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ORIGINAL PAPER

Visuospatial Bias in Children with Autism Spectrum Disorder: Evidence from Line Bisection Tasks

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Abstract

Previous studies have found reduced leftward bias of facial processing in individuals with Autism Spectrum Disorder (ASD). However, it is not clear whether they manifest a leftward bias in general visual processing. To shed light on this issue, the current study used the manual line bisection task to assess children 5 to 15 years of age with ASD as well as typically developing (TD) children. Results showed that children with ASD, similar to TD children, demonstrate a leftward bias in general visual processing, especially for bisecting long lines (≧ 80 mm). In both groups, participant performance in line bisection was affected by the hand used, the length of the line, the cueing symbol, and the location of the symbol. The ASD group showed a rightward bias when bisecting short lines (30 mm) with their left hands, which slightly differed from the TD group. These results indicate that while ASD individuals and TD individuals share a similar leftward bias in general visual processing, when using their left hands to bisect short lines, ASD individuals may show an atypical bias pattern.

Keywords Autism spectrum disorder · Visuospatial bias · Line bisection task · Visual processing

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental disorder characterized by abnormal social interactions as well as restricted interests and repetitive behaviors (APA, 2013). Individuals with ASD often exhibit atypical facial processing (Meaux et al., 2011). In recent years, several evidences have been found suggesting that individuals with ASD show an atypical visuospatial bias for faces which may be the cause of their abnormal facial processing and, more generally, an obstacle to social interaction engagement.

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Visuospatial Bias for Faces

Studies using chimeric face tasks have found that, in typically developing (TD) individuals, face identification and facial emotion recognition are based primarily on the viewer's left visual field (Aljuhanay et al., 2010), which has been termed left perceptual bias and has been observed in children from the age of six (Chiang et al., 2000). Left perceptual bias has also been demonstrated by examining the eye-movement patterns of TD individuals. When looking at faces, the majority of participants' initial saccades were found to be toward the left side (Butler et al., 2005; Leonards & Scott-Samuel, 2005), with more time spent fixated to the left than the right side of the face they were viewing (Mertens et al., 1993). This eye-movement pattern has been termed the left gaze bias. The left gaze bias has been observed during various face processing tasks including free viewing, familiarity judgement, and expression judgement

(Guo et al., 2012), and has been observed to be present from infancy (Liu et al., 2011; Xiao et al., 2014).

In contrast to TD individuals, those with ASD show atypical visuospatial bias in chimeric face tests. Ashwin et al. (2005) found that, similar to the TD group, the Asperger syndrome group showed a left visual field bias in a facial emotion task (i.e., happy versus angry), but this bias was reduced in identity-focused chimeric tasks (Ashwin et al., 2005). A study by Taylor et al. (2012) used the "Universal" Chimeric Faces Task which included six emotional expressions (i.e., happiness, sadness, surprise, disgust, fear, anger) and found that children with ASD showed a left hemispatial bias for only two of the facial expressions, "happiness" and "anger" (Taylor et al., 2012). Results for the children with ASD aged 11 to 15 years revealed an overall pattern of lateralization similar to TD children aged 5 to 6 years, and a less lateralized pattern than TD children aged 7 to 8 years (Taylor et al., 2012). Using an eye-tracking task, Dundas et al. (2012a) found that the TD group revealed significantly more fixation points on the left visual field than the right when processing a face, while the ASD group showed no preference in their eye movements (Dundas et al., 2012a). Dundas et al. (2012b) also studied infants at high and low risks for ASD and found that infants at low risk for ASD showed a preference for the left visual field when they are looking at a face, while infants at high risk for ASD did not demonstrate a left visual field bias (Dundas et al., 2012a).

Overall, existing research suggests that individuals with ASD demonstrated less left bias in facial processing. But what is the mechanism behind the bias? Research on TD individuals has shown that a leftward attention bias in general visual processing maybe one of the factors which mediates the left bias of facial processing (Levy et al., 1983; Luh et al., 1991; Yovel et al., 2008). But how does general visual processing take place in ASD individuals? Does an atypical bias in general visual processing contribute to reduced facial bias in individuals with ASD?

