sensory stimuli impairs performance on a wide range of perceptual tasks, including those responsible for social skills such as the recognition of emotion. The main aim of the current study was to investigate whether using coloured lenses can improve the recognition of emotion by children with ASD.

Atypical visual processing has been widely reported in individuals with ASD (e.g. Latham, Chung, Allen, Tavassoli & Baron-Cohen, 2013; see Simmons et al., 2009, for a review), and atypical visual function has been identified as one of the earliest and most stable markers of ASD. For example, the duration of saccades at seven months has been shown to distinguish children receiving a later diagnosis of ASD (Wass et al., 2015). Others have reported atypical visual-perceptual behaviour on a range of tasks such as motion discrimination (see Dakin & Frith, 2005 for a review), colour perception (Franklin et al., 2008), depth perception (Kaplan, 2006), and visual completion tasks (De Wit, Schlooz, Hulstijn, & van Lier, 2007).

Unusual perceptual processing has also been reported in response to a range of social stimuli (Mottron et al., 2007). For example, children with ASD make less frequent and atypically timed eye contact compared to those without, and have difficulties in sustaining joint attention with people (Dawson, Osterling, Meltzoff & Kuhl, 2000). They are also reported as having difficulty orienting to faces and in discriminating them, and show diminished fixations on the eyes during tasks such as face recognition (Harms, Martin & Wallace 2010; Senju & Johnson, 2009; Tanaka & Sung, 2016). These deficits have been found to extend to dynamic stimuli such as images of people interacting, or people expressing emotion in various ways (including vocal and nonverbal communication) (Smith, Montagne, Perrett, Gill & Gallaher, 2010; Pelphrey, Morris, McCarthy & Labar, 2007).

Atypical visual processing has also been thought to contribute to the social difficulties experienced by individuals with ASD. For example, the frequency of lateral glances and visual hypo-responsivity predicts poorer social skills and greater overall ASD symptomology (Hellendoorn et al., 2014; Kern et al., 2007). Furthermore, children with the atypical visual function described above have been identified as having more social deficits due to difficulties in social learning from visual cues (Farran & McGaha, 2001).

Many of the perceptual atypicalities reported in ASD are reminiscent of those referred to in other literature as visual stress (Wilkins 1995, 2003; Robertson & Simmons, 2015). Visual stress here refers to visual discomfort and perceptual distortion most notably when viewing spatially repetitive material such as text and can include symptoms such as blurring or apparent movement, or colours around letters (Wilkins

& Nimmo-Smith, 1984). Although visual stress has been noted in individuals with ASD when reading (Ludlow et al., 2006; 2014), both the existence and definition of visual stress has been heavily debated. It is not yet clear how the perceptual behaviours reported in ASD would be accounted for in non-text-based stimuli, although the prevalence of stressful visual stimuli in the modern urban environment has been noted (Wilkins et al 2018). Some have argued that the visual abnormalities should be considered as visual sensory behaviours characterised by hypersensitivity to environmental stimuli (Ludlow & Wilkins, 2014). For those individuals who experience either high levels of visual stress and/or visual sensory disturbances, perceptual distortions have been found to be reduced with the use of a transparent coloured overlay (Wilkins, 2003).

The Intuitive Coloured Overlays are sheets of coloured plastic that were designed to be placed over text when reading. They sample chromaticities systematically and comprehensively so that if there is any colour that might benefit reading, there is an overlay or combination of overlays available that provides a close approximation to this colour (Wilkins et al., 1994). In children with ASD, it has been shown that reading speed is increased when using overlays chosen individually to increase the clarity of the text. The increase in reading speed was considerably greater than in controls matched for age and verbal intelligence (Ludlow et al., 2006). More general improvements in perceptual function have subsequently been found: visual search and matching to sample both improve with an overlay (Ludlow et al., 2008).

More recently, overlays have been shown to have beneficial effects on social perception. For example, the use of a coloured overlay improves the classification of facial expressions on a paper version of the test, “Reading the Mind in the Eyes” by Baron-Cohen, Jolliffe, Mortimore, & Robertson (1997), see Ludlow, Taylor-Whiffen & Wilkins (2012). Similar findings in typically developing children have also been reported (Whiting & Robinson, 2001). In a recent study the findings have been confirmed using two-alternative forced choice psychophysics. In a computerised task, two faces were presented in monochrome photos and participants asked to choose which of the two showed the stronger emotion, a task requiring integration of all facial features. In individuals with ASD, faces were recognised more accurately when the screen was tinted with a colour chosen earlier as improving the clarity of text (Whitaker, Jones, Wilkins & Roberson, 2014). The above findings highlight a link between the use of coloured light and the perception of social stimuli.

The current study addressed whether spectacles with coloured lenses would improve the understanding of social interactions by children with ASD.  We used videos of everyday social exchanges and required participants to observe the videos and decide on the emotion each conveyed. Precision tints were selected using the Intuitive Colorimeter, a simple optical instrument that illuminates a page of text with coloured light and permits the hue and saturation of the colour to be varied independently and continuously at a constant luminance. The colour chosen as improving clarity was optimised while the eyes were colour adapted. Tinted lenses that reproduced that colour under conventional white lighting were provided at least one month after the initial assessment.

To address the children’s understanding of social interactions, we used the Awareness of Social Inference Test (TASIT) (McDonald et al., 2003). The TASIT requires participants to integrate a range of social cues from the face, prosody, gesture and social context in order to identify emotions, beliefs and intentions, using short films of adults engaged in conversational encounters based on everyday situations. The first part of the TASIT assesses the recognition of spontaneous emotional expression of seven different emotions (happy, surprised, neutral, sad, angry, fear and disgust). The second part assesses an individual's ability to interpret naturalistic social interactions containing sincerity, "simple sarcasm" when the social exchange would be meaningful whether or not the sarcasm was understood, and "paradoxical sarcasm" in which the meaning of the exchange can only be understood by appreciating the sarcasm. Studies using the TASIT demonstrate impaired perception of sarcasm in ASD (Mathersul et al., 2013).

We first hypothesised that the children with ASD would have more difficulty than controls at recognising both basic and more complex emotions (Emotion Evaluation Test (EET) and the Social Inference-Minimal Test (SI-M) from the TASIT) (McDonald et al., 2003). We predicted that children with and without ASD who showed higher levels of visual sensory disturbances would show the greatest improvements with the colour filters, but that the improvements would not occur if the colour differed from that chosen for clarity.

