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Where to Draw the Line: Evaluating Visuospatial and Attentional Processing in Individuals with Autism Spectrum Disorders

by

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Abstract

Objective: We investigated visuospatial processing in individuals with autism using bisection and quadrisection tasks to evaluate the presence of a possible downward vertical spatial bias that could provide insights into the preference for attending to the mouth in ASD populations.

Methods: Twenty participants with ASD and 20 age, IQ, and sex-matched control participants were recruited (ages 6-23). Participants were asked to bisect, quadrisect from the top, and quadrisect from the bottom vertical lines placed in their left, center, and right visual spaces. Distance from the true midpoint and quadripoint were calculated and compared between the two groups.

Results: No significant difference was found between the ASD and control groups for vertical line bisections or bottom quadrisections. However, ASD participants had a greater deviation above the true top quadripoint than control participants for top quadrisections (t(37)=1.74, p=0.045).

Conclusion: Our results indicate that there is no downward spatial bias in ASD populations, and thus attentional biases are likely not contributing to the mouth preference exhibited by individuals with ASD. Rather, for the top quadrisections there is an upward bias in the ASD group. This may be due to the more local attentional demands of the quadrisection task but needs further investigation.

Keywords

Autism; line bisection and quadrisection; vertical attention; local and global attention; spatial bias; dorsal and ventral streams

Introduction

Autism spectrum disorders (ASD) are characterized by repetitive behavioral patterns and difficulty with social interactions, communication, and development of interpersonal relationships (Lord, Elsabbagh, Baird, & Veenstra-Vanderweele, 2018). Latest estimates of the prevalence of ASD by the Centers for Disease Control and Prevention is 1 out of 54 children (Maenner et al., 2020).

The neurobehavioral mechanisms behind social interaction difficulties exhibited by individuals with ASD are not yet fully understood. However, development of interpersonal relationships and effective social communication are related to the ability to interpret facial expressions. Individuals with ASD have been shown to have face-emotion recognition deficits, and this could be related to attending more to the mouth during social interactions, whereas neurotypical individuals focus more on the eyes (Lozier, Vanmeter, & Marsh, 2014; Neumann, Spezio, Piven, & Aldophs, 2006). Since perception depends upon attention, attentional biases could conceivably be a contributing factor as to why individuals with ASD have altered patterns of visual scanning of faces, which might be related to the impairments in facial emotional recognition.

In order to properly interact with the environment, a person must be able to attend to spatial stimuli. One major neurological disorder that prevents patients from properly interacting with their environment is spatial neglect, which is associated with hemispheric brain damage, particularly from strokes (Corbetta & Shulman, 2011; Li & Malhotra, 2015). Spatial neglect is the inability to attend to certain aspects of visual space, and although most studies have focused on neglect with regards to horizontal space, reports have shown that neglect can also occur in vertical space (Rapcsak, Cimino, & Heilman, 1988; Michael, Aleksandra, & Heilman, 2020). Line bisection tasks, tests of spatial attention, have been used as simple and effective clinical markers of visuospatial bias for neglect patients. During vertical line bisections and quadrisections, neurotypical individuals demonstrate an upward bias, termed altitudinal pseudoneglect, and this tendency has provided some insights into the typical allocation of vertical attention (Falchook, Mody, Srivastava, Williamson, & Heilman, 2012; Heber, Siebertz, Wolter, Kuhlen, & Fimm, 2010; Jewell & McCourt, 2000).

During visual processing, information leaves the primary visual cortex and is subdivided into two extrastriate areas, including the dorsal (“where”) stream projecting to the parietal lobe and the ventral (“what”) stream projecting to the temporal lobe (Fellman & Van Essen, 1991; Young, 1992). The dorsal stream is implicated in processing the relative spatial location of objects, whereas the ventral stream is associated with face and object recognition (Mishkin, Ungerleider, & Macko, 1983). Additionally, evidence from patients with bilateral hemispheric focal lesions has revealed that the ventral visual association areas appear to mediate attention to upper visual space (Shelton, Bowers, & Heilman, 1990) and the dorsal stream is associated with directing attention to lower visual space (Butter, Evans, Kirsch, & Kewman, 1989; Rapcsak et al., 1988). Based on these studies the altitudinal pseudoneglect displayed by normal participants during vertical line bisection tasks has been proposed to result from the ventral system’s dominance in allocating vertical attention (Drain & Reuter-Lorenz, 1996). Furthermore, allocentric (object-to-object) representations of space are associated with the ventral stream, and egocentric (self-to-object) representations are mediated by the dorsal stream (Neggers, Van der Lubbe, Ramsey, & Postma, 2006). Therefore, it is also proposed that the upward bias during vertical line bisections is due to the allocentric (object-based) nature of the bisection task, which would activate the ventral stream over the dorsal stream (Falchook et al., 2012). Lastly, the local vs global attentional demands of a task may also influence line bisection and quadrisection judgements, as can be seen with quadrisections (which require more focal attention) resulting in a greater upward bias compared to bisections (Falchook et al., 2012).