Visuospatial Bias for Non-face Stimuli

TD individuals show a slight leftward bias in general visuospatial processing, such that they judge the subjective midpoint to be to the left in line bisection tasks, and tend to judge stimuli appearing in the left visual field as being larger, brighter, or more numerous than comparable stimuli appearing in the right visual field, while also responding more quickly to stimuli appearing in the left visual field (Charles et al., 2007), also known as "pseudoneglect" (Jewell & McCourt, 2000). Pseudoneglect denotes a visuospatial bias in favour of the left side, which reflects a functional architecture feature of the visual attention system in the human brain (Benwell, 2015). Some studies have found that ASD individuals may have abnormal left visual field processing in general visuospatial tasks. English et al., (2015, 2017) conducted a series of studies on the visual spatial bias in individuals with different autistic traits which found that participants with high autistic traits showed less left bias in both the greyscales task (English et al., 2015) and the landmark task (English et al., 2017) than participants with low autistic traits, and that there was a negative correlation between the left bias and the social skill scores as measured using the Autism Spectrum Quotient questionnaire (English et al., 2015).Using a gap-overlap task, a study by Bryson et al. (2018) found that the disengagement of attention in the left and right visual fields is asymmetric in children with ASD. When compared to the performance of TD infants, the latency of attentional disengagement in ASD infants was significantly longer only when the new stimulus appeared in the left visual field; when the stimulus appeared in the ASD individuals' right visual field, there was no significant difference in attentional disengagement latency between ASD and control groups (Bryson et al., 2018). Although the gap-overlap tasks were used to measure attentional disengagement and the tasks differed from those used by English et al., (2015, 2017), all of these results indicate that individuals with ASD or higher autistic trait levels process information in the leftward visual field differently compared to TD individuals.

In contrast with the aforementioned findings, however, some studies have found that autistic individuals exhibited a similar left visual field bias to that of TD people. Using symmetric outdoor and indoor scene pictures, one study found that children with ASD showed the same left-field fixation advantage as TD children (Li, 2014). A visual spatial orientation study by Wainwright and Biyson (1996) showed that when stimulus was presented at one of the three positions—left, middle, or right—ASD participants did not show the same advantage in the left visual field as the chronological-age-matched TD group, but there were no differences found between the ASD group and the mental-age-matched TD group (Wainwright & Biyson, 1996).

Overall, existing research is inconclusive regarding discrepancies on the leftward bias between ASD individuals and TD individuals in general visual processing. Moreover, some shortcomings also exist in previous studies. English et al., (2015, 2017) recruited neurotypical adults with high or low autistic traits rather than individuals diagnosed with ASD as participants for their study, while in the studies by Li (2014) and Wainwright and Biyson (1996), the chronological-age and cognitive ability of the two groups were not strictly controlled.

Current Study

In summary, there is no consistent conclusion as to whether ASD individuals show pseudoneglect in general visual processing. To address this gap in knowledge, the current study used the classical line bisection task to explore whether ASD individuals had a left bias in their general visual space.

Studies have shown that the length of the line, the hand they use, and the end-of-line cues all affect TD participant responses in the line bisection task. The "line-length effect" describes the phenomenon that, when the horizontal viewing angle of a line is greater than six degrees, individuals show a slightly left bias; when the horizontal angle of view is less than six degrees, the subjective midpoint of the line does not have a left bias, but instead tends towards the line's objective midpoint (Benwell et al., 2014). The hand used to perform the task has also been shown to affect an individual's performance in line bisection tasks (Jewell & McCourt, 2000), and notably affect line bisection performance in children with dyslexia and attention deficit hyperactivity disorder (Waldie & Hausmann, 2010). Finally, the cues that identify the end of a line have also been shown to influence line bisection performance (Jewell & McCourt, 2000; Michel et al., 2011). With these details in mind, the current study investigated the line bisection tasks of children with ASD by examining the effects of line length, hand use, and line end cues using two separate experiments.

Table 1 Mean age (SD), mean combined raven test (SD), and independent sample t-test for ASD and TD groups in Experiment 1

	TD[a] group ($n=37$)	ASD[b] group ($n=28$)	t	p
Age	9.585 ± 3.289	10.277 ± 2.828	− .892	.376
CRT[c]	39.784 ± 14.100	34.857 ± 13.646	1.414	.162

[a]Typical-developmental
[b]Autism spectrum disorder
[c]Combined Raven Test

Table 2 Mean age (SD), mean combined Raven test (CRT; SD), and independent sample t-test for ASD and TD groups in Experiment 2

	TD[a] group ($n=37$)	ASD[b] group ($n=30$)	t	p
Age	9.552 ± 3.310	10.027 ± 2.897	− .617	.539
CRT[c]	39.540 ± 14.346	34.000 ± 13.869	1.595	.115

[a]Typical-developmental
[b]Autism spectrum disorder
[c]Combined Raven test

Method

Participants

For the ASD group, children with ASD were recruited from institutions which provide them with educational service. The inclusion criteria were: (a) a previous diagnosis of ASD by experienced pediatricians in provincial hospitals; (b) between 5 and 15 years of age; (c) right-handed (Oldfield, 1971); (d) could pass a comprehension check in which the child was presented with an image (i.e., three figures, five trees, or three flowers, side by side) and asked three times to indicate which person, tree, or flower was in the middle to ensure they understood the meaning of the term "middle" by answering correctly each time; e) normal or corrected-to-normal visual acuity and the ability to concentrate on an ongoing task for at least 15 min; (f) not taking antipsychotic medicine.