## Methods

*Participants*

Fourteen children with Autism Spectrum Disorders (mean age 12.4. SD 1.46); were recruited from two mainstream schools. Prior diagnosis of ASD was provided by both the parents and the school records and was independently confirmed by assessment with the ADOS-2 (Lord et al., 2015). Four of the children also had an additional diagnosis of Attention Deficit Hyperactivity Disorder (ADHD). The ASD group was compared with a control group of typically developing children (TD) from the same schools. None of the control group had any known clinical diagnosis, and they were selected from the same year groups as the children with ASD. The control group were matched to the ASD children on non-verbal IQ (Raven Matrices, Raven, Raven & Court, 1998) and verbal-IQ British Picture Vocabulary Scale (Dunn & Dunn, 2009). All participants had normal or corrected to normal vision (6/6 vision in both eyes as measured using a Snellen chart at 6m). Colour vision was assessed using the City University Colour Vision Test (3rd edition; Fletcher, 1998). All children had normal colour vision. To assess sensory reactivity, parents of all children completed the Sensory Profile (Dunn, 1999). Table 1 summarises the characteristics of the participants.

INSERT TABLE 1 ABOUT HERE

*Materials*

Children were examined using an Intuitive Colorimeter Mark 2 (Cerium Visual Technologies, Tenterden, Kent), an apparatus that allowed the independent control of hue (colour) and saturation (depth of colour) without any associated change in luminance (Wilkins, & Sihra, 2000). The examination procedure (Wilkins, 1993) allows for colour adaptation and obtains a colour suitable for reducing visual stress, when present.

Emotion recognition was measured using the *Emotion Evaluation Test* (EET) and the *Social Inference-Minimal Test* (SI-M)(Parts 1 and 2) of the awareness of social inference test (*TASIT*). The *EET* included 28 short vignettes (15-60 seconds) presented as movies on a laptop computer showing professional actors portraying seven different emotional expressions (happy, surprised, sad, angry, anxious, disgusted and neutral) while enacting a neutral script of everyday situations. The neutral expression was included but was not analysed. Each emotion was shown four times, making a total of 28 presentations, of which 24 were analysed. In some scenes, there is only one actor talking, either on the telephone or directly to the camera. In other scenes, where there were two actors, instructions were given to the children as to which person to focus on. Participants were required to select which of the seven emotions was shown for each script. Cue cards were used to show the options of the different emotions available. The scores were added together giving a maximum total score of 24 and a chance total score of 1/7*24= 3.4 (because the neutral was included in the presentation but not analysed).

The *Social Inference-Minimal Test (SI-M)* comprises 15 short (15-60 seconds) vignettes that contain dialogues between two trained actors, conveying either a sincere or sarcastic exchange. It requires the viewer to detect the sarcastic inference based on the demeanour of the actors, such as their tone of voice, facial expression or gestures. In the sincere verbal exchanges (five vignettes) the targeted speakers mean what they are saying, i.e. the words spoken, and the paralinguistic cues are consistent, thus no irony is implied, and the verbal content accurately signifies the speaker’s intended meaning. In the simple sarcasm exchanges (five vignettes), one of the actors is being sarcastic (the literal meaning is contrary to the actual spoken message) but this can only be determined by reading the paralinguistic cues, such as facial expression, voice prosody and hand and body posture. The content of the verbal script for both the sincere exchange and simple sarcasm exchange could be similar, such that “I’d be happy to do it. I’ve got plenty of time” could be an example script for either. However, only in the sincere exchange does the speaker say what they mean. In the paradoxical sarcasm exchange (five vignettes), the dialogue between the two actors can only be understood if one of them is identified as being sarcastic.

The vignettes of actors making sincere, sarcastic or paradoxically sarcastic statements were shown to participants, who were aware that they would subsequently be asked to endorse or reject a series of statements about what a specific actor was doing, saying, thinking, and feeling. The answers determine whether the viewer understood the meaning and intentions of the exchange. For example, based on what the actor was doing the participant might be asked ‘Is Ruth trying to make Gary feel OK about cancelling,’ or ‘Is he trying to say that she looks OK? Each vignette was scored for correctly identifying what the actor was doing, saying, thinking or feeling, requiring a YES/NO answer for each, a maximum of 4 marks per vignette, and a maximum of 60 marks for all 15 vignettes. The chance score was therefore 30.

*Procedure*

The study involved a *Masked Procedure.* With the use of the Intuitive Colorimeter children were individually assessed for precision tinted lenses.  The clarity and visual comfort of text illuminated by coloured light was determined as follows. Twelve different hues were presented and those hues that improved the clarity of the text were short-listed. Those in the shortlist were then compared. The best overall was chosen and optimised by small alternate changes in hue and saturation, so as to keep the eyes colour-adapted. Spectral filters that provided that colour under conventional white lighting (fluorescent, CIE type F3) were provided for the subsequent testing at least one month later. Neither the children nor their examiner viewed the colour of the matching lenses at the time of colorimetry. The chromaticities are shown as unfilled points in Figure 1.

INSERT FIGURE 1 ABOUT HERE

Placebo (control) filters were created by providing a chromaticity that differed by a given CIE 1976 UCS chromaticity from the lenses chosen for clarity. A computer algorithm calculated the difference between the selected chromaticity and the chromaticity of the white light in the colorimeter (0.237, 0.512) i.e. the saturation ($s_{uv}$). The two chromaticities that lay the same distance from the white point and differed from the selected chromaticity by 0.077, were calculated and one of these (the one that provided a good match in transmission) was chosen as the control. A chromaticity difference of 0.07 is sufficient to remove any beneficial effect on reading (Aldrich et al., 2018). The combination of tinted trial lenses that provided the closest approximation to this control was then selected. The chromaticities of the controls are connected by a line to the chromaticities of the "active" (chosen) chromaticities, in Figure 1.

Ultimately, once matched with trial lenses the average separation of the chromaticites of the chosen and control tints was 0.093 (SD 0.021). The transmissions of the tints were closely matched to within 2.3% overall and to within an average of 9.7% individually. One TD individual chose a yellow tint that was matched to a grey (0.21,0.47); otherwise chosen and control tints were of similar saturation. The average u' and v' values provide a measure of the centre of the distribution of chromaticities. For the active lenses the average u' and v' values were respectively 0.205 (SD 0.059) and 0.431 (SD 0.041) for the ASD group and 0.203 (SD 0.063) and 0.453 (SD0.041) for the control group. The difference between the groups did not approach significance ($p$>.17). The average u' and v' values for the control lenses were respectively 0.214 (SD 0.060) and 0.463 (SD 0.063) for the ASD group and 0.206 (SD 0.033) and 0.446 (SD 0.060) for the typically developing group. Again, the difference between the groups did not approach significance ($p$>.46).

The same researcher carried out all testing, but she was provided with the two differently coloured lenses by an independent researcher who did not identify which was active and which was the placebo. The interval of one month between the two assessments meant that the researcher did not remember the colorimeter settings on which the lenses were based. It is unlikely that the children could identify the active and placebo tints because it is usually the case that observers are surprised by the colour appearance of the lenses that provide the chromaticity of light they have chosen in the colorimeter, owing to adaptation to the coloured light (Wilkins, et al., 1993). This adaptation and the one-month interval militate against experimenter or participants recognising the chosen colour on the basis of its appearance. At the time of testing the children were not informed that any of the lenses provided a colour of light they had previously chosen.

