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# Research in Autism Spectrum Disorders

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## Disembedding performance and eye gaze behavior of adolescents with Autism Spectrum Disorder



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### ABSTRACT

**Background:** Atypical visual perception in individuals with Autism Spectrum Disorders (ASD) may contribute to superiority in disembedding tasks. Gaze behavior has provided some insights in to mechanisms underlying this purported superiority in children, however evidence is limited and requires additional investigation.

**Method:** The performance and gaze behavior of 27 adolescents with ASD and 27 matched typically developing (TD) peers were examined during the Figure Ground Subtest of the Test of Visual Perception Skills-third edition (TVPS-3).

**Results:** Compared to their TD counterparts, adolescents with ASD were no different in accuracy, however, had a longer response time. Differences in gaze behavior were also observed, characterized by adolescents with ASD spending less time viewing the incorrect and target figures, and spending a greater proportion of time viewing irrelevant areas of the stimuli compared to TD adolescents.

**Conclusions:** Results suggest that while altered visual perception was observed, this did not contribute to superiority in disembedding tasks in adolescents with ASD. Future research is required to elucidate conditions under which altered visual perception may contribute to behavioral superiority.

### 1. Introduction

Successful interaction with one's surroundings is dependent on the ability to acquire and process visuospatial information to develop meaning and guide interaction (Navon, 1977). While Typically Developing (TD) individuals exhibit a global perception bias during visual information processing, individuals diagnosed with Autism Spectrum Disorders (ASD) have been purported to display a preference to local information, or a lack of partiality to holistic processes (Iarocci & McDonald, 2006; Navon, 1977). Theoretical stances attempting to explain this altered visual perception in ASD have pointed to conflicting mechanisms. The Weak Central Coherence Theory (WCC) (Frith, 1989) proposes that deficits in central coherence may weaken the ability to perceive the global context, resulting in a bias towards local information (Frith, 1989; Happe & Frith, 2006). In contrast, the Enhanced Perceptual

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Functioning (EPF) standpoint attributes this preference to superior low-level processing rather than any deficit (Motttron & Burrack, 2001; Motttron, Dawson, Soulieres, Hubert, & Burack, 2006). Due to this purported bias to local information, resultant of either a deficit in central coherence or enhanced low level processing, it has been argued that these altered perceptual abilities may result in particular visual-spatial skills that surpass those of TD individuals (Brosnan, Gwilliam, & Walker, 2012; Happe & Frith, 2006; Jolliffe & Baron-Cohen, 1997; O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Shah & Frith, 1983). Disembedding tasks, or tasks that require the identification or localization of a target figure within a complex array, are predominantly used to examine the possible facilitative effect of enhanced low level/local processing (Dakin & Frith, 2005).

Although previous research appears to indicate that individuals with ASD may show superiority in disembedding tasks in terms of accuracy (Brosnan et al., 2012; Shah & Frith, 1983) or response time (Brosnan et al., 2012; de Jong, Kemner, & Engeland, 2006; Keehn et al., 2009; Pellicano, Mayberry, Durkin, & Maley, 2006; Ropar & Mitchell, 2001; Russell-Smith, Mayberry, & Bayliss, 2010; Russell-Smith, Mayberry, Bayliss, & Sng, 2012), the evidence remains equivocal (Horlin, Black, Falkmer, & Falkmer, 2014; Muth, Hönekopp, & Falter, 2014; Simmons et al., 2009) with large heterogeneity found between studies (Muth et al., 2014). Methodological issues within the current body of research that may contribute to this heterogeneity include possible type II errors, differences in sample characteristics and variability in the measures used (Edgin & Pennington, 2005; Horlin, Black et al., 2014; Kaldy, Giserman, Carter, & Blaser, 2013; Muth et al., 2014; Schlooz & Hulstijn, 2014; Schlooz et al., 2006). It has been postulated that ASD superiority in disembedding tasks may only become evident in tasks which are sufficiently complex (Schlooz & Hulstijn, 2014). In particular, some evidence has suggested that superiority may be age-dependent, with reaction times of children with ASD being faster at younger ages (approximately 6–14 years) but becoming more comparable to TD adolescents as they age (Edgin & Pennington, 2005).

Though a large body of research explores the behavioral aspects of disembedding, few studies have examined the visual attention of individuals with ASD that may underlie performance and provide some important cues in deciphering the incongruity between studies. To date, eye gaze behavior during disembedding tasks has been observed in children (Keehn et al., 2009, Horlin, Albrecht et al., 2014). One study using the Embedded Figures Test (EFT) (Witkin, Oltman, Raskin, & Karp, 1971) with children aged between 12 and 13 years of age found that in addition to a faster response time, children with ASD exhibited shorter fixations on the complex arrays and shorter first and final fixations, with findings suggesting that children with ASD had an advantage in initially encoding the complex stimuli and locating the target items within the arrays (Keehn et al., 2009). Another study using the Figure-Ground Subtest of the Test of Visual Perceptual Skills – 3rd edition (TVPS-3) (Martin, 2006) found that children with ASD aged between eight and 13 years made shorter and fewer fixations to the target figure, however, this did not result in better accuracy (Horlin, Albrecht et al., 2014).

While these results have been found in children, it is not known how visual perception may contribute to performance in disembedding tasks further along the developmental trajectory. This is of particular importance given that ASD-linked disembedding superiority has been shown to decline as individual’s age out of childhood (Edgin & Pennington, 2005). Adolescence, in particular, is marked as a significant period of change, characterized by a decline in functioning and a time point where individuals with ASD may begin to be left behind by their peers in regard to social and adaptive function development (Picci & Scherf, 2015). Given the importance of this developmental period, the current study seeks to replicate the study of Horlin, Albrecht et al. (2014) to determine if similar gaze patterns are observable in an adolescent sample and whether differences in visual attention contribute to enhanced performance in a disembedding task. Based on previous assumptions of superiority, it was hypothesized that individuals with ASD would: 1) be more accurate and have shorter response times; and 2) exhibit shorter and fewer fixations to the target and response items compared to the TD adolescents.