The TD control group consisted of right-handed TD children of the same sex and chronological age as the children in the ASD group (i.e., 5 to 15 years of age) recruited from kindergarten and schools. Children in the TD group did not have any mental disorders (e.g., mental retardation, attention deficit hyperactivity disorder, etc.,) and were not taking antipsychotic medicine. They had normal or corrected-to-normal visual acuity and had also passed the comprehension check.

In total, there were 31 children in the ASD group (female = 2) and 40 in the TD group (female = 2). All of them participated in both experiments. Based on Boxplot, both mild Outliers and extreme Outliers of the dependent measures were excluded. After excluding data outliers in each experiment, Experiment 1 had 28 participants in the ASD group and 37 in the TD group, and Experiment 2 had 30 participants in the ASD group and 37 in the TD group. There was no significant difference between the two groups with regards to ages and CRT scores, as shown in Tables 1 and 2.

Measures

Edinburgh Handedness Inventory (Oldfield, 1971). The Chinese version of the Edinburgh Handedness Inventory was used to measure the handedness of participants. The asymmetry-index provided by this test is calculated as $R-L/R+L\times 100$, and results in values between − 100 and + 100 (Yang et al., 2018). Ambidextrous or left-handed children who scored below 60 were excluded from the study.

Childhood Autism Rating Scale (CARS; Schopler et al., 1980). The Chinese version of the CARS was used to measure the severity of ASD participants' core symptoms (Li et al., 2005). The CARS consists of 15 scales, each reflecting a specific feature of autism. A trained therapist rates each child based on their observations and interviews with the child's parents in the child institutions.

Combined Raven Test (CRT). Chinese researcher Dan Li combined the first three units of the Raven's Colored Progressive Matrices and the last three units of the Raven's Standard Progressive Matrices to form a measure that used 72 questions in six units, called the Combined Raven Test

(Wang et al., 2007). A trained research assistant measured each participant at either their child facility or school.

ASD group participants answered all the measures listed above. The TD group participants took the Edinburgh Handedness Inventory and CRT, but not the CARS.

Materials and Procedure

Experiment 1

Lines of different lengths (i.e., 30 mm, 80 mm, 130 mm, and 180 mm) were printed on A4 paper. The lines were 0.5 mm thick and at the center of the page. Each page contained only one line. A total of eight copies were made of each line length, making a total of 32 lines, each on their own separate page. As the participants sat at a desk, they were presented with one horizontal line at a time, centered to their body, placed approximately 40 cm away from their eyes. As each line was presented, the participants were instructed to mark the midpoint of the line with a ballpoint pen ("Please draw the midpoint of this line with your right/left hand. Please note not to measure the line with your fingers. Just look at the line with your eyes, and then draw the midpoint."). The participants were asked to draw the midpoint of four lines of different lengths first by using their right hand, and then the same on another four lines using their left hands. The order in which the different lengths were presented was random. After drawing 16 lines, the participant was given a five-minute break before continuing to mark another 16 lines.

Experiment 2

One line (200 mm long, 0.5 mm thick) was printed alone on an A4 piece of paper. The left, right, or bilateral ends of the line were denoted with cue symbols of ">" or "<". The cue symbol line thickness was 0.5 mm and formed an angle of 90 degrees. The full size of the cue symbol was 5 mm wide and 10 mm long. There were six different conditions: (a) four lines with a ">" symbol at the left end of the line ("left >"); (b) four lines with a ">" symbol at the right end of the line ("right >"); (c) four lines with a "<" symbol at the left end of the line ("left <"); (d) four lines with a "<" symbol at the right end of the line ("right <"); (e) four lines with "<" symbols at the bilateral ends of the line ("two <"); (f) four lines with ">" symbols at the bilateral ends of the line ("two >"). There were 24 lines in total. See Fig. 1 for a visual depiction of each of the line conditions. The lines were presented to the participants one at a time, centered to their body, and the participants were asked to mark the midpoint of the line using their right hands ("You can see there is/are symbol(s) like an arrow on the end(s) of the line. The symbol is the decoration of the line. Ignore the decoration and mark the midpoint of the line with your right hand. Please note not to measure the line with your fingers. Just look at the line with your eyes, and then draw the midpoint."). The lines of each different condition were presented to the participants in a random order.