Both the EET and SI-M have two different versions of the task (A and B), which provided the opportunity to use one version of the task with the chosen colour filter and the other one with the placebo colour. The order in which the children completed A and B was randomised for both tasks, as was the order in which the children received the chosen tint, and the researcher selected the order of the two selected colour tints not knowing which was the chosen or placebo tint.

All the participants completed the EET first and were tested individually in a room at their school. It was first explained to the participant that he or she would be shown a video of some people interacting and that he or she would be asked questions about these interactions. The video was in colour and presented on the computer screen. Practice items preceded each section to familiarize the participant with the task requirements. The video was then paused after each vignette, and the participant was asked to respond to questions concerning the content of the video. The children completed both parts A and B, one with each of the tints, with a small 5-minute break in between. The SI-M was carried out using the same procedure as the EET and using similar instructions. There was at least a week between participants undertaking the EET and SI-M.

All procedures were in accordance with the ethical standards of the 1964 Helsinki declaration and its later amendments. Informed consent was obtained from all individual participants included in the study. Ethical approval was granted for the study by the University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee.

## Results

*The Emotion Evaluation Test (EET).*

A repeated measures analysis of variance with a 2 (Group: ASD vs.TD, between participants) x 2 (Tint: Placebo vs. chosen colour, within participants), was carried out for total scores of the TASIT 1. This analysis revealed a non-significant main effect of group, *F* (1, 26) = .57, *MSE*= 8.64, *p*= .46, $\eta^2$= .022, as well as a significant effect of tint, *F* (1, 26) = 9.16, *MSE*= 31.05, *p*= .006, $\eta^2$=.32. A significant Group x tints interaction was also present, *F* (1, 26) = 11.97, *MSE*= 41.14, *p*= .002, *η2*=.26. Analysis of this interaction revealed the ASD children showed better overall performance with their chosen colour tint compared to placebo, *t* (13) = 4.96, $p < .001$ (Bonferroni adjustment *p*= .012), whereas there was no significant difference found in performance of the TD children using the two different tints, *t* (13) = .29, *p* = .78. This is shown in Figure 2.

INSERT FIGURE 2 ABOUT HERE

A repeated measures analysis of variance with a 2 (Group: ASD vs. TD, between-participant factor) x 6 (Emotions: Happy, Surprised, Sad, Angry, Revolted, Anxious, within-participants factor) x 2 (Tint: Placebo vs. chosen colour, within-participants factor) design revealed a non-significant main effect of Group, *F* (1, 26) = .27, *MSE*=.50, *p* = .61, $\eta^2$= .02. However, there was a significant main effect of Tint, *F* (1, 26) = 9.66, *MSE* = 6.57, *p* = .005, $\eta^2$= .27, with better performance overall with a chosen colour tint compared to a placebo tint $M_{Chosen\ tint}$= 21.53, *SD*= 3.13; $M_{Chosen\ tint}$= 20.04, *SD*= 3.14). As well as a significant main effect of Emotion, *F*(5, 130)=9.05, *MSE*=6.17, $p < .001$, $\eta^2$=.26; Happy (*M* = 5.23, *SD* = .58) and Surprised (*M*=4.89, *SD*= .87) were recognised better than the other emotions (Sad *M* =4.18, *SD*=1.13; Angry *M*=4.04, *SD*=1.04; Revolted *M* = 4.21, *SD* = 1.46, Anxious *M*=3.87, *SD* = 1.18)( all $t < 4.49$ and all $p < .001$).

Importantly, the Group x Tint interaction was the only one reaching significance, *F* (1, 26) = 5.36, MSE=3.65, *p*=.03, $\eta^2$=.17 (all other $F < 1.76$, all other $p > .13$). Analysis of this interaction with Bonferroni corrections (adjusted correction = .012) revealed that typically developing children performed in a similar manner with the placebo tint (TD $M_{Placebotint}$= 21.28, *SD*= 2.61) and the chosen tint ( TD $M_{Chosen\ tint}$= 21.07, *SD*= 3.02, *t*(13)=.29, *p*=.78), whereas ASD children performed significantly worse with the placebo tint (ASD $M_{Placebo\ tint}$= 18.78, *SD*= 3.21) than with the chosen tint (ASD $M_{Chosen\ tint}$= 22.00, *SD*= 3.28, *t*(13)=4.96, *p*<.001).

There were significantly more children with ASD (11/14) than TD (5/14), whose performance improved by more than 5% with their chosen coloured filters than the placebo filters, $\chi^2$ = 5.85; *df*=1, *p* = .02, and the magnitude of improvement for these individuals was higher for the ASD group (ASD: *M* =14.61% *SD* =6.86, TD: *M* =9.28% *SD* =1.95).

*Social Inference-Minimal Test (SI-M)*

A total score was calculated by adding the scores across the three subscales (Sincere, Simple, and Paradoxical Sarcasm) with both categories of tinted lenses. Figure 3 shows scores averaged across the three sarcasm conditions for the ASD and control groups for chosen and placebo tints.

INSERT FIGURE 3 ABOUT HERE

A repeated measures analysis of variance with a 2 (Group: ASD vs. TD, between participants) x 2 (coloured tints, within participants) x 3 (type of sarcasm: simple, sincere and paradoxical, within-participants), revealed non-significant main effects of Group, *F* (1, 24) = .02, *MSE*= 31.64, *p*= .89, $\eta^2$=.01, Tint, *F* (1, 24) = .3.09, *MSE*= 9.03, *p*= .09, $\eta^2$=.11, or Sarcasm, *F* (2, 48) = 3.20, *MSE*= 17.23, *p*= .05, $\eta^2$=.12.

Once more, the Group x Tint interaction was the only one reaching significance, $F$ (1, 24) = 6.01, $MSE$= 9.03, $p$=.02, $\eta^2$=.20, (all other $F$<1.18, all other $p$>.32). As with the previous analysis and similar Bonferroni adjustment ($p$<.012), the control group perform at similar levels with the placebo tint (TD $M_{placebo\ tint}$ = 45.15, $SD$ = 6.31) and the chosen tint (TD $M_{chosen\ tint}$ =43.46, $SD$= 9.73, $t$ (13) = .79, $p$ = .44), whereas the ASD group performed worse with the placebo tint (ASD $M_{Placebo\ tint}$= 41.84, $SD$ = 7.20) than using the chosen tint (ASD $M_{chosen\ tint}$= 46.53, SD= 6.69, , $t$ (13) = 2.89, $p$ = .01). This is illustrated in Figure 3.

There was no significant difference in the number of ASD children (9) compared to typically developing children (5), who showed more than 5% improvement with their chosen filters $\chi 2$ = 3.59; $df$=1, $p$ = .05, although the magnitude of improvement was greater for the ASD group (ASD: $M$= 26.07% $SD$ =12.14, TD $M$= 16.42% $SD$ =8.60).

