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Preliminary findings on the different gaze patterns on animal-based and human-based picture books in autistic children

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Picture books are commonly used as teaching materials for young children. There is a lack of understanding about how autistic children view picture books, raising the question of the type of picture books suitable for children on the autism spectrum. The current study aimed to investigate gaze characteristics of autistic children compared to non-autistic children when viewing animal- and human-based picture books using eye-tracking technology. Twelve pictures were selected from existing picture books (six animal-based, six human-based). Each picture was presented to participants (29 autistic children, M_{age} = 52.32 months, male: female = 25:4; 40 non-autistic children, M_{age} = 49.56 months, male: female = 24:16; age range = 42–62 months) in a random sequence. Participants' gaze data were recorded. Autistic children showed longer time to first fixation, shorter total fixation time, and less fixation points to characters in picture books compared to non-autistic children. Animal versus human characters shortened the time to first fixation in autistic but not non-autistic children. Both groups showed greater attention to socially relevant areas, hands and faces, in animal compared to human picture books. Autistic children showed reduced visual attention during picture book viewing compared to non-autistic children. Animal-based picture books were more effective at attracting and maintaining visual attention to socially relevant areas, suggesting their potential as educational tools for autistic children.

Keywords Autism spectrum, Picture books, Eye-tracking, Gaze characteristics

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by differences in social interaction, communication, and restricted and repetitive behaviors and interests[1]. Autistic individuals are commonly found to demonstrate difficulties with basic socio-communicative behaviors, such as maintaining eye contact, interpreting facial expressions, and understanding social gestures[2–4]. These differences in social communication and interaction are often accompanied by atypical patterns of visual perception and attention allocation. For instance, autistic individuals may demonstrate enhanced detail-focused processing and reduced global integration[5]. Such differences in visual processing may have significant implications for how autistic children respond to socially relevant areas like faces and gestures in picture books. Recent theories on visual processing in autism suggest that autistic individuals may exhibit atypical attention to social stimuli, such as faces and gestures, due to differences in neural processing[6,7]. These differences may influence how autistic children engage with picture books, particularly those featuring human characters.

Picture books are books that use illustrations, with or without words, to convey stories, are a valuable tool for fostering language acquisition, social understanding, and emotional learning in young children[8,9]. Picture books are a common and valuable tool for supporting early childhood development, including language acquisition, social understanding, and emotional learning. Research has consistently demonstrated the benefits of picture books in enhancing vocabulary, narrative skills, and socioemotional abilities in neurotypical children[10–12]. For example, picture books have been shown to enhance vocabulary acquisition, narrative skills, and emotional understanding in young children[11]. In autistic children, picture books have been found to reduce inappropriate behaviors and improve socio-communicative skills, such as joint attention and emotion recognition[13,14]. However, autistic children may engage with picture books differently than their neurotypical peers, potentially due to differences in visual perception, social information processing, and unique interests or preferences. These differences raise important questions about the design and effectiveness of picture books for autistic children,

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particularly regarding the types of characters and visual elements that capture their attention and facilitate learning.

Picture books typically feature two main types of characters: human characters and anthropomorphic animal characters[15,16]. Since the early twentieth century, researchers have proposed that animal-based picture books may be more effective for children than human-based ones[17,18]. The rationale is that viewing animal pictures allows psychological distancing from the adult world, which more closely connects with children and encourages greater freedom of expression. Consistent with this idea, an early study reported that viewing animal pictures elicited more novel ideas in children compared to viewing human pictures[19]. Research has explored the role of anthropomorphism in picture books, particularly for autistic children. Studies suggest that anthropomorphic animals may serve as a bridge between the social world and autistic children, who often show a preference for animals over humans[20,21]. This preference is also observed in neurotypical children, who may find it easier to recognize and interpret social errors in stories featuring animal characters compared to human characters, likely due to the simplified and exaggerated social cues often depicted in animal stories[22]. These findings raise intriguing questions about whether similar patterns might be observed in autistic children, who may also find animal characters more accessible and engaging.