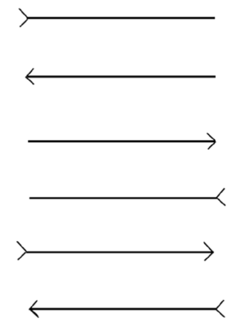

Fig. 1 Line conditions used in Experiment 2

Data Analysis

The marked "midpoint" position was measured lengthwise from the left side of the line using a ruler, with an accuracy of 0.5 mm. The visuospatial bias value was calculated using the formula $\text{measured left half} - \text{true half}/\text{true half} \times 100$ (Waldie & Hausmann, 2010). The measured left half was the length from the left end of a line to the marked midpoint, and the true half was the real half of a line. A negative value indicated that the subjective midpoint was positioned to the left (i.e., a leftward bias); a positive value meant that the subjective midpoint was positioned to the right (i.e., a rightward bias). There were four trials performed under each condition (e.g., 30 mm and right hand). The average of the four trials was calculated to be a value under one condition for a participant. In Experiment 1, the response bias was analyzed using repeated measurements ANOVA using line length (i.e., 30 mm, 80 mm, 130 mm, 180 mm) and hand used (i.e., left, right) as within-subject factors, while group (i.e., ASD children, TD children) was a between-subject factor. In Experiment 2, the response bias was analyzed using repeated measurements ANOVA with Cueing Location (i.e., right cue, left cue, two cues) and Cue Symbol (i.e., <, >) as within-subject factors, and group (i.e., ASD children, TD children) as a between-subject factor. A single sample *t*-test was used to analyze whether the left or right bias was significant. Correlation analysis was used to assess the relationship between the value of visuospatial bias and CARS.

The visuospatial bias value was either positive or negative, and averaging the value reduced the distance of the subjective midpoint to the objective midpoint. The absolute value of the visuospatial bias of each line and an independent sample *t*-test were used to compare the accuracy of the line bisection between the two groups.

Results

Experiment 1

Main and Interaction Effects of Group, Hand Used, and Length

A mixed design analysis of variance showed that the main effect of the group was not significant: $F(1,63)=1.081$, $p=0.302>0.05$, $\eta_p^2=0.017$. The main effect of the hand used was significant: $F(1,63)=18.052$, $p=0.000$, $\eta_p^2=0.223$. Both groups' participants showed stronger leftward bias with the right hand ($M=-4.092$, $SD=0.565$) than with the left hand ($M=-1.854$, $SD=0.481$). The main effect of the line length was significant for both two groups: $F(3,61)=10.066$, $p=0.000$, $\eta_p^2=0.331$. Paired comparison showed that the leftward bias when marking the 180 mm line ($M=-4.464$, $SD=0.577$) was significantly stronger than when marking the 130 mm line ($M=-3.343$, $SD=0.592$, $p=0.013$), the 80 mm line ($M=-2.951$, $SD=0.565$, $p=0.011$), and the 30 mm line ($M=-1.135$, $SD=0.519$, $p=0.000$).The leftward bias when marking the 130 mm line was non-significantly stronger than when marking the 80 mm line ($p=0.443$), and significantly stronger than when marking the 30 mm line($p=0.000$).The leftward bias when marking the 80 mm line was significantly stronger than when marking the 30 mm line($p=0.001$). On the whole, in both two groups, the longer the length, the stronger the leftward bias. The interaction effect between hand used and line length was significant: $F(3,61)=7.478$, $p=0.000$, $\eta_p^2=0.269$. Further analysis on the simple effect revealed that there was no significant difference between the different line lengths when using the right hand: $F(3,61)=1.747$, $p=0.167$, $\eta_p^2=0.079$ (paired comparison at its smallest: $p=0.155$). When using the left hand, a simple effect of line length was significant: $F(3,21)=13.804$, $p=0.000$, $\eta_p^2=0.404$. Through further multiple comparisons, we found that when both ASD and TD participants marked the midpoint with their left hands, the bias value for the 30 mm length line ($M=1.607$, $SD=0.703$) was significantly greater than for the 80 mm length line ($M=-2.451$, $SD=0.761$, $p=0.000$), the 130 mm length line ($M=-2.704$, $SD=0.665$, $p=0.000$), the 180 mm length line ($M=-3.868$, $SD=0.671$, $p=0.000$).There were no significant differences between the other different line lengths ($ps>0.375$). There was no significant interaction found among the factors of the group, the line length, and the hand used (see Table 3).