*Predictors of Performance with chosen and placebo tints*

Pearson correlations were carried out to test the relationships between the four different sensory quadrants of the sensory profile (Dunn et al., 2009), and the performance with the two filters for each group. Only sensory seeking had a significant relationship with performance for the emotion evaluation test. For the ASD group those higher on sensory seeking showed poorer performance both with the chosen ($r$ =-.72, $p$ = .01) and placebo ($r$ = -.61, $p$ = .04) filter for the Emotion Evaluation Test. For the TD children this was only significant for the placebo condition ($r$ =-.62, $p$ = .02). There were no other significant correlations between the other three sensory measures (Sensory avoidance, low registration and sensory sensitivity and performance with and without the chosen tint: $r$ < .04, $p$ <.77). Furthermore, for the Social Inference-Minimal Test, none of the sensory measures was found to correlate with performance in identifying sarcasm with the chosen and placebo tint for either group ($r < .04$, $p < .77$).

## Discussion

The current study aimed to establish whether coloured filters would improve the recognition of emotion by individuals with ASD. Emotion recognition was measured with two tasks (Emotion Evaluation Test and the Social Inference-Minimal Test; McDonald et al., 2003). The performance of those with ASD and controls was assessed while wearing spectacles with coloured lenses. The lenses provided light of a chromaticity that had earlier been chosen to improve clarity of text or lenses that differed in colour (placebo tint). Whilst the ASD group's emotion recognition was poorer than the controls when wearing the placebo glasses, performance improved to match the controls when wearing lenses providing light of a similar colour as chosen to reduce visual distortions of text.

Coloured filters have previously been demonstrated to improve reading speed, (Ludlow, Wilkins & Heaton, 2006), visual matching to sample (Ludlow, Wilkins & Heaton, 2008), and to enhance recognition of facial emotions in children with ASD (Ludlow et al., 2012, Whitaker et al., 2016). A single case study (Ludlow & Wilkins, 2009) has also shown the possible benefits of precision ophthalmic tints. The present study is the first to use a double masked design to compare precision with control tints in a task known to address social perception of emotion, as identified by children's ability to understand and respond to different social situations (McDonald et al., 2003).

Based on previous research, the first hypothesis of the study was that children with ASD would show deficits in the recognition of emotion compared to control children. As expected, children with ASD performed significantly more poorly than control children when wearing the placebo tint, and this was despite the children with ASD being compared to a younger group of typically developing children. This is consistent with previous research showing that when deficits in emotion recognition are reported in ASD, they are often found with a brief or more-subtle presentation of the emotional stimuli (Rump, Giovannelli, Minshew, & Strauss, 2009). However, no significant differences were found between groups in identifying sarcasm and sincerity. Here, it is possible that children with ASD were aided by the inclusion of auditory cues, as it has been shown that young children initially depend more heavily on intonation than on context when recognizing sarcasm (Capelli, Nakagawa, Madden, 1990).

While we were careful to ensure the experimenter did not know the correct tint, it is not clear whether the children were aware of their chosen colour. The children were not shown the colour of lens that matched the colour of light in the colorimeter, neither were they informed that the tints tested included the colour chosen one month earlier. Performance at remembering the colour of lighting has previously been shown to be poor (D'ath, Thomson & Wilkins, 2006). Individuals are often surprised by the appearance of the colour of the lens that provides the colour of light they have chosen in the Intuitive Colorimeter because of the strong saturation (Wilkins et al., 1992). No relationship has been found between the colour overlay chosen for improving clarity of text and the children's colour likes and dislikes (Ludlow et al., 2008).

The present findings support the proposition that some of the sensory problems experienced by children with ASD are similar to those that have been termed visual stress, and attributed to a cortical hyperexcitability (Ludlow et al., 2016). The cortical hyperexcitability theory (Wilkins, 2003) suggests that different colors can cause a shift in the major locus of activation away from hyper-excitable areas of the visual cortex to areas that are less hyper-excitable (Huang et al., 2011; Coutts, Cooper, Elwell & Wilkins, 2012). It has also been suggested that sensory hypersensitivity in autism is related to cortical hyper-excitability (Green et al., 2015). The individual's cue for optimal choice of colour is his/her perception of a decrease in visual distortion when using the specific colour chosen (Evans, 2005; Ludlow et al., 2006; Wilkins, 2003). Supporting evidence for the cortical hyperexcitability account comes from neuroimaging studies showing a normalisation of cortical hyperexcitability in patients with migraine with the use of precision ophthalmic tints (e.g Huang, Zong, Wilkins, Jenkins, Bozoki, & Cao, 2011), and evidence of cortical hyperexcitablity in autism (Takarae & Sweeney, 2017). While the effect of tints on neural responses in ASD has yet to be established, this will be pivotal for future studies in addressing whether reducing over-activation in visual areas, stabilises perception and enhances the ability to process faces (Haigh, 2018).

**Implications**

Further research is required before it is known whether precision tints are a worthwhile and long-lasting clinical intervention. Not all the children with ASD benefited, and improvement was also noted in a small proportion of typically developing children. Therefore, it is possible that it is those individuals with higher levels of sensory disturbances who will show improvements with the use of a colour tint (Ludlow &

Wilkins, 2016). In the current study, both the ASD and controls who showed higher sensory seeking behaviours (e.g. have difficulty sitting still, enjoys strong odours), also showed the poorest performance on the emotion recognition task. It is possible that children who score high in sensory seeking may report higher levels of visual discomfort in their environment, and a chosen colour tint may alleviate sensory disturbances that are uncomfortable. In previous literature, children with autism who score high in sensory seeking behaviours have been shown to actively choose a pleasurable stimulus to focus on because it is judged as more comfortable and calming (Gillingham, 2000), and helped to avoid more disturbing input (Liss, Saulnier, Fein, & Kinsbourne, 2006).

The findings suggested sensory difficulties in children with ASD may be remediated with the use of a colour tint. Our study extends the evidence of the benefit from these chosen colours in tasks other than reading and may have ramifications in helping some children to improve in their recognition of social stimuli. The relationship between sensory behaviours and visual stress need to be further established to identify which group of children with ASD will show the greatest benefit from the use of a coloured tint.

**Acknowledgements**: The authors thank the participants.

**Funding:** This project was funded by a grant from Action Medical Research and the Baily Thomas Charitable Fund. Ref: GN2047 "Diagnosis and treatment of visual and visuoperceptual anomalies in autism spectrum conditions".

**Conflict of Interest**: The Intuitive Overlays and Intuitive Colorimeter were designed by AJW when he was employed by the British Medical Research Council. The MRC own the rights. AJW received an “Award to Inventors” from the MRC, based on royalties on sales of Intuitive Overlays and the Intuitive Colorimeter. This award for overlays has now lapsed, and an Intuitive Colorimeter was not purchased for this study. All other authors declare no conflict of interest.

**References**

Aldrich, A., Lovell-patel, R., Allen, P., and Wilkins, A. J. (2018) The repeatability of colorimetry is precise(ly) as expected.," *Neuro-ophthalmology Vis. Sci.*, vol. 3, no. April, pp. 1–6, 2018.