Compared to neurotypical individuals, studies have found differences in the dorsal and ventral association networks of individuals with ASD. For example, motion-processing experiments have revealed altered performance on tasks associated with the dorsal stream in individuals with ASD (Spencer et al., 2000). Additionally, previous fMRI research has shown that the ventral visual cortex appears to be organized differently in high-functioning adults with ASD, which supports the well-established finding that individuals with ASD have reduced activation within face-selective regions (Humphreys, Hasson, Avidan, Minshew, & Behrmann, 2008). Since these more ventral portions of the visual processing network mediate upward attention, the primary aim of this study is to learn if people with ASD have atypical vertical attention, such that a downward attentional bias might be a factor in the mouth preference observed in facial scanning in ASD. To investigate this, we led 20 ASD and 20 control participants through vertical line bisection and quadrisection tasks. By elucidating whether an attentional disorder could be influencing the visuospatial processing of individuals with ASD, we may reveal insights into a mechanism that could be contributing to the impairment of facial recognition within social communication.

Methods

Participants

Participants included 20 individuals with ASD and 20 age and sex-matched neurotypical individuals, between the ages of 6 and 23 (ASD mean = 14.3 ± 5.26 SD, control mean = 14.3 ± 4.99 SD). Of the 40 participants, 32 participants were male and 8 were female, of which 4 females were control and 4 females were ASD participants. All participants were right-handed and were required to have an IQ score above 85. Overall groups had comparable mean IQ scores as measured by the Wechsler Abbreviated Scale of Intelligence II (ASD mean = 107.0 ± 2.61 SD, control mean = 107.7 ± 2.36 SD). The neurotypical group consisted of individuals without history of any neuropsychiatric or neurodevelopmental disorders. All participants volunteered and signed informed consents approved by the University of Missouri-Columbia Institutional Review Board.

Apparatus

This study used a trifold white poster board with dimensions of 121.9 cm × 91.4 cm. Each wing of the poster board had a width of 30.5 cm, and the center section was 61 cm wide. The poster board was placed on a cabinet and propped up against a wall. Pieces of paper 21.6 cm × 27.9 cm with centered black vertical lines 22.7 cm in length and 1 cm in width were used for the bisection and quadrisection tasks. During these tasks, pieces of paper were pinned to the board using tacks and adjusted in height such that the center of the line was at each participant's eye level. For bisection and quadrisection tasks in the center space, the black vertical line to be bisected was located at the participant's midsagittal plane. The pieces of paper were horizontally adjusted for bisection and quadrisection tasks in the left and right hemispaces such that the lines were located 19.7 cm to the left or right of a participant's midsagittal plane.

Procedures

Consistent with the methodology used by Falchook et al. (2012), each participant was instructed to stand with their midsagittal plane facing the center of the board, and participants were guided to stand 45.7 cm from the board for each trial. Each piece of paper with a vertical line was then placed one at a time in the center, left, or right hemispace. The order in which the vertical lines were presented was randomized both within and across participants. Each participant was instructed to not move their feet, body, or head, and to keep their eyes fixated on the center panel. Therefore, for bisection tasks participants' eyes were pointed towards the sheet of paper, and for quadrisection tasks the participants' gaze was still fixated forward, requiring them to use their peripheral vision.

Participants were asked to bisect ("mark a line through the middle") and quadrisect ("mark a line 25% from the top or 25% from the bottom") the vertical lines using a pen. For each trial, participants were instructed on which hand to use, and this was also randomized within and between participants. After each trial, the piece of paper was removed, a new unmarked piece of paper with a vertical line was presented with a new set of conditions, and the participants were not given feedback on their performance. For each participant, 6 trials were completed for each condition (left, center, and right hemispaces) using each hand. This resulted in a total of 36 bisection trials and 72 quadrisection trials for each participant.

Analyses

Each attempted bisection and quadrisection was analyzed by comparing the trial to the true bisection or quadrisection. Bisection trials and top quadrisection trials were measured from the top of the line, while bottom quadrisection trials were measured from the bottom of the line. Utilizing the strategy presented by Falchook et al. (2012), error ratios were calculated for each trial. To calculate error ratios, the equation (113.5 mm - x mm)/113.5 mm was used for line bisections, the equation (56.75 mm - x mm)/56.75 mm was used for top quadrisections, and the equation (x mm - 56.75 mm)/56.75 mm was used for bottom quadrisections, where x is the distance from the participant's mark to the top of the line for bisections and top quadrisections, and to the bottom of the line for bottom quadrisections. For all conditions (bisection, top quadrisection, and bottom quadrisection), a positive error ratio signified an upward bias from the true midpoint or quadripoint, and a negative error ratio represented a downward bias from the true midpoint or quadripoint. For each condition (for example, right hand bisection in the left hemispace), the six trials were averaged to find the mean error ratio for that participant. A t-test was used to compare the mean error ratios between the ASD and control groups to determine the effect of bisection vs quadrisection, hand, and spatial placement.