Visuospatial Bias Test

A single sample t-test with 0 was conducted for each group. When using the right hand to mark the midpoint of all lines, both groups showed significant leftward bias. When using the left hand to mark the midpoint of the 30 mm line, TD participants showed no leftward or rightward bias ($p=0.931$), while ASD participants did show significant rightward bias ($p=0.001$). When marking the midpoint of the 80 mm line with the left hand, TD participants showed significant leftward side bias ($p=0.001$) while the ASD group showed no bias ($p=0.234$). When marking the midpoint of the 130 mm line with the left hand, TD participants again showed significant leftward side bias ($p=0.000$), while ASD participants showed marginally significant leftward bias ($p=0.088$). When marking the midpoint of the 180 mm line, both groups showed significant leftward bias. See Tables 4 and 5 for the full analysis results.

Although no significant interaction between groups, line length, or hand used was found in the AVONA, the visuospatial bias when using the left hand seemed to differ between the two groups. Thus, a further comparison between the two groups under each condition was conducted. The results of t-test are shown in Table 6. In the condition of 30 mm line with left hand, there was a significant difference between groups: $t(63)=-2.157$, $p=0.035$, $d=0.551$. The ASD group ($M=3.124$, $SD=4.635$) showed significant stronger rightward bias when compared with the TD group ($M=0.090$, $SD=6.251$). In the conditions of 80 mm, 130 mm, or 180 mm with the left hand, the bias values of the ASD group were all slightly larger than those of the TD group, but the difference was not significant. There were no significant differences found when participants used their right hands.

Accuracy Comparison

We used the absolute value of the visuospatial bias value for the t-test and found no significant difference in accuracy between the two groups (see Table 7).

Table 3 Main and interaction effects of group (i.e., ASD, TD) × hand used (i.e., right, left) × length (i.e., 30 mm, 80 mm, 130 mm, 180 mm) ANOVA

Effect	F	p	η_p^2
Group	1.081	.302	.017
Hand used	18.052	.000	.223
Hand used × Group	2.466	.121	.038
Line length	10.066	.000	.331
Line length × Group	.242	.866	.012
Hand used × Length	7.748	.000	.269
Hand used × Line length × Group	1.022	.389	.048

Table 4 Visuospatial bias in TD group in Experiment 1

	Right[a] 30 mm	Right 80 mm	Right 130 mm	Right 180 mm	Left[b] 30 mm	Left 80 mm	Left 130 mm	Left 180 mm
M ± SD	− 3.626 ± 5.666	− 3.818 ± 5.914	− 3.670 ± 5.206	− 5.488 ± 5.219	.090 ± 6.251	− 3.277 ± 5.216	− 3.451 ± 4.868	− 4.321 ± 5.119
t	− 3.893	− 3.926	− 4.287	− 6.396	.088	− 3.822	− 4.312	− 5.134
p	.000	.000	.000	.000	.931	.001	.000	.000

[a]Participants used their right hands

[b]Participants used their left hands

Table 5 Visuospatial bias in ASD group in Experiment 1

	Right[a] 30 mm	Right 80 mm	Right 130 mm	Right 180 mm	Left[b] 30 mm	Left 80 mm	Left 130 mm	Left 180 mm
M ± SD	− 4.127 ± 4.981	− 3.084 ± 5.630	− 4.293 ± 6.536	− 4.630 ± 6.023	3.124 ± 4.635	− 1.626 ± 7.060	− 1.957 ± 5.849	− 3.416 ± 5.659
t	− 4.384	− 2.899	− 3.475	− 4.068	3.566	− 1.218	− 1.771	− 3.194
p	.000	.007	.002	.000	.001	.234	.088	.004

[a]Participants used their right hands

[b]Participants used their left hands

Table 6 Visuospatial bias comparison of ASD and TD groups in Experiment 1

	Right[a] 30 mm	Right 80 mm	Right 130 mm	Right 180 mm	Left[b] 30 mm	Left 80 mm	Left 130 mm	Left 180 mm
TD	− 3.626 ± 5.666	− 3.818 ± 5.914	− 3.670 ± 5.206	− 5.488 ± 5.219	.090 ± 6.251	− 3.277 ± 5.216	− 3.451 ± 4.868	− 4.321 ± 5.119
ASD	− 4.127 ± 4.981	− 3.084 ± 5.630	− 4.293 ± 6.536	− 4.630 ± 6.023	3.124 ± 4.635	− 1.626 ± 7.060	− 1.957 ± 5.849	− 3.416 ± 5.659
t	.371	− .505	.428	− .614	− 2.157	− 1.085	− 1.123	− .674
p	.712	.615	.670	.541	.035	.282	.266	.503