Attwood, T. (2006). *Asperger's Syndrome: A guide parents and practitioners*. London: Jessica Kingsley.

Baron-Cohen, S. Jolliffe, T. Mortimore, C. and Robertson, M. (1997). Another advanced test of theory of mind: evidence from very high functioning adults with autism or Asperger Syndrome. *Journal of Child Psychology and Psychiatry* 38, 813-822.

Capelli, C. A., Nakagawa, N., & Madden, C. M. (1990). How children understand sarcasm: The role of context and intonation. *Child Development*, 61(6), 1824-1841.doi.org/10.1111/j.1467-8624.1990.tb03568.x

Coutts, L. V., Cooper, C. E., Elwell, C. E., & Wilkins, A. J. (2012). Time course of the haemodynamic response to visual stimulation in migraine, measured using near-infrared spectroscopy. *Cephalalgia*, *32*(8), 621-629. doi.org/10.1177/0333102412444474.

D'Ath, P. J., David Thomson, W., & Wilkins, A. J. (2007). Memory for the color of non-monochromatic lights. Color Research & Application, 32(1), 11-15.

Dakin, S., & Frith, U. (2005). Vagaries of visual perception in autism. *Neuron*, 48(3), 497-507. doi.org/10.1016/j.neuron.2005.10.018.

Dawson, G., Osterling, J., Meltzoff, A. N., & Kuhl, P. (2000). Case study of the development of an infant with autism from birth to two years of age. *Journal of Applied Developmental Psychology*, 21(3), 299-313. doi.org/10.1016/S0193-3973(99)00042-8.

De Wit, T. C., Schlooz, W. A., Hulstijn, W., & Van Lier, R. (2007). Visual completion and complexity of visual shape in children with pervasive developmental disorder. *European child & adolescent psychiatry, 16*(3), 168-177. doi.org/10.1007/s00787-006-0585-9.

Dunn, L. M., & Dunn, D. M. (2009). The British picture vocabulary scale. GL Assessment Limited, Brentford.

Evans, B. J. (2005). The need for optometric investigation in suspected Meares–Irlen syndrome or visual stress. *Ophthalmic and Physiological Optics*, 25(4), 363-370. doi.org/10.1111/j.1475-1313.2005.00289.x

Farran, D., & McGaha, C. (2001). Interactions in an inclusive classroom: The effects of visual status and setting. Journal of Visual Impairment & Blindness (JVIB), 95(02).

Fletcher, R. (1998). *The City University colour vision test*. London: Keeler.

Franklin, A., Sowden, P., Burley, R., Notman, L., & Alder, E. (2008). Color perception in children with autism. *Journal of Autism and Developmental Disorders, 38*(10), 1837-1847. doi.org/10.1007/s10803-008-0574-6

Gillingham, G. (2000). *Autism, a New Understanding!: Solving the" mystery" of Autism, Asperger's and PDD-NOS*. Tacit Publishing Inc; 1st edition.

Green, S., Hernandez, L., Tottenham, N., Krasileva, K., Bookheimer, S.Y. & Dapretto, M. (2015) Neurobiology of sensory overresponsivity in youth with autism spectrum disorders. *JAMA Psychiatry,* 72, 778–786. doi:10.1001/jamapsychiatry.2015.0737.

Haigh, S. M. (2018). Variable sensory perception in autism. *European Journal of Neuroscience*, 47(6), 602-609. /doi.org/10.1111/ejn.13601.

Harms, M. B., Martin, A., & Wallace, G. L. (2010). Facial emotion recognition in autism spectrum disorders: a review of behavioral and neuroimaging studies. *Neuropsychology review*, 20(3), 290-322. doi.org/10.1007/s11065-010-9138-6.

Hellendoorn, A., Langstraat, I., Wijnroks, L., Buitelaar, J. K., van Daalen, E., & Leseman, P. P. (2014). The relationship between atypical visual processing and social skills in young children with autism. *Research in developmental disabilities,* 35(2), 423-428.

Huang, J., Zong, X., Wilkins, A., Jenkins, B., Bozoki, A., & Cao, Y. (2011). fMRI evidence that precision ophthalmic tints reduce cortical hyperactivation in migraine. *Cephalalgia*, 31(8), 925-936. doi.org/10.1177/0333102411409076

Kaplan, M., (2006). *Seeing through new eyes: Changing the lives of children with autism, Asperger syndrome and other developmental disabilities through vision therapy*. Jessica Kingsley, London.

Kern, J. K., Trivedi, M. H., Grannemann, B. D., Garver, C. R., Johnson, D. G., Andrews, A. A., Salva, J.S., Mehta, J.A & Schroeder, J. L. (2007). Sensory correlations in autism. *Autism,* 11(2), 123-134. doi.org/10.1177/1362361307075702.

Latham, K., Chung, S. L., Allen, P. M., Tavassoli, T., & Baron-Cohen, S. (2013). Spatial localisation in autism: evidence for differences in early cortical visual processing. *Molecular autism*, 4(1), 4. doi.org/10.1186/2040-2392-4-4.

Liss, M., Saulnier, C., Fein, D., & Kinsbourne, M. (2006). Sensory and attention abnormalities in autistic spectrum disorders. *Autism*, 10(2), 155-172. doi.org/10.1177/1362361306062021.

Lord, C., Rutter, M., Pamela C., Dilavore, & Risi, S. (2008). *ADOS: Autism diagnostic observation schedule*. Boston: Hogrefe.

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., Bishop, S. L., & Schedule, A. A. D. O. (2015). ADOS-2. *Manual (Part I): Modules*, 1-4.

Ludlow, A. K., Wilkins, A. J., & Heaton, P. (2006). The effect of coloured overlays on reading ability in children with autism. *Journal of Autism and Developmental Disorders*, 36(4), 507-516. doi.org/10.1007/s10803-006-0090-5.

Ludlow, A. K., Wilkins, A. J., & Heaton, P. (2008). Colored overlays enhance visual perceptual performance in children with autism spectrum disorders. *Research in Autism Spectrum Disorders*, 2(3), 498-515. doi.org/10.1016/j.rasd.2007.10.001.

Ludlow, A. K., & Wilkins, A. J. (2009). Case report: color as a therapeutic intervention. *Journal of autism and developmental disorders*, *39*(5), 815-818. DOI 10.1007/s10803-008-0672-5.

Ludlow, A. K., Taylor-Whiffen, E., & Wilkins, A. J. (2012). Coloured filters enhance the visual perception of social cues in children with autism spectrum disorders. *ISRN neurology*, 2012: 298098.

Ludlow, A. K., & Wilkins, A. J. (2016). Atypical Sensory behaviours in children with Tourette's Syndrome and in children with Autism Spectrum Disorders. *Research in developmental disabilities*, 56, 108-116. /doi.org/10.1016/j.ridd.2016.05.019.