Results

The results of the t-test indicate that there was no statistically significant difference between the ASD and control groups for left vs right hand conditions (t(37) = 0.133, p = 0.448), or for left vs center vs right visual space conditions. Therefore, data was collapsed across hand and visual space conditions to determine the overall comparison between ASD and control groups for bisections, top quadrisections, and bottom quadrisections. Results revealed no statistically significant difference between ASD and control groups for bisections (t(38) = 1.73, p = 0.831) or for bottom quadrisections (t(37) = 1.73, p = 0.401). However, there was a statistically significant difference for top quadrisections, with ASD participants having a greater deviation above the true top quadripoint than control participants (t(37) = 1.74, p = 0.045) (Figure 1).

Overall, the results demonstrate that individuals with ASD have similar upward biases in vertical line bisection tasks as neurotypical individuals. Additionally, individuals with ASD also tend to favor the ends of the vertical line during quadrisection tasks, similar to neurotypical individuals. However, as above, the upward bias for vertical top quadrisection tasks was greater for ASD individuals, which is the opposite of what would be expected if the mouth preference in facial scanning in ASD was driven by an attentional bias.

Discussion

Since the atypical gaze pattern in many studies suggests preference for the mouth rather than the eyes during social communication, this study aimed to determine the presence of vertical downward spatial bias. The results of this study found that there was no significant difference between the ASD and control groups for either bisection or for bottom quadrisections, which suggests that an attentional bias is not responsible for the mouth preference exhibited by individuals with ASD during social communication. It is worth noting that data on facial scanning preferences in ASD have mixed findings. While numerous studies reported a preference for gazing at the mouth in individuals with ASD (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Neumann et al., 2006), a recent study that investigated facial processing did not support the excess mouth/diminished eye gaze hypothesis in ASD, but rather a more exploratory facial scanning style (Vettori et al., 2020). Many with ASD are trained to look at the eyes during early intervention, potentially impacting findings in older individuals, but assessing spatial bias remains of interest to understand what could be driving this overall difference in facial scanning.

The results of this study do reveal a difference between ASD and control groups on top quadrisection tasks, with ASD participants deviating more towards the top of the line and thus exhibiting greater upward spatial bias compared to neurotypical individuals. These results are opposite of what would be expected if vertical spatial bias was responsible for the mouth preference in ASD. Falchook et al. (2012) demonstrated that neurotypical individuals exhibit an upwards vertical bias during both bisections and quadrisections, with a greater upwards bias for quadrisections compared to bisections. Researchers postulated that this greater upwards bias for quadrisections was due to the more local attentional demands of the task leading to a greater activation of the ventral stream. In our results, individuals with ASD demonstrated an even greater upward bias in top quadrisection tasks compared to the typical upward bias for neurotypical individuals performing this task. Thus, the greater upward bias during the top quadrisection tasks in the ASD group may highlight an underlying mechanism of a tendency towards local over global visuospatial processing in individuals with ASD.

These findings may also relate to the well-established hypothesis of weak central coherence in ASD populations, wherein individuals with ASD have difficulties extracting meaning or seeing the big picture. The mechanisms behind this processing style have been reported to consist of an increased emphasis on the local aspects of stimuli and/or deficits in the processing of global stimuli (Happé & Frith, 2006). Studies have had mixed findings regarding whether visual processing patterns can be explained by a local bias (Bertone, Mottron, Jelenic, & Faubert, 2005; Joseph, Keehan, Connolly, Wolfe, & Horowitz, 2009) vs a global deficit (Nayer, Voyles, Kiorpes, & Di Martino, 2017). The varied findings could be due to different methods for analyzing global vs local processing, such as visual search tasks and embedded figure tasks, or may also be explained by the diverse nature of autism symptomatology. Stevenson et al. (2018) found that enhanced local processing does not come at the expense of global processing, but moreover reflects a default in the processing strategy. Consistent with these results, since bisection tasks require more global processing and quadrisection tasks require more local processing, our findings support that individuals with ASD have exaggerated local processing and baseline global processing compared to neurotypical individuals.