## 2. Materials and methods

### 2.1. Participant demographics

Participants were required to be aged 13–17 years, understand written and verbal English and have adequate vision, with the use of corrective devices if necessary. Adolescents with ASD were required to have a diagnosis of Autism, Asperger Syndrome (AS) or Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) according to the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV-TR) (American Psychiatric Association, 2000) or equivalent diagnosis according to the DSM-5 (American Psychiatric Association, 2013), with medical records sighted to confirm diagnosis. Adolescents with ASD with a comorbid diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) were included if it did not affect the participants’ ability to attend for the entirety of the task, with this decision being based on parental reports of attention, as well as observations during the trial. Adolescents with a co-morbid cognitive impairment (such as intellectual disability) were excluded to control for confounding factors. TD adolescents were required to score below a cut-off score of 15 on the Social Communication Questionnaire (SCQ; Rutter et al., 2003) to be eligible for inclusion. Participants were recruited from local research institutes, service providers and social media platforms. A total of 31 TD adolescents and 29 adolescents with ASD participated in the study. One participant with ASD was excluded due to a comorbid diagnosis of intellectual disability and one was excluded due to equipment failure (inadequate calibration or failure to record). Four TD participants were excluded due to equipment failure. Data from 27 adolescents with ASD, with diagnoses consisting of Autism (n = 21), AS (n = 2) and PDD-NOS (n = 4) (six female) and 27 TD adolescents (9 female) were available for analysis (Table 1). Six of the participants included in the ASD group had a reported comorbid diagnosis of ADHD.<sup>1</sup> All included adolescents were aged between

<sup>1</sup> Secondary statistical analysis excluding participants with ADHD (n = 6) yielded a similar pattern of results as the primary analysis and are

**Table 1**

Participant demographics and clinical characteristics for participants with Autism Spectrum Disorder (ASD) and typically developing (TD) controls. Means and standard deviations (SD).

	ASD ( <i>n</i> = 27)	TD ( <i>n</i> = 27)	Tests of Association
Age years (SD)	14.9 (1.34)	15.4 (1.67)	U = 311 <i>z</i> = 0.93 <i>p</i> = 0.36
Gender Male (%)	21 (77.8%)	18 (66.7%)	$\chi^2$ (1) = 0.83 <i>p</i> = 0.36
RSPM <sup>a</sup> (SD)	5.78 (2.33)	5.63 (2.15)	U = 343.50 <i>z</i> = 0.37 <i>p</i> = 0.71
SCQ <sup>b</sup> (SD)	13.33 (4.00)	6.74 (4.3)	U = 105.50 <i>z</i> = 4.5 <i>p</i> < 0.001

<sup>a</sup> Raven's Standard Progressive Matrices.

<sup>b</sup> Social Communication Questionnaire.

13 and 17 years; adolescents with ASD had a mean age of 14.9 years (SD = 1.34), while the TD group had a mean age of 15.4 years (SD = 1.67). The two groups did not differ significantly in age (*p* = 0.36), gender (*p* = 0.36) or Raven's Standard Progressive Matrices scores (*p* = 0.71) (RSPM; Raven, 1989). Adolescents with ASD had a significantly higher score on the SCQ than the TD adolescents (*p* < 0.01).

## 2.2. Measures

### 2.2.1. Test of visual acuity

The 2 m 2000 Series EDTRS chart 3 (Precision Vision, 2000) was used to confirm that participants had adequate vision to complete the computerized task. In a standing position, participants were required to correctly read the 20/20 vision line from a distance of two meters. If participants had difficulty reading the 20/20 vision line, they were asked to read a font size 12 sentence from a piece of paper at a reading distance (approximately 65 cm). As the purpose of this task was confirmatory in nature, participants were only required to score above the 20/20 vision line with no further measurements taken.

### 2.2.2. The Social Communication Questionnaire (SCQ)

The SCQ – current form (Rutter et al., 2003) was used to screen groups for ASD symptomatology. The SCQ is a 40-item primary caregiver questionnaire based on the Autism Diagnostic Interview-Revised (ADI-R). The SCQ consists of “yes/no” questions based on past and present behavior and ASD symptomatology including social functioning, stereotyped behavior, and language skills. It has good internal consistency with reliability measured by an alpha coefficient of 0.90 and is strongly correlated with the ADI-R with a correlation coefficient of 0.71 (Rutter et al., 2003). The SCQ is valid for individuals aged 4–40 years with a sensitivity of 0.85 and specificity of 0.75 to identify individuals with ASD.

### 2.2.3. Raven's Standard Progressive Matrices

The Raven's Standard Progressive Matrices test (RSPM) (Raven, 1989, 2000) was used to assess abstract reasoning and fluid intelligence in both groups. The RSPM is a 60-item assessment consisting of five sets of 12 pattern matching tasks, which increase in complexity. The RSPM is reported to have excellent internal consistency ( $\alpha$  = 0.97–1.00) (Raven, 2000). To reduce the assessment administration time, a nine-item abbreviated version of the RSPM was used (Bilker et al., 2012). This short form has been found to have high criterion validity (*r* = 0.91) and is highly correlated with the RSPM (*r* = 0.98) (Bilker et al., 2012).

### 2.2.4. Test of visual perceptual skills 3rd edition

The Figure Ground Subtest of the TVPS-3 (Martin, 2006) was used to test participants' visual perceptual skills in disembedding performance. Participants viewed two practice items and 16 test items, each of which consisted of a target shape and four response options, one of which contained the hidden target shape. All participants were exposed to the test items in accordance with the administration guidelines for the assessment (Martin, 2006). Items increased in difficulty with the 16<sup>th</sup> item being the most complex (Martin, 2006). The practice items were used to demonstrate the task to the participants so were not included in the analysis. Participants indicated their chosen response by pressing the corresponding key on the keyboard. No time limit was set and participants were required to answer each item before progressing to the next. The Figure Ground Subtest of the TVPS-3 has good internal consistency with a coefficient alpha of 0.82 (Martin, 2006).