Mathersul, D., McDonald, S., & Rushby, J. A. (2013). Understanding advanced theory of mind and empathy in high-functioning adults with autism spectrum disorder. *Journal of Clinical and Experimental Neuropsychology*, 35(6), 655-668. doi.org/10.1080/13803395.2013.809700

McDonald, S., Flanagan, S., Rollins, J., & Kinch, J. (2003). TASIT: A new clinical tool for assessing social perception after traumatic brain injury. *The Journal of head trauma rehabilitation*, 18(3), 219-238.

Mottron, L., Mineau, S., Martel, G., Bernier, C. S. C., Berthiaume, C., Dawson, M., Lemay, Palardy, S., Charman, T & Faubert, J. (2007). Lateral glances toward moving stimuli among young children with autism: Early regulation of locally oriented perception? *Development and psychopathology*, 19(1), 23-36. doi.org/10.1017/S0954579407070022.

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

Pelphrey, K. A., Morris, J. P., McCarthy, G., & LaBar, K. S. (2007). Perception of dynamic changes in facial affect and identity in autism. *Social cognitive and affective neuroscience, 2*(2), 140-149. doi.org/10.1093/scan/nsm010

Raven, J., & Raven, J. C & Court, JH (1998). *Manual for Raven's progressive matrices and vocabulary scales*. Oxford : Oxford Psychologists Press

Robertson, A.E. & Simmons, D.R. (2015). The sensory experiences of adults with autism spectrum disorder: A qualitative analysis. *Perception*, 44, 569-586.

Rump, K. M., Giovannelli, J. L., Minshew, N. J., & Strauss, M. S. (2009). The development of emotion recognition in individuals with autism. *Child development*, 80(5), 1434-1447. doi.org/10.1111/j.1467-8624.2009.01343.x

Senju, A., & Johnson, M. H. (2009). Atypical eye contact in autism: models, mechanisms and development. *Neuroscience & Biobehavioral Reviews*, *33*(8), 1204-1214.

Simmons, D. R., Robertson, A. E., McKay, L. S., Toal, E., McAleer, P., & Pollick, F. E. (2009). Vision in autism spectrum disorders. *Vision research*, *49*(22), 2705-2739. doi.org/10.1016/j.visres.2009.08.005

Smith, M. J. L., Montagne, B., Perrett, D. I., Gill, M., & Gallagher, L. (2010). Detecting subtle facial emotion recognition deficits in high-functioning autism using dynamic stimuli of varying intensities. *Neuropsychologia, 48*(9), 2777-2781. doi.org/10.1016/j.neuropsychologia.2010.03.008

Takarae, Y., & Sweeney, J. (2017). Neural Hyperexcitability in Autism Spectrum Disorders. *Brain sciences, 7*(10), 129. oi.org/10.3390/brainsci7100129

Tanaka, J. W., & Sung, A. (2016). The “eye avoidance” hypothesis of autism face processing. *Journal of autism and developmental disorders*, 46(5), 1538-1552. doi.org/10.1007/s10803-013-1976-7

Wass, S. V., Jones, E. J., Gliga, T., Smith, T. J., Charman, T., Johnson, M. H., ... & Davies, K. (2015). Shorter spontaneous fixation durations in infants with later emerging autism. *Scientific Reports*, 5, 8284. doi.org/10.1038/srep08284

Whitaker, L., Jones, C. R., Wilkins, A. J., & Roberson, D. (2016). Judging the intensity of emotional expression in faces: the effects of colored tints on individuals with autism spectrum disorder. *Autism Research,* 9(4), 450-459. doi.org/10

White, B. B., & White, M. S. (1987). Autism from the inside. *Medical hypotheses*, 24(3), 223-229..1002/aur.1506

Whiting, P. R., & Robinson, G. L. (2001). The interpretation of emotion from facial expressions for children with a visual sub-type of dyslexia. *Australian Journal of Learning Difficulties*, 6(4), 6-14. doi.org/10.1080/19404150109546682

Wilkins, A. J. (1993). A System for Precision Ophthalmic Tinting: A Manual for the Intuitive Colorimeter and Trial Lenses. *Cerium Visual Technologies, Tenterden, Kent*

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

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

Wilkins, A. J., & Sihra, N. (2001). A colorizer for use in determining an optimal ophthalmic tint. *Color Research & Application*, 26(3), *246-253.*

Wilkins, A. J., & Nimmo-Smith, I. (1984). On the reduction of eye-strain when reading. *Ophthalmic and Physiological Optics,* 4(1), 53-59. doi.org/10.1111/j.1475-1313.1984.tb00332.x

Wilkins, A. J., Evans, B. J. W., Brown, J. A., Busby, A. E., Wingfield, A. E., Jeanes, R. J., & Bald, J. (1994). Double-masked placebo-controlled trial of precision spectral filters in children who use coloured overlays. *Ophthalmic and*

*Physiological Optics*, 14(4), 365-370. doi.org/10.1111/j.1475-1313.1994.tb00126.x

Wilkins, A.J., Milroy, R., Nimmo-Smith,I., Wright, A., Tyrrell, R., Holland, K., Martin, J., Bald, J., Yale, S., Miles, T., Noakes,T. (1992). Preliminary observations concerning treatment of visual discomfort and associated perceptual distortion. *Ophthalmic and Physiological Optics*, 12, 257-263.

Table 1. Mean and Standard Deviations of Matching Criteria and Sensory Profile Scores by Group

| | Group | | | | |
|---|---|---|---|---|---|
| | ASD | | Control | | |
| | *Mean* | *SD* | *Mean* | *SD* | *t* (26) |
| Matching Criteria | | | | | |
| BPVS | 93.78 | 19.09 | 89.07 | 13.78 | .75 |
| Ravens | 105.21 | 17.20 | 107.64 | 9.53 | .46 |
| Age | 12.46 | 1.46 | 10.00 | .65 | 5.73** |
| Sensory Scores | | | | | |
| Sensory Seeking | 53.54 | 17.67 | 24.08 | 20.06 | 3.72** |
| Sensory Avoidance | 61.27 | 19.36 | 25.41 | 17.83 | 4.24** |
| Sensory Sensitivity | 61.00 | 14.38 | 25.58 | 17.60 | 5.25** |
| Low Registration | 55.63 | 19.92 | 24.00 | 15.14 | 4.31** |