Overall, our results do support the hypothesis that individuals with ASD have different perceptual strategies, regardless of their impact on facial scanning during social communication. One study using fMRI scans found that individuals with ASD have lower activation in the face-selective fusiform gyrus during facial processing, and higher activation of the object-related medial occipital gyrus. Additionally, their results also found that individuals with ASD had higher cortical activation in regions associated with visual search during facial processing, which supports the hypothesis of a local-processing bias (Hubl et al., 2003). Another study that investigated visual processing along different points of the ventral stream pathway in individuals with ASD found enhanced fine-form (local) processing in the primary visual cortex and deficits in gestalt face-processing in the fusiform gyrus (Yamasaki et al., 2017). These studies support our findings that enhanced local processing underlies visual perception in ASD populations.

While this evidence seems to be in agreement with local processing perceptual strategies in ASD, they are the opposite of what would be expected for spatial orientation being a factor in the mouth vs eye preference exhibited by ASD populations. If the greater upward bias in top quadrisections we found was impacting facial scanning, then we would observe greater eye gazing and less mouth gazing in individuals with ASD. Since this is not the case, there must be other factors contributing to the atypical facial scanning in ASD, such as decreased social salience of the eyes. Future studies should further investigate the upward vertical bias during top quadrisection tasks reported here as it might have other effects on visuospatial perception in ASD.

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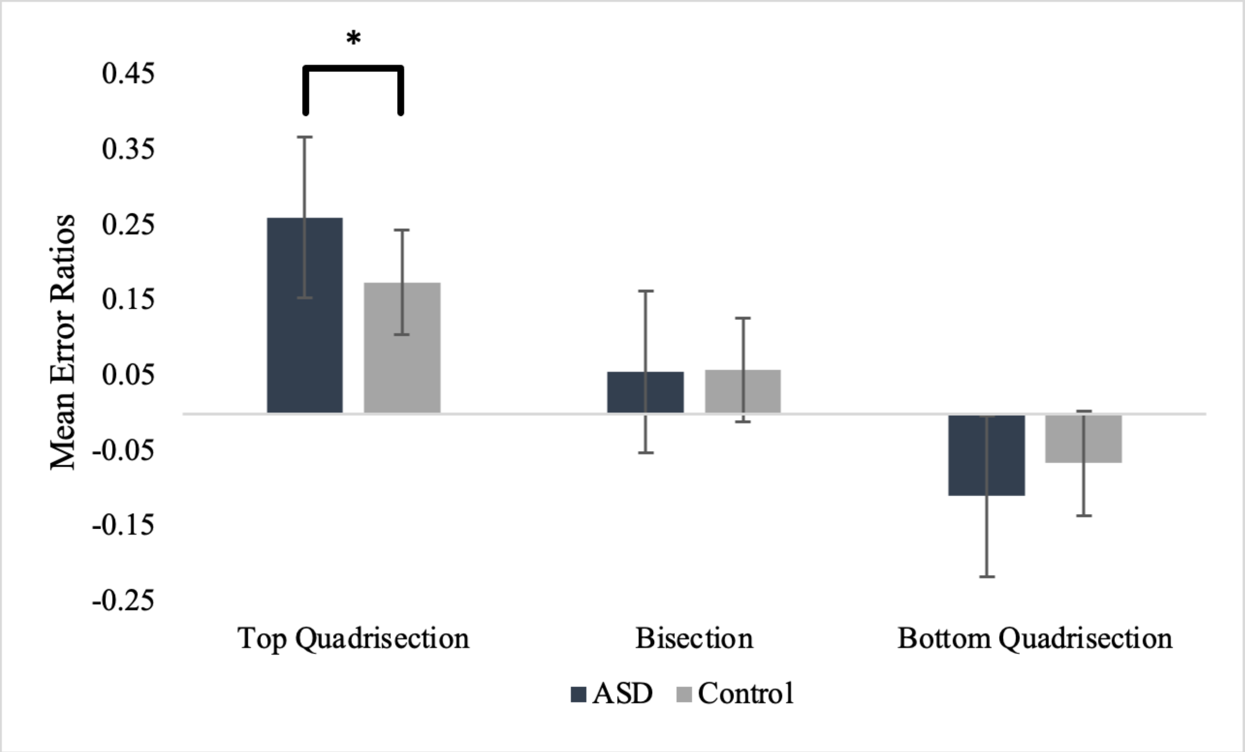

Figure 1: Mean error ratios for vertical line top quadrisection, bisection, and bottom quadrisection. Positive error ratios denote an upwards bias, while negative error ratios denote a downwards bias. Error ratios were calculated with the equations (113.5 mm - x mm)/113.5 mm for bisections, (56.75 mm - x mm)/56.75 mm for top quadrisections, and (x mm - 56.75 mm)/56.75 mm for bottom quadrisections. *$p < 0.05$.