(footnote continued)

available on request from the first author.

### 2.3. Apparatus

The SensoMotoric Instruments (SMI) (2014) remote eye tracker device (RED) collected eye movement data. This device is a dark-pupil tracking system using infrared light to illuminate the eye and detect the pupil. The RED is a contact-free device, allowing participants to wear corrective devices (glasses or contact lenses) if necessary and allows free head movements within a range of 40 cm x 20 cm at 70 cm distance. The RED was interfaced with a laptop and fixated underneath a 22" screen on which the stimuli were presented. Prior to completion of the task, a five-point calibration and validation were completed to ensure that the recorded data were valid. To reduce systematic error, participants were instructed to keep their heads and bodies as still as possible and to only use their eye movements when viewing the stimuli. If the participant moved out of range for an extended period of time, the eye tracker was recalibrated. To ensure participants were in the optimal position for the RED, an adjustable chair and table were used. Eye tracking data were collected in 60 Hz to maintain consistency with the previous study (Horlin, Albrecht et al., 2014). SMI IView X, BeGaze 3.4 and Experiment Centre 3.0 software (SensoMotoric Instruments, 2014) were used to manage eye tracker data acquisition and stimuli presentation.

### 2.4. Procedure

Ethical clearance from the Human Research Ethical Committee at Curtin University Western Australia was obtained (HR194/2013). Participants were provided with two cinema tickets as a token of appreciation following completion of the trial. Participants were provided with visual and verbal instructions and reminded of their freedom to withdraw from the study at any point. The parent/guardian either stayed in the room with the participant on the provision that no noise was made or in the waiting area outside the trial room, depending on the comfort of the participant. Participants were screened for visual acuity using the 2 m 2000 Series Revised EDTRS Chart 3 (Precision Vision, 2000). Participants then completed the nine-item short RSPM (Bilker et al., 2012). During this time, the parents of the participants had the opportunity to complete the SCQ if they had not done so before the commencement of the session. Following the completion of the screening procedures, participants were seated in front of the monitor and were orientated to the eye tracker. The five-point calibration and validation stage was completed to ensure the accuracy of the eye tracker. Following a successful calibration, participants were orientated to the task and the first practice item of the TVPS-3 was used to demonstrate the task requirements. Participants then viewed one additional practice item and 16 test items of the TVPS-3 (Martin, 2006).

### 2.5. Eye tracking data management

Data were managed using BeGaze 3.4 Software from SMI (2014) and SPSS version 25 software (IBM Corp, Released 2017). Rectangular Areas of Interest (AOI) were defined with the BeGaze AOI editor tools for the purposes of fixation data analysis. Each item was classified into six AOIs consisting of target, complex array options 1–4, and white space, i.e., space other than the target or complex array. Prior to analysis, these AOIs were re-coded to 'Target' 'Correct array', 'Incorrect arrays' ( $k = 3$  per stimuli), and 'Whitespace' for the 16 test items. The 'whitespace' AOI was defined as the area outside of the other AOIs (Fig. 1).

Prior to analysis, fixation accuracy checks were conducted. Calibration offsets were completed for participants with calibrations above  $1^\circ$  on either axis, but only if the number of fixations increased after offset adjustments (Falkmer, Dukic, Dahlman, Bjallmark, & Larsson, 2008). Four participants were found to have calibrations above  $1^\circ$ . Following the trial of calibration offsets for these participants, one TD participant had an increase in the number of fixations following corrections. Therefore, the offset correction was applied.

Accuracy, response time, fixation duration and proportion of fixations were the foci of analyses. Accuracy and response time data were obtained from SMI BeGaze 3.4 software, which recorded keypresses made by the participants. Each key press was recoded as 'correct' or 'incorrect' for each item. For participants ( $n = 16$  across both groups) who made multiple data entries for one stimulus, the last self-corrected response was used for analysis. Fixation count and duration of fixations data were retrieved from the BeGaze 3.4 software. In the current study, fixation count was defined as the total number of fixations a participant made to each AOI for each stimulus, this was calculated as a proportion of fixations to each AOI for the purposes of analysis. Fixation durations were defined as the duration of each fixation a participant made to each AOI.

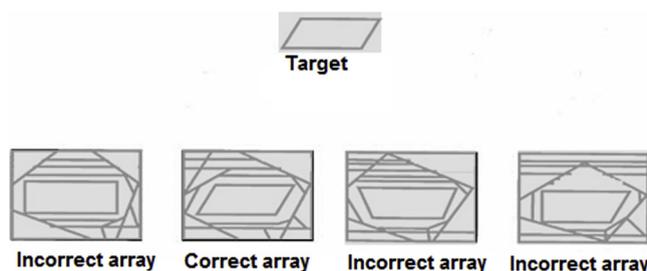


Fig. 1. Classification of Areas of interest including target, correct arrays, incorrect arrays and whitespace.

## 2.6. Statistical analyses

Power calculations indicated that a sample size of 27 participants in each group, using an  $\alpha$  of 0.05 and a  $\beta$  of 0.2, would be adequate to detect a moderate to large group difference (Altman, 1991), i.e., a Cohen's  $d$  of 0.78 or larger to be detected. Statistical analyses were performed using SPSS version 25 software (IBM Corp, Released 2017) with the critical  $\alpha$ -value set to 0.05.

Mann-Whitney U tests were conducted to assess any group differences in demographic data (e.g., age, SCQ, RSPM) as Kolmogorov Smirnov tests found the data to be not normally distributed. A Chi-square test was conducted to determine group differences due to gender.