*Note*: $p < .01$; $p < .05$

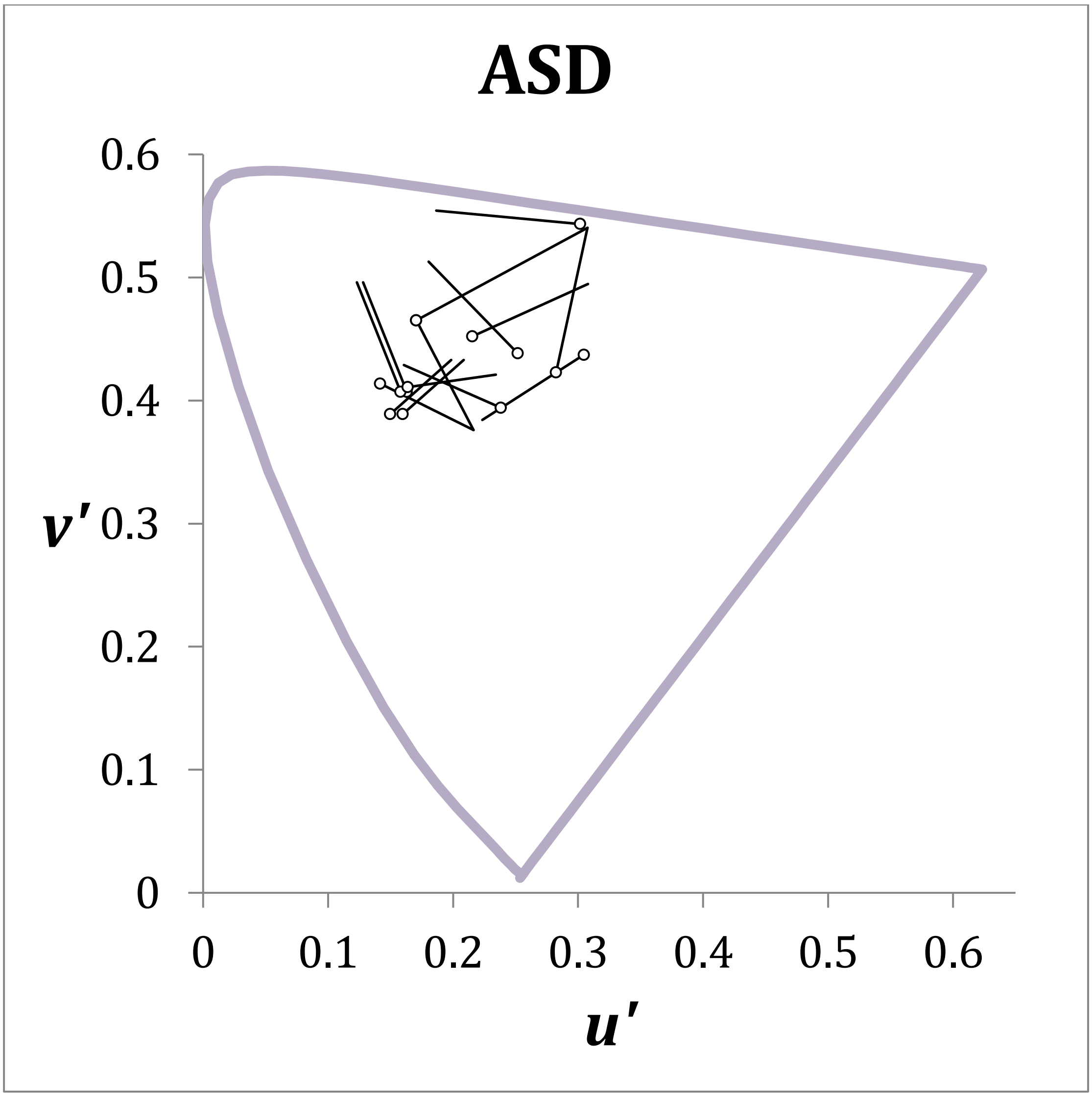
Figure Captions

Figure 1. Chromaticities chosen in the Intuitive Colorimeter as providing a comfortable light when viewing text. The chromaticities shown as white points are connected by a line to the chromaticity selected as control: a. ASD group; b. Control group of typically developing children.

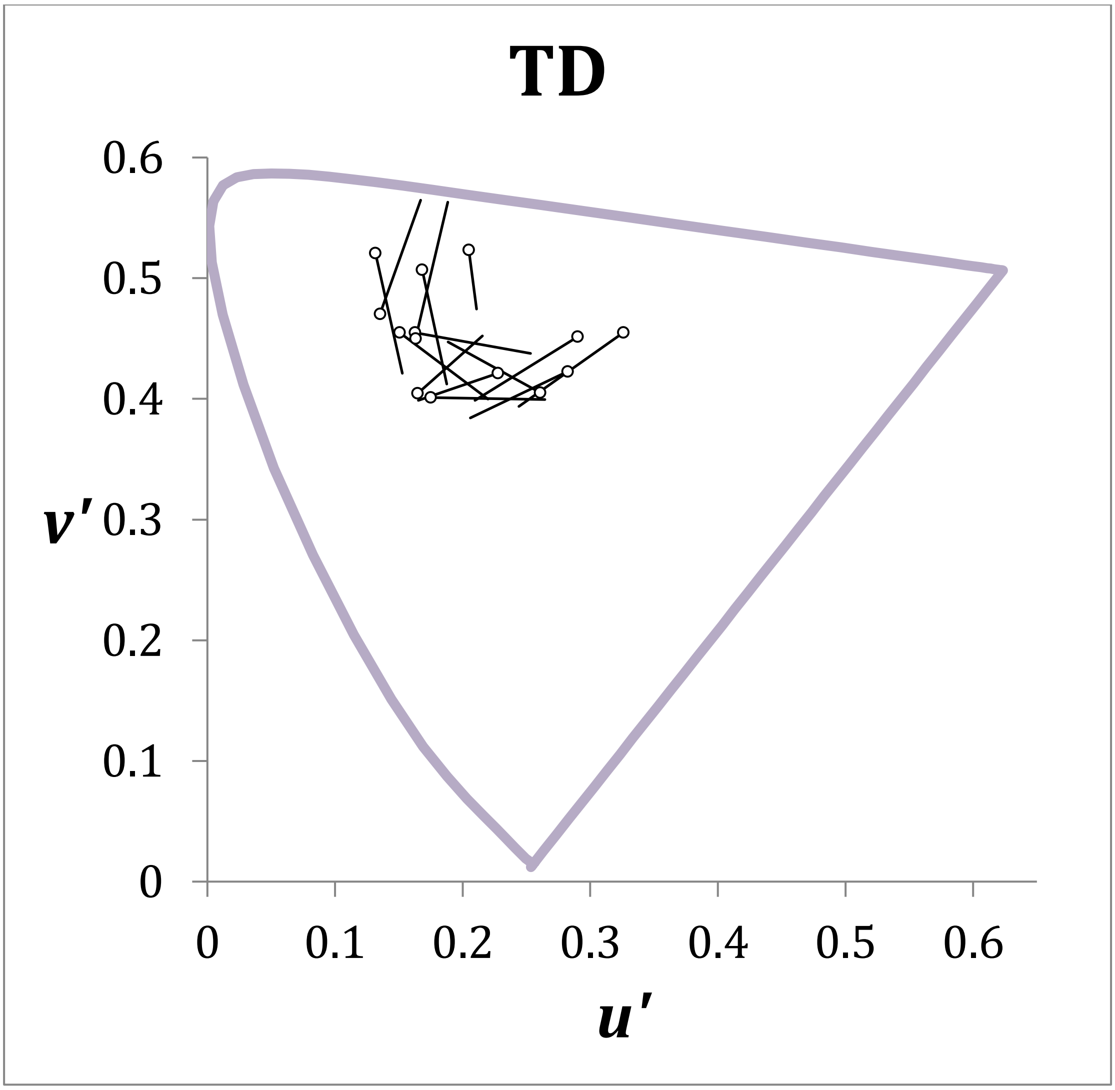
Figure 2. Mean number of emotions identified in the EET using placebo and chosen tint for ASD and typically developing (TD) children. Bars show standard deviations. *$p$<.05; ***$p$<.001.