[a]Participants used their right hands

[b]Participants used their left hands

Table 7 Accuracy comparison of ASD and TD groups in Experiment 1

	Right[a] 30 mm	Right 80 mm	Right 130 mm	Right 180 mm	Left[b] 30 mm	Left 80 mm	Left 130 mm	Left 180 mm
TD	6.599 ± 3.729	6.774 ± 3.991	6.435 ± 3.500	7.057 ± 4.007	7.658 ± 4.791	6.132 ± 2.965	6.809 ± 2.821	6.783 ± 3.445
ASD	6.746 ± 3.215	6.432 ± 3.566	7.411 ± 4.118	6.980 ± 3.669	6.702 ± 4.383	7.437 ± 4.051	7.081 ± 3.123	6.006 ± 3.396
t	− .166	.357	− 1.032	.079	.826	− 1.500	− .368	.906
p	.868	.722	.306	.937	.412	.139	.714	.368

[a]Participants used their right hands

[b]Participants used their left hands

Relationship Between Visuospatial Bias and Severity of Autism Symptoms

Correlation analysis showed that the visuospatial bias values had no significant correlation with the CARS values for the ASD participants (see Table 8).

Experiment 2

Main and Interaction Effects of Group, Cue Symbol, and Cue Location

The mixed design analysis of ANOVA showed that the main effect of the group was not significant: $F(1,65) = 0.258$, $p = 0.613$, $\eta_p^2 = 0.004$. The main effect of the cue symbol

Table 8 Correlation analysis between visuospatial bias and autism symptoms in Experiment 1

	Right[a] 30 mm	Right 80 mm	Right 130 mm	Right 180 mm	Left[b] 30 mm	Left 80 mm	Left 130 mm	Left 180 mm
R[c]	.160	.010	.175	.285	.088	.167	.164	.281
p	.417	.961	.373	.141	.658	.396	.403	.148

[a]Participants used their right hands; [b]Participants used their left hands; [c]Correlation coefficient

Table 9 Main and interaction effects of group (i.e., ASD, TD) × cue symbol (i.e., <, >) × cue location (i.e., right cue, left cue, two cues) ANOVA

Effect	*F*	*p*	η_p^2
Group	0.017	.898	0.000
Cue symbol	28.975	.000	.308
Cue symbol × Group	.091	.764	.001
Cue location	3.257	.045	.092
Cue location × Group	1.820	.170	.054
Cue symbol × Cue location	1.170	.317	.035
Cue symbol × Cue location × Group	.466	.629	.014

was significant: $F(1,65) = 28.975$, $p = 0.000$, $\eta_p^2 = 0.308$. The leftward bias of the symbol ">" ($M = -5.602$, $SD = 0.558$) was stronger than that of "<" ($M = -4.104$, $SD = 0.575$). The main effect of the cue location was significant: $F(2,64) = 3.257$, $p = 0.045$, $\eta_p^2 = 0.092$. The leftward bias of the left location ($M = -5.612$, $SD = 0.690$) was stronger than both that of the right location ($M = -4.498$, $SD = 0.593$) and that of the bilateral location ($M = -4.448$, $SD = 0.551$). There was no significant difference between the right and bilateral placements ($p = 0.909$), and no significant interaction between the cue symbol and the cue location. There was no significant interaction found among the factors of the group, the cue symbol, and the cue location (see Table 9).

Visuospatial Bias Test

A single sample *t*-test with 0 was conducted for both groups. Significant left bias was found in both groups. No matter which type of cue symbol was used, or where the cue was located, participants in both groups showed left bias (see Tables 10 and 11).

Accuracy Comparison

We used the absolute value of the visuospatial bias value for the *t*-test and found no significant difference in accuracy between the two groups (see Table 12).

Relationship Between Visuospatial Bias and Severity of Autism Symptoms

Correlation analysis showed that visuospatial bias values had no significant correlation with the CARS values for the ASD participants in Experiment 2 (see Table 13).

Discussion

The results of the two experiments conducted in the current study showed that there was a significant leftward bias in both ASD and TD groups—in which all participants were right-handed—in visual space processing, and no significant difference in bias value or accuracy between the two groups. In Experiment 1, both groups manifested a significantly stronger leftward bias with the right hand than with the left hand, and the longer the line length, the stronger the leftward bias. In Experiment 2, we found that the midpoint of the line using ">" as a cue symbol was marked as being more toward the left. The leftward bias of the left cue location was stronger than both that of the right cue location and the bilateral cue location. In both experiments, no correlation

Table 10 Visuospatial bias in TD group in Experiment 2

	Left[a]<[b]	Right[c]>[d]	Left>	Right<	Two>	Two<
M ± SD	− 4.426 ± 6.614	− 4.563 ± 4.557	− 5.793 ± 6.325	− 3.334 ± 5.339	− 5.486 ± 4.547	− 3.841 ± 4.894
t	− 4.070	− 6.091	− 5.571	− 3.799	− 7.340	− 4.775
p	.000	.000	.000	.001	.000	.000