To determine differences between groups in behavioral and fixation data, multivariate analyses were undertaken using Generalized Estimating Equations (GEE), where dependent variables were binary categorical (accuracy of response (correct/incorrect), and linear mixed models were used where dependent variables were continuous. These models were used as they take into account the internal correlation structure in the data, due to the multiple observations per participant. A backward stepwise process was followed to develop the models, whereby the least significant independent variable was dropped, one at a time until all variables remaining in the model were statistically significantly associated with the outcome. Bonferroni corrected pairwise interactions between the remaining significant variables were then explored. Specific information about the modeling method and fixed effects included for analysis are described below. For the analysis of 'correct' responses (correct/incorrect), the independent variables considered for inclusion in this model were the group (ASD/TD), as well as stimulus number (1–16) to account for the stimulus items increasing in difficulty.

Group differences (ASD/TD) in response time were compared after adjustment for stimulus level (continuous variable ranging from 1 to 16). For analysis of fixation duration and proportion of fixations, all AOIs were included. Group differences (ASD/TD) for both variables were assessed after adjustment for AOI (correct, incorrect, target, white space), and stimulus (continuous variable ranging from 1 to 16). As data were found to be not normally distributed, a Box-Cox transformation was applied to response time, fixation duration and fixation proportion variables to correct for skewness.

## 3. Results

### 3.1. Accuracy of response

Accuracy of performance on the disembedding task was not statistically different for the two groups (Wald Chi Square = 0.43,  $df = 1$ , OR = 0.78, 95% CI = 0.38–1.62;  $p = 0.51$ ). On average, participants with ASD achieved an accuracy rate of 85.9% across stimuli (mean number of correct responses: 13.6, SD: 2.8), while TD adolescents achieved an accuracy rate of 88.4% (mean number of correct responses: 14.1, SD: 2.1; Fig. 2). The main effect of stimulus was significant, (Wald Chi Square = 134.36,  $df = 14$ ,  $p < 0.01$ ), with Bonferroni adjusted pairwise comparisons indicating that accuracy tended to decrease with increasing stimulus difficulty for both groups. Accuracy was lower for stimulus 10 compared to one ( $p = 0.02$ ), three ( $p < 0.01$ ), and four ( $p = 0.01$ ). Stimulus 15 had lower accuracy when compared to stimuli one ( $p < 0.01$ ), three ( $p < 0.01$ ), four ( $p < 0.01$ ), five ( $p = 0.02$ ), six ( $p < 0.01$ ), seven ( $p < 0.01$ ), eight ( $p < 0.01$ ), nine ( $p = 0.03$ ), 12 ( $p < 0.01$ ) and 13 ( $p < 0.01$ ), and stimulus 16 had lower accuracy when compared to stimuli three ( $p = 0.03$ ) and four ( $p = 0.03$ ).

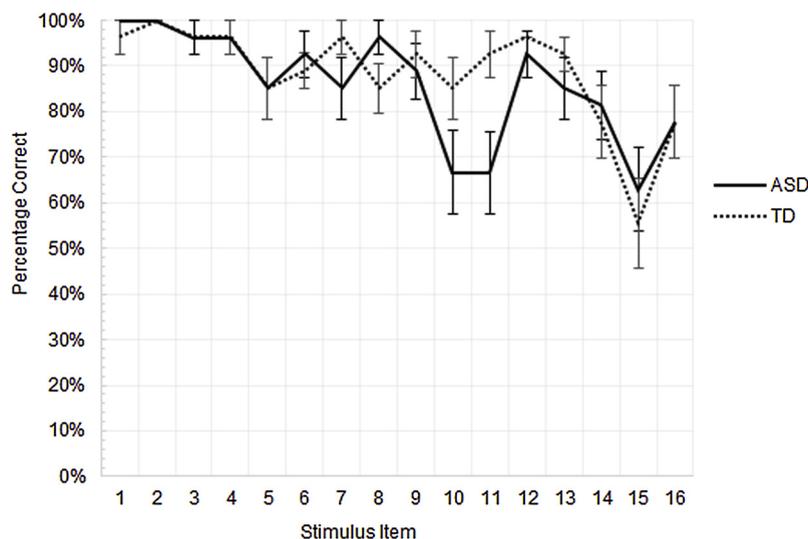


Fig. 2. Percentage of correct responses for adolescents with and without Autism Spectrum Disorder across all items.

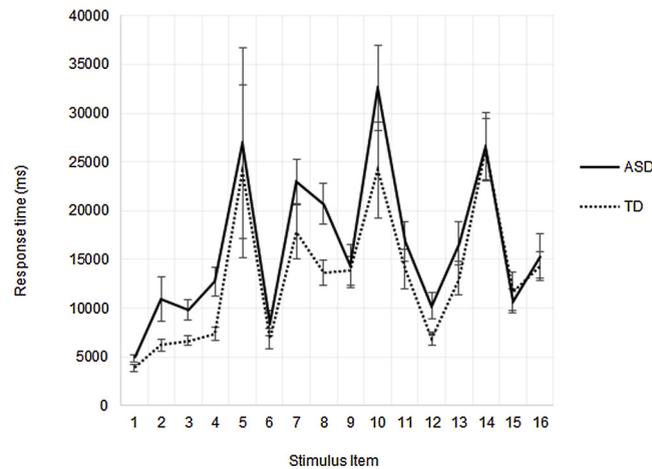


Fig. 3. Mean response time for adolescents with and without Autism Spectrum Disorder.

### 3.2. Response time

Between group differences existed for response time (Fig. 3). Participants with ASD demonstrated a significantly longer response time compared with the TD participants, regardless of stimulus number (1–16),  $F(1) = 7.15$ ;  $p = 0.01$ . A significant main effect of stimulus,  $F(15) = 291.20$ ;  $p < 0.01$ , indicated that for both groups, responses became longer as stimulus difficulty increased. The interaction between group and stimulus was also significant,  $F(15) = 8.67$ ;  $p < 0.01$ . Bonferroni adjusted comparisons revealed that adolescents with ASD had significantly longer response times for stimulus items 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, and 12 compared to TD adolescents ( $p < 0.04$ ). There were no significant differences in response time between groups for items 9, 13, 14, 15 or 16.