Figure 3. Mean number of sarcasm exchanges identified in the SI-M using placebo and chosen tint for ASD and typically developing (TD) children. Bars show standard deviations. **$p$<.01.

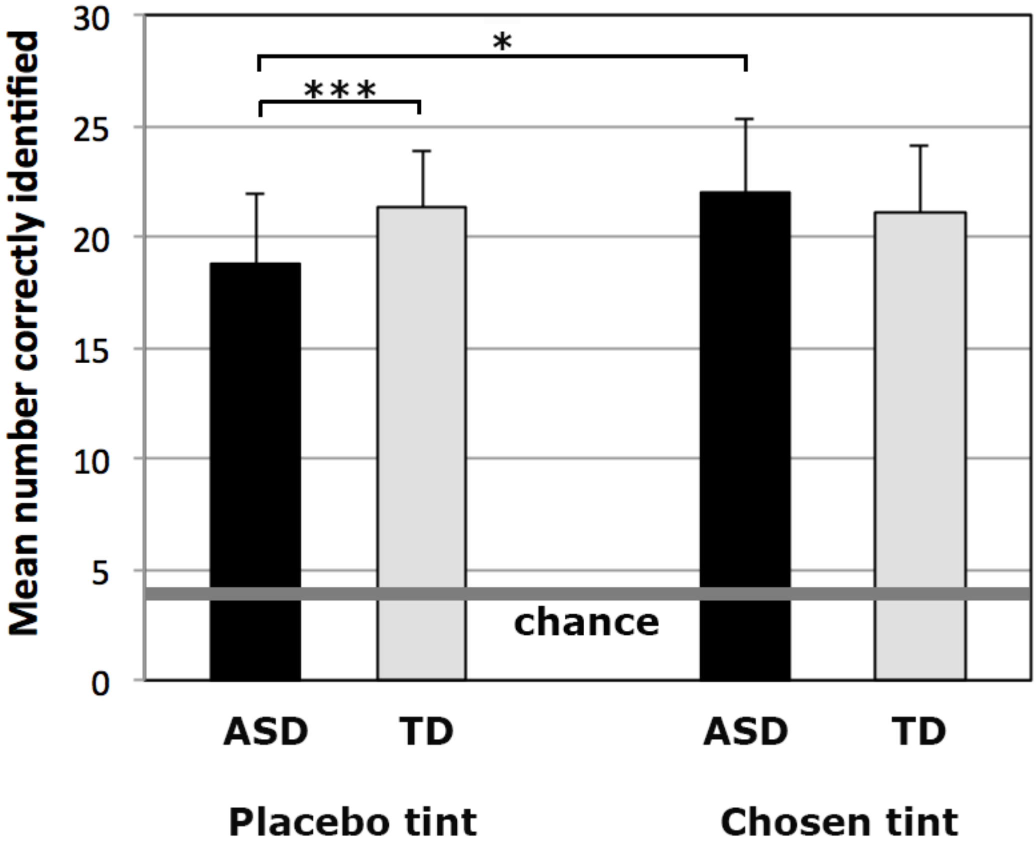
1a



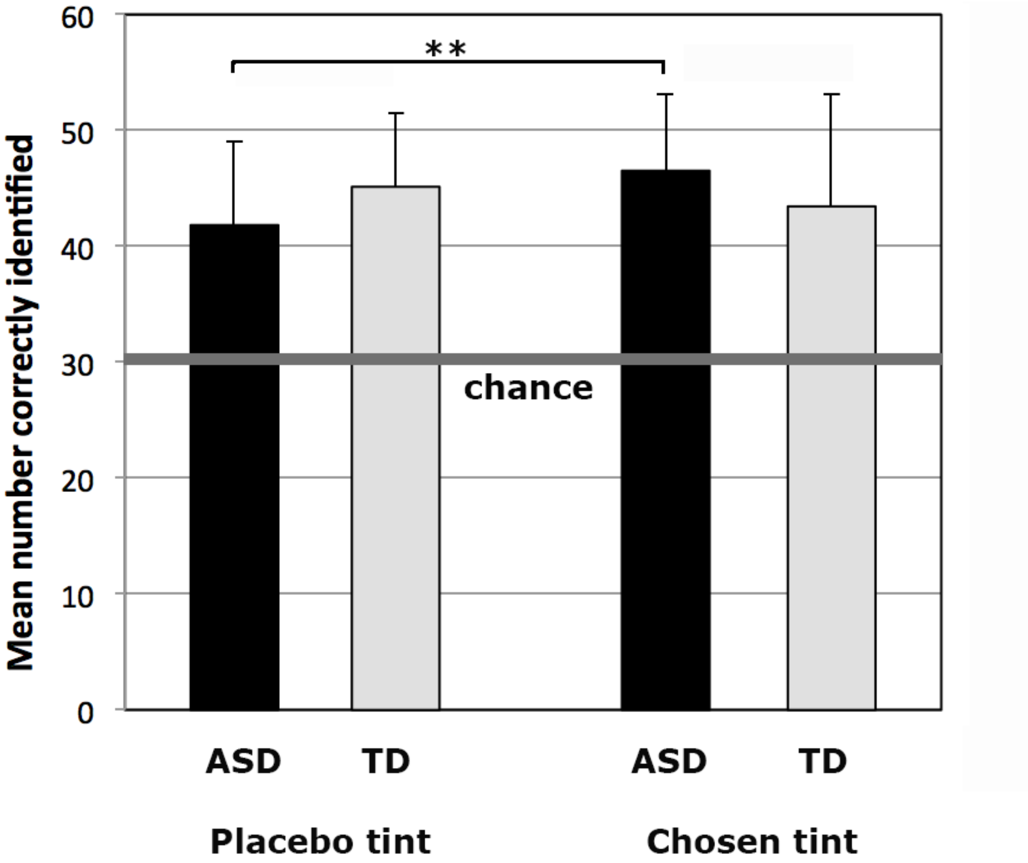
1b


TD
0.6
0.5
0.4
v′
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
u′

2


30
25
20
15
10
5
0
Mean number correctly identified
*
***
chance
ASD
TD
ASD
TD
Placebo tint
Chosen tint

3


60
50
40
30
20
10
0
Mean number correctly identified
**
chance
ASD
TD
ASD
TD
Placebo tint
Chosen tint