[a]Cue symbol located at the left end of the line
[b]Cue symbol was "<"
[c]Cue symbol located at the right end of the line
[d]Cue symbol was ">"

Table 11 Visuospatial bias in ASD group in Experiment 2

	Left[a]<[b]	Right[c]>[d]	Left>	Right<	Two>	Two<
M ± SD	− 5.250 ± 5.768	− 5.338 ± 4.979	− 6.981 ± 5.478	− 4.758 ± 6.442	− 5.450 ± 5.498	− 3.015 ± 5.045
t	− 4.985	− 5.871	− 6.980	− 4.046	− 5.430	− 3.274
p	.000	.000	.000	.000	.000	.003

[a]Cue symbol located at the left end of the line

[b]Cue symbol was "<"

[c]Cue symbol located at the right end of the line

[d]Cue symbol was ">"

Table 12 Accuracy comparison of the two groups (i.e., ASD, TD) in Experiment 2

	Left[a]<[b]	Right[c]>[d]	Left>	Right<	Two>	Two<
TD	6.959 ± 4.399	6.144 ± 3.320	7.523 ± 4.673	6.382 ± 2.974	6.527 ± 3.495	6.111 ± 3.137
ASD	7.867 ± 4.143	7.738 ± 4.078	8.231 ± 4.087	7.517 ± 4.078	7.733 ± 4.074	6.043 ± 3.084
t	− .861	− 1.763	− .652	− 1.316	− 1.304	.089
p	.392	.083	.517	.193	.197	.929

[a]Cue symbol located at the left end of the line

[b]Cue symbol was "<"

[c]Cue symbol located at the right end of the line

[d]Cue symbol was ">"

Table 13 Correlation analysis between visuospatial bias and autism symptoms in Experiment 2

	Left[a]<[b]	Right[c]>[d]	Left>	Right<	Two>	Two<
R[e]	.116	.254	.179	.112	.060	.061
p	.542	.175	.343	.554	.754	.750

[a]Cue symbol located at the left end of the line

[b]Cue symbol was "<"

[c]Cue symbol located at the right end of the line

[d]Cue symbol was ">"

[e]Correlation coefficient

was found between the bias value in line bisection and the severity of autism symptoms.

Our results showed no significant difference in visuospatial bias between the two groups. This is consistent with the findings of both Li (2014) and Wainwright and Biyson (1996), who found that the visuospatial bias for ASD participants was similar to that of TD participants when the mental age was matched (Wainwright & Biyson, 1996). Our results are inconsistent to findings of studies focusing on individuals with high autistic traits (English et al., 2015, 2017). A reason for this discrepancy could be that, in previous studies by English et al., (2015, 2017), participants were all TD adults who had high or low autistic traits. In our study, our participants were TD children as well as children with ASD. Additionally, although English et al., (2015, 2017) believed there to be significant differences in visuospatial bias between participants with high and low autistic traits, we found the significance to be questionable as the between-groups effect size was small (in the 2015 study, $\eta_p^2 = 0.02$; in the 2017 study, for the greyscales task, $r = 0.17$, for the landmark task, $r = 0.17$; Cohen, 1992). Based on the results of the current study as well as the small effect size in the two repeated studies by English et al., (2015, 2017), it is likely that individuals with ASD also have a left visuospatial bias similar to that of TD individuals, and that the difference between the two groups is insignificant in this, especially when the participants used their right hands.

The primary differences found between the right-handed ASD and TD groups in the current study manifested largely in the use of the left hand to bisect the short lines. When they marked the midpoint on the 30 mm lines using their left hands, the bias value of the ASD group was significantly larger than that of the TD group, and the ASD group showed a significant right bias. For the 80 mm, 130 mm, and 180 mm lines, although the differences were not significant between the two groups, the midpoints drawn by the ASD participants were all slightly more towards the right. Neurological research has found that visuospatial bias in TD individuals is associated with lateralized brain function. Visuospatial skills are right-hemisphere specialized, and the right ventral attention network (mainly temporo-parietal junction and inferior parietal lobule) contributes to the visuospatial bias (Benwell et al., 2014; Pourrahimi et al., 2014; Quinlan & Culham, 2007; Thiebaut de Schotten et al., 2011). Studies have also found aberrant brain lateralization in individuals with autism (Floris et al., 2015; Hiraishi et al., 2015), and ASD individuals show contrasting patterns of connectivity (Fitzgerald et al., 2015) or hyper-connectivity (Farrant & Uddin, 2016) in ventral attention networks when compared to TD controls. In the current study, it is possible that using the left hand enlarged the ASD individual's atypical cerebral asymmetry and aberrant connectivity, which in turn caused the ASD group to exhibit more right bias in short lines. However, it should also be noted that the observed difference between the right-handed ASD and TD groups in the use of the left hand to bisect short lines (30 mm) is relatively weak and needs to be further confirmed by future research.