### 3.3. Fixation duration

The main effect of group was not significant, indicating that fixation durations were similar between adolescents with and without ASD,  $F(1) = 1.02$ ;  $p = 0.32$ . A main effect of stimulus was significant  $F(15) = 19.82$ ;  $p < 0.01$ , which indicated that fixation durations become longer as the stimulus became more difficult regardless of group. The main effect of AOI was also significant,  $F(3) = 404.08$ ;  $p < 0.01$ , indicating that regardless of group, fixation durations to the whitespace were shorter than those to the correct ( $p < 0.01$ ), incorrect ( $p < 0.01$ ), and target ( $p < 0.01$ ) AOIs, fixation durations to the correct AOI were longer than those to all other AOIs (target:  $p < 0.01$ , incorrect:  $p < 0.01$ , whitespace:  $p < 0.01$ ), while fixation durations to the incorrect AOI were longer than to the target ( $p = 0.01$ ). A three-way interaction between group, AOI and stimulus also appeared to be significant,  $F(108) = 3.38$ ,  $p < 0.01$ , although Bonferroni corrected pairwise comparisons revealed significant effects only for adolescents with ASD to make longer fixations to the target ( $p < 0.01$ ) and whitespace ( $p < 0.01$ ) of stimulus number 4.

### 3.4. Proportion of fixations

The main effect of group was not significant,  $F(1) = 0.03$ ;  $p = 0.87$ . However, a two-way interaction between group and AOI,  $F(3) = 17.23$ ;  $p < 0.01$ , was found (Fig. 4), with Bonferroni adjusted comparisons indicating that adolescents with ASD had a lower fixation proportion to the incorrect ( $p = 0.04$ ) and target ( $p < 0.01$ ) AOIs, and spent a greater proportion of time fixating on the whitespace ( $p < 0.01$ ) compared to TD adolescents. Main effects of AOI were also found,  $F(3) = 368.8$ ;  $p < 0.01$ . Proportion of fixations to the correct AOI were longer than to all other AOIs ( $p < 0.01$ ), followed by the target ( $p < 0.01$ ), incorrect AOI ( $p < 0.01$ ) and whitespace ( $p < 0.01$ ).

## 4. Discussion and implications

While atypical gaze-behavior was observed in adolescents with ASD, indicative of altered visual perception, this did not contribute to superiority during the disembedding task. In fact, contrary to the hypothesis, adolescents with ASD performed the disembedding task slower than their TD counterparts and were no different in accuracy.

Adolescents with ASD appeared to make fewer fixation to both the target and incorrect complex arrays. These findings are similar to Horlin, Albrecht et al. (2014) who found that children with ASD made shorter and fewer fixations to the target figure and Keehn et al. (2009) who found that children with ASD made shorter fixations on the complex array, as well as making shorter initial fixations compared to their TD counterparts. It was suggested by these previous studies that shorter fixations to the complex arrays may suggest that the local features are more overt for children with ASD and shorter initial fixations and reduced and shorter fixations to the target may suggest an advantage in the initial encoding of the stimuli and increased saliency of the target (Horlin,

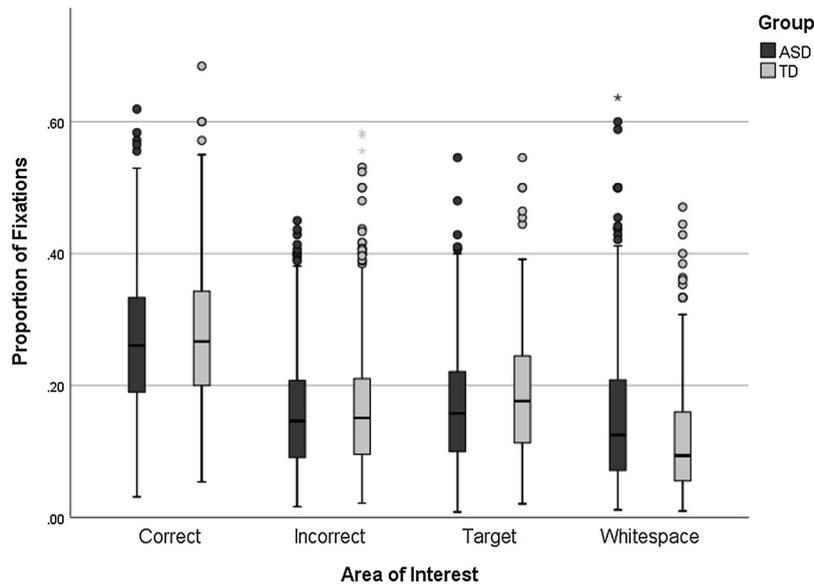


Fig. 4. Proportion of fixations on Areas of Interest for adolescents with and without Autism Spectrum Disorder.

Albrecht et al., 2014; Keehn et al., 2009). In the child studies, this gaze behavior was proposed to be indicative of a processing advantage (Horlin, Albrecht et al., 2014; Keehn et al., 2009), contributing to superior (Keehn et al., 2009), or at least comparable behavioral performance (Horlin, Albrecht et al., 2014). Though gaze patterns were similar in adolescents with ASD in the current study, their accuracy was comparable to TD adolescents, and their response time was longer.

Despite adolescents with ASD showing evidence for an information processing advantage when considering the target figure and incorrect array, they also spent more time viewing irrelevant areas, i.e., space other than the target or complex arrays compared to TD counterparts, possibly explaining their longer response time. This increased time spent viewing the white space may have several potential explanations. Firstly, it is possible that the participants with ASD may have had higher levels of anxiety than TD adolescents, as they might be more predisposed to apprehensiveness and frustration, particularly in an experimental environment, due to socio-communicative difficulties (Horlin, Black et al., 2014; Kaland, Mortensen, & Smith, 2007), or may have presented with increased inattention during the trial. It is however also possible that TD adolescents more consistently determined the white space as not relevant to the task and adjusted their fixation pattern accordingly. The participants with ASD may not as consistently have adjusted their distribution of fixations based on an assessment of the information's relevance for the task. In this case, the information processing style seen in ASD may be taken as more indicative of a deficit in central coherence rather than enhanced low-level processing. While increased gaze towards the whitespace may have been caused by poorer calibrations in the ASD group, this is unlikely given the fixation accuracy checks conducted prior to analysis and the size of the AOIs.

It is possible that the comparably longer response time observed in adolescents, but not in children with ASD may indicate changes in functioning of these individuals across the developmental trajectory (Uddin, Supekar, & Menon, 2013). Indeed, previous behavioral research on this topic has suggested that while individuals with ASD may show superiority compared with TD peers in response time during childhood, this advantage may disappear as they age, possibly due to a lack of skill development with practice as children with ASD age (Edgin & Pennington, 2005). These patterns of visual perception and performance may represent changes in the neural functioning of these individuals across the developmental trajectory, possibly due to pubertal influences which occur during this period (Picci & Scherf, 2015; Uddin et al., 2013). Given that significant changes in functioning (Picci & Scherf, 2015) and neural connectivity (Uddin et al., 2013) are shown to occur during the period of adolescence, future research should seek to understand the neural mechanisms possibly contributing to visual perception in individuals with ASD, and how these may change along the developmental trajectory.

A number of explanations may be put forth to explain why the current study differed from previous studies showing superiority in visual search ability in individuals with ASD (Mitchell & Ropar, 2004). The largest incongruity comes from the stimuli that were utilized. The Figure Ground Subtest of the TVPS-3 (Martin, 2006) has only been used by one study previously (Horlin, Albrecht et al., 2014), therefore limitations exist in the ability to draw comparisons between the present study and its predecessors. The benefit of using the TVPS-3 over the more commonly used stimuli (EFT, child EFT) is that it offers four options per item in which the target may be hidden with each item increasing in difficulty, reducing the probability of an individual being correct from a guess, with 25% probability rather than 50% seen in other stimuli (Martin, 2006). The TVPS-3 is designed for ages four to 19 years and aims to result in a comprehensive assessment of perceptual abilities separate from motor skills. Hence, the cognitive demands of the TVPS-3 (Martin, 2006) should be sufficient to observe enhanced performance in the participants with ASD given previous postulations that an ASD advantage in these tasks may only become evident if the task is complex (Schlooz & Hulstijn, 2014). However, despite the fact that the task increased in difficulty from items one to 16, and the participants were well under the age range for the test, ceiling

effects were evident in both groups in two items. It could be argued that the stimuli presented here were not sufficiently complex to observe enhanced behavioral performance (Schlooz & Hulstijn, 2014).

Despite the mentioned advantages of using the TVPS-3, some concern may arise as to the validity of the TVPS-3 as a traditional disembedding task. While previous research has defined disembedding tasks as those tasks with target shapes sharing boundaries and contours with the larger context (Milne & Szczerbinski, 2009), others may argue that continuous lines through the target figure are required (De-Wit, Huygelier, Van der Hallen, Chamberlain, & Wagemans, 2017). In the current study, while all 16 items had target items sharing borders with the larger embedded context, only seven items had lines bisecting the target. Indeed it has been argued that the number of continued lines through a target may influence the difficulty of disembedding tasks (De-Wit et al., 2017), therefore a lack of continued lines in all stimuli items may have contributed to the unexpected disembedding outcomes in the current study. However, stimulus number (ranging from 1 to 16) was included in the model analysis for all variables, showing it unlikely that the stimuli with or without bisecting lines through the target influenced performance in the current study. While additional research may be required to investigate the influence of stimuli on visual perceptual abilities (De-Wit et al., 2017), replicating the experimental paradigm of Horlin, Albrecht et al. (2014) has shown that visual attention differences in children in this particular task are not replicated in an adolescent population.

There have been further suggestions that superior performance may be positively correlated with the severity of ASD symptomatology (Chen, Lemonnier, Lazartigues, & Planche, 2008; Schlooz & Hulstijn, 2014; White & Saldana, 2011). Therefore, the absence of ASD superiority in this study may have been the result of lower ASD symptomatology within the group of adolescents with ASD. While the SCQ did not serve as a diagnostic measure in the current study, it was used to validate the diagnostic reports sighted to account for the severity of ASD symptomatology within the group of participants. While a formal diagnosis was not undertaken as part of this study, the citing of diagnostic records was deemed appropriate to confirm diagnosis of ASD given that a multi-disciplinary team assessment is required for diagnosis in the region, with an error rate similar to that of other 'gold-standard' diagnostic measures (Falkmer, Anderson, Falkmer, & Horlin, 2013; Wooltenden, Sarkov, Ridley, & Williams, 2012). While there is some suggestion that higher levels of symptomatology are required for superior performance there has also been evidence to suggest superior performance can be seen in TD individuals with autistic traits (Russell-Smith et al., 2010, 2012) perhaps contradicting this hypothesis. While behavioral performance superiority was not evident in this study, there may be indications that superiority may occur on a continuum similar to that of ASD symptomatology (Happe & Frith, 2006).