The ASD group also seemed to be more affected by the line length when using their left hands. Right bias was evident when marking the 30 mm lines; no bias was shown when marking the 80 mm lines; marginally significant left bias was seen when marking the 130 mm lines ($p = 0.088$). It was only when the line was as long as 180 mm that the ASD group showed significant left bias, similar to that shown by the TD group. Previous research on TD individuals has proven that there is a correlation between the line-length effect and the activation of the right temporo-parietal junction (rTPJ; Benwell et al., 2014). The longer the line, the more the rTPJ was activated, while shorter lines appeared to activate the ventral network with less strength (Benwell et al., 2014). However, an fMRI study indicated increased activation of the TPJ with increased functional connectivity between TPJ and cerebellum in individuals with ASD, relative to TD individuals, when performing visual research tasks (Keehn et al., 2010). There seems to be some inconsistency between the two existing studies (Benwell et al., 2014; Keehn et al., 2010), and further brain imaging investigations are needed to delineate whether the activation of the TPJ is differently associated with the visuospatial bias observed in the ASD and the TD groups.

In the current study, as the line length increased in Experiment 1, the subjective midpoint was placed more to the left, which is consistent with previous findings (Jewell & McCourt, 2000). Additionally, we found that the leftward bias was stronger when individuals used their right (dominant) hands rather than their left (non-dominant) hands, which is inconsistent with previous findings of a study of TD children (Van Vugt et al., 2000). Previous studies have found that when children or adults mark midpoints with their left hands rather than their right hands, the subjective midpoint is placed more leftward (Failla et al., 2003; Jewell & McCourt, 2000; Van Vugt et al., 2000). Since there have been few line bisection studies using Chinese children, it is unsure whether this discrepancy is caused by differences between Chinese and Western cultures (i.e., Chinese children are trained to hold chopsticks and to operate objects with their right hands from an early age) or due to the details of the experiments.

Experiment 2 found that the ASD participants performed similarly to the TD participants, in that the leftward bias was significantly stronger when the cue symbol was “>” than when it was “<”. This indicates that the ASD participants were able to process the “>” as the line went to the left, and “<” as the line went to the right. In other words, the ASD participants were able to process the line and cue symbols as a whole rather than as separate parts. Experiment 2 showed that when the symbol appeared on the left side, the leftward bias was the largest in both groups. This is in line with previous findings (Kuhn et al., 2012; Michel et al., 2011) and suggests that ASD individuals are as susceptible to the effects of the left-side cue symbol as TD individuals.

The current study adopted the line bisection task, which is the classical task for "pseudoneglect" and reflects a basically functional feature of the visual attention system in the human brain. The line bisection task was easier for children to understand and perform than the greyscales task as adopted by English et al. (2015) or the landmark task as adopted by English et al. (2017). Furthermore, in contrast to the outdoor and indoor scene pictures adopted by Li (2014), the line bisection task is more of a general visual task, which is not affected by faces or other irrelevant factors. On the issue of participants, the current study recruited children with a previous diagnosis of ASD for the ASD group and TD children for the control group, rather than using neurotypical adults with high or low autistic traits as recruited by English et al., (2015, 2017). Moreover, the ASD and TD groups were matched in both chronological age and cognitive ability (i.e., CRT scores), which provided better control than in the studies of Li (2014) or Wainwright and Biyson (1996).

The current study is not without limitations, however, such as a large age span in which the ages of ASD participants ranged from 5.56 to 14.58 years. Although there was no overall difference in the ages of participants in the ASD group and the TD group, the large age range requires a larger sample size to determine whether there is a developmental pattern of visuospatial bias. The main reason for this limitation in the current study is that the number of ASD children at child institutions with high cognitive ability who were able to participate in the study was small.

Future research should change the recruitment area or unit to hopefully build ASD samples with a smaller age range.

To summarize, the current study found a similar leftward bias in children with ASD and in TD children. In both ASD and TD groups, the line bisection tasks were affected by within-group factors including the hand used, the line length, the cueing symbol, and the symbol location. The ASD group showed a rightward bias when bisecting short lines (30 mm) with their left hands, which slightly differed from the results obtained from the TD group. Future studies using the landmark task or the greyscales task may help confirm and further explore the cognitive mechanisms underlying ASD individuals' tendency towards a right bias on short lines.

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Declarations

Conflict of interest The authors have no financial or proprietary interests in any material discussed in this article.

Ethical Approval Approval was obtained from the ethics committee of University of Jinan. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed Consent Informed consent was obtained from legal guardians.

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