Results from the current study and two previous eye tracking studies (Horlin, Albrecht et al., 2014; Keehn et al., 2009) show promise in elucidating whether individuals with ASD process visuospatial information differently than their TD peers. Questions are raised over whether behavioral superiority in terms of accuracy or response time is evident in adolescents with ASD, and whether enhanced visuospatial processing continues to lead to superior behavioral performance in adolescents and adults with ASD. There is still a notion that individuals with ASD outperform their TD peers in visual search tasks (Kaldy, Giserman, Carter, & Blaser, 2016), however, the current study indicates that this is not always the case. Further research using different experimental paradigms may be required to elucidate the effect of stimuli on the findings of visual perception in ASD.

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## References

- Altman, D. (1991). *Practical statistics for medical research* (1st ed.). London: Chapman and Hall.
- American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders* (4th edition). Washington, DC: American Psychiatric Publishing Text Revision (DSM-IV-TR).
- American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders: DSM-5*. Arlington, VA: American Psychiatric Association.
- Bilker, W., Hansen, J. A., Bresinger, C. M., Richard, J., Gur, R. E., & Gur, R. C. (2012). Development of abbreviated nine—Item forms of the Raven's Standard Progressive Matrices Test. *Assesment*, 19(3), 354–369. <https://doi.org/10.1177/1073191112446655>.
- Bronan, M., Gwilliam, L., & Walker, I. (2012). The relationship between visual acuity, the Embedded Figures Test and systemizing in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 42(11), 2491–2497. <https://doi.org/10.1007/s10803-012-1505-0>.
- Chen, F., Lemonnier, E., Lazartigues, A., & Planche, P. (2008). Non-superior disembedding performance in children with high-functioning autism and its cognitive style account. *Research in Autism Spectrum Disorders*, 2(4), 739–752. <https://doi.org/10.1016/j.rasd.2008.03.003>.
- Dakin, S., & Frith, U. (2005). Vagaries of visual perception in autism. *Neuron*, 48(3), 497–507. <https://doi.org/10.1016/j.neuron.2005.10.018>.
- De-Wit, L., Huygelier, H., Van der Hallen, R., Chamberlain, R., & Wagemans, J. (2017). Developing the Leuven Embedded Figures Test (L-EFT): Testing the stimulus features that influence embedding. *PeerJ*, 5, e2862. <https://doi.org/10.7717/peerj.2862>.
- de Jong, M., Kemner, C., & Engeland, H. (2006). Superior disembedding performance of high-functioning individuals with autism spectrum disorders and their parents: The need for subtle measures. *Journal of Autism and Developmental Disorders*, 36(5), 677–683. <https://doi.org/10.1007/s10803-006-0113-2>.
- Edgin, J. O., & Pennington, B. F. (2005). Spatial cognition in autism spectrum disorders: Superior, impaired, or just intact? *Journal of Autism and Developmental Disorders*, 35(6), 729–745. <https://doi.org/10.1007/s10803-005-0020-y>.
- Falkmer, T., Anderson, K., Falkmer, M., & Horlin, C. (2013). Diagnostic procedures in autism spectrum disorders: A systematic literature review. *European Child & Adolescent Psychiatry*, 22(6), 329–340. <https://doi.org/10.1007/s00787-013-0375-0>.
- Falkmer, T., Dukic, T., Dahlman, J., Bjallmark, A., & Larsson, M. (2008). Fixation identification in centroid versus star-point modes using eye-tracking data. *Perceptual and Motor Skills*, 106(3), 710–724. <https://doi.org/10.2466/PMS.106.3.710-724>.
- Frith, U. (1989). *Autism: Explaining the enigma*. Oxford: Blackwell Science.
- Happe, F., & Frith, U. (2006). The weak coherence account: Detail focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*,

- 36(1), 5–25. <https://doi.org/10.1007/s10803-005-0039-0>.
- Horlin, C., Albrecht, M., Falkmer, M., Leung, D., Ordqvist, A., Tan, T., ... Falkmer, T. (2014). Visual search strategies of children with and without autism spectrum disorders during an embedded figures task. *Research in Autism Spectrum Disorders*, 8(5), 463–471. <https://doi.org/10.1016/j.rasd.2014.01.006>.
- Horlin, C., Black, M., Falkmer, M., & Falkmer, T. (2014). Proficiency of individuals with autism spectrum disorders at disembedding figures: A systematic review. *Developmental Neurorehabilitation*, 19(1), 1–10. <https://doi.org/10.3109/17518423.2014.888102>.
- Iarocci, G., & McDonald, J. (2006). Sensory integration and the perceptual experience of persons with autism. *Journal of Autism and Developmental Disorders*, 36(1), 77–90. <https://doi.org/10.1007/s10803-005-0044-3>.
- IBM Corp (2017). *IBM statistics for windows, version 20.0*. Released Armonk, NY: IBM Corp.
- Jolliffe, T., & Baron-Cohen, S. (1997). Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? *Child Psychology and Psychiatry*, 38(5), 527–534. <https://doi.org/10.1111/j.1469-7610.1997.tb01539.x>.
- Kaland, N., Mortensen, E., & Smith, L. (2007). Disembedding performance in children and adolescents with Asperger syndrome or high functioning autism. *Autism*, 11(1), 81–92. <https://doi.org/10.1177/1362361307070988>.
- Kaldy, Z., Giserman, I., Carter, A. S., & Blaser, E. (2013). The mechanisms underlying the ASD advantage in visual search. *Journal of Autism and Developmental Disorders*, 46(5), 1513–1527. <https://doi.org/10.1007/s10803-013-1957-x>.
- Kaldy, Z., Giserman, I., Carter, A. S., & Blaser, E. (2016). The mechanisms underlying the ASD advantage in visual search. *Journal of Autism and Developmental Disorders*, 46(5), 1513–1527.
- Keehn, B., Brenner, L. A., Ramos, A. I., Lincoln, A. J., Marshall, S. P., & Müller, R. A. (2009). Brief report: Eye movement patterns during an embedded figures test in children with ASD. *Journal of Autism and Developmental Disorders*, 39(2), 383–387. <https://doi.org/10.1007/s10803-008-0608-0>.
- Martin, N. A. (2006). *Test of visual perception skills* (third edition). Novato, CA: Academic Therapy Publications.
- Milne, E., & Szczerbinski, M. (2009). Global and local perceptual style, field-independence, and central coherence: An attempt at concept validation. *Advances in Cognitive Psychology*, 5, 1–26. <https://doi.org/10.2478/v10053-008-0062-8>.
- Mitchell, P., & Ropar, D. (2004). Visuo-spatial abilities in autism: A review. *Infant and Child Development*, 13(3), 185–198. <https://doi.org/10.1002/icd.348>.
- Mottron, L., & Burack, J. (2001). Enhanced perceptual functioning in the development of autism. In J. Burack, T. Charman, N. Yirmiya, & P. Zelazo (Eds.). *The development of autism: Perspectives from theory and research* (pp. 131–148). Mahwah, NJ: Erlbaum.
- Mottron, L., Dawson, M., Soulières, 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. <https://doi.org/10.1007/s10803-005-0040-7>.
- Muth, A., Hönekopp, J., & Falter, C. M. (2014). Visuo-spatial performance in autism: A meta-analysis. *Journal of Autism and Developmental Disorders*, 44(12), 3245–3263. <https://doi.org/10.1007/s10803-014-2188-5>.
- Navon, D. (1977). Forrest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, 9(3), 30. [https://doi.org/10.1016/0010-0285\(77\)90012-3](https://doi.org/10.1016/0010-0285(77)90012-3).
- O’Riordan, M., Plaisted, K., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. *Journal of Experimental Psychology Human Perception and Performance*, 27(3), 719–730. <https://doi.org/10.1111/j.1469-7610.00748>.
- Pellicano, E., Mayberry, M., Durkin, K., & Maley, A. (2006). Multiple cognitive capabilities/deficits in children with an autism spectrum disorder: "Weak" central coherence and its relationship to theory of mind and executive control. *Development and Psychopathology*, 18(1), 77–98. <https://doi.org/10.1017/S0954579406060056>.
- Picci, G., & Scherf, S. (2015). A two-hit model of autism: Adolescence as the second hit. *Clinical Psychological Science*, 3(3), 349–371. <https://doi.org/10.1177/2167702614540646>.
- Precision Vision (2000). *Revised 2000 series ETDRS charts-2 meters*. Retrieved from [www.precision-vision.com](http://www.precision-vision.com).
- Raven, J. (1989). Raven Progressive Matrices: A review of national norming studies and ethnic and socioeconomic variation within the United States. *Journal of Educational Measurement*, 21(1), 1–16. <https://doi.org/10.1111/j.1745-3984.1989.tb00314.x>.
- Raven, J. (2000). The Raven’s Progressive Matrices: Change and stability over culture and time. *Cognitive Psychology*, 41(1), 1–48. <https://doi.org/10.1006/cogp.1999.0735>.
- Ropar, D., & Mitchell, P. (2001). Susceptibility to illusions and performance on visuo-spatial tasks in individuals with autism. *Journal of Child Psychology and Psychiatry*, 42(4), 539–549. <https://doi.org/10.1111/1469-7610.00748>.
- Russell-Smith, S., Mayberry, M., & Bayliss, D. (2010). Are the autism and positive schizotypy spectra diametrically opposed in local versus global processing? *Journal of Autism and Developmental Disorders*, 40(8), 968–977. <https://doi.org/10.1007/s10803-010-0945-7>.
- Russell-Smith, S., Mayberry, M., Bayliss, D., & Sng, A. (2012). Support for a link between the local processing bias and social deficits in autism: An investigation of embedded figure test performance in non clinical individuals. *Journal of Autism and Developmental Disorders*, 42(11), 2420–2430. <https://doi.org/10.1007/s10803-012-1506-z>.
- Rutter, M., Bailey, A., & Lord, C. (2003). *The Social Communication Questionnaire*. Los Angeles: Western Psychological Services 633–645.
- Schlooz, & Hulstijn (2014). Boys with autism spectrum disorders show superior performance on the adult Embedded Figures test. *Research in Autism Spectrum Disorders*, 8, 1–7. <https://doi.org/10.1016/j.rasd.2013.10.004>.
- Schlooz, Hulstijn, van den Broek, van der Pijll, Gabreels, van der Gaag, ... Rotteveel (2006). Fragmented visuospatial processing in children with pervasive developmental disorder. *Journal of Autism and Developmental Disorders*, 36(8), 1025–1037. <https://doi.org/10.1007/s10803-006-0140-z>.
- SensoMotoric Instruments (2014). *SMI gaze and eye tracking systems*. Retrieved from [www.smivision.com](http://www.smivision.com).
- Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry*, 24(4), 613–620. <https://doi.org/10.1111/j.1469-7610.1983.tb00137.x>.
- 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. <https://doi.org/10.1016/j.visres.2009.08.005>.
- Uddin, L., Supekar, K., & Menon, V. (2013). Reconceptualizing functional brain connectivity in autism from a developmental perspective. *Frontiers in Human Neuroscience*, 7(458), 1–11. <https://doi.org/10.3389/fnhum.2013.00458>.
- White, S. J., & Saldana, D. (2011). Performance of children with autism on the Embedded Figures Test: A closer look at a popular task. *Journal of Autism and Developmental Disorders*, 41(11), 1565–1572. <https://doi.org/10.1007/s10803-011-1182-4>.
- Witkin, H., Oltman, P., Raskin, E., & Karp, S. (1971). *A manual for the embedded figures test*. Palo Alto, CA: Consulting Psychologists Press Inc.
- Wooltenden, S., Sarkovoy, V., Ridley, G., & Williams, K. (2012). A systematic review of the diagnostic stability of autism spectrum disorder. *Research in Autism Spectrum Disorders*, 6, 345–354. <https://doi.org/10.1016/j.rasd.2011.06.008>.