Although picture books have been widely studied, few studies have focused specifically on their use with autistic children. Research suggests that picture books can enhance imagination, socio-communicative skills, and emotional understanding in autistic children while reducing inappropriate behaviors[13,14]. For example, Khantreejitranon[13] found that picture books incorporating social stories effectively reduced behaviors such as aggression, non-compliance, and self-stimulatory actions in preschool children with ASD. The structured and visually engaging nature of picture books provides a clear and predictable framework, helping autistic children understand social norms and appropriate behaviors in various contexts.

However, autistic children may engage with picture books differently due to atypical visual perception and processing. For instance, they may focus more on non-social elements, such as objects or backgrounds, rather than socially relevant features like faces or gestures[5,23,24]. Additionally, autistic children may struggle to process the social information conveyed by characters, such as facial expressions, eye contact, and body language[4,6,7,25]. These differences suggest that autistic children may not fully benefit from the social learning opportunities embedded in traditional picture books.

Interestingly, it has been hypothesized that autistic children may spend more time looking at animal characters compared to human characters in picture books. This preference could stem from several factors. First, animal characters may present fewer demands for processing complex social cues, as their expressions and behaviors are often simpler and more predictable than those of human characters. Second, autistic children may have a heightened interest in animals, which has been documented in both anecdotal reports and empirical studies[26,27]. Third, animals may evoke less social anxiety or pressure compared to human characters, making them more engaging and less overwhelming for autistic children. If this hypothesis is supported, it could have significant implications for designing picture books that better cater to the interests and needs of autistic children, potentially leveraging their affinity for animals to facilitate social and emotional learning.

Despite these insights, many studies on picture books and autism are limited by small sample sizes (fewer than 10 participants). A recent eye-tracking study reported that autistic children sustained longer gaze duration on a researcher-designed picture book, which contained simplified patterns and content, compared to the original picture book[28]. This finding suggests that existing picture books for non-autistic children may not elicit the same level of interest and attention in autistic children, prompting questions about the efficacy of using picture books designed for non-autistic education in autistic children.

Furthermore, while studies have shown that autistic children exhibit greater visual attention to animal faces compared to human faces in photographs[29–31], it remains unclear whether this preference extends to illustrated animal characters in picture books. These studies, however, used photographs of animals, and it is uncertain whether the interest displayed by autistic children toward animal photographs would transfer to a preference for viewing animal characters versus human characters in picture books. Several reasons may contribute to the different styles of picture book viewing between autistic and non-autistic children. First, some autistic individuals demonstrate atypical visual perception and processing, which may lead to differences in how a picture is viewed[5,23,24]. Second, autistic children may have difficulty processing the social information expressed by the characters in picture books. Some studies have shown that autistic individuals demonstrate different perception and interpretation of socially relevant regions of figures, such as faces, eyes, and gestures, compared to non-autistic individuals[4,6,7,25]. Due to different interests and processing of the social areas in picture books, autistic children may not benefit from the opportunities to learn about the social skills and interactions embedded within those social areas of picture books, such as the facial expressions, eye contact, gestures, and body language of the characters. These elements often convey social and emotional information that is crucial for understanding social interactions and relationships. Autistic children may process or focus on these areas differently, which can affect their ability to interpret and learn from the social cues presented in the illustrations.

Hand gestures play a crucial role in social communication, serving as nonverbal cues that facilitate understanding, emotion expression, and interactive engagement. In typical development, hand gestures complement spoken language, enhancing meaning and aiding comprehension, particularly in early childhood when verbal communication skills are still emerging. However, autistic children often demonstrate atypical processing of hand gestures, which can affect their ability to interpret social cues effectively. Studies have shown that autistic individuals tend to focus less on hand gestures during social interactions compared to their neurotypical peers, potentially missing important contextual information that contributes to meaning-making in conversations[32,33]. This reduced attention to hand gestures may be linked to broader differences in visual processing, such as a preference for object-based over social stimuli[7]. Understanding how autistic children perceive and attend to hand gestures in picture books is essential, as gestures often provide additional context

for understanding characters' intentions, emotions, and social interactions. By examining gaze patterns directed at hand areas, this study aims to explore whether autistic children allocate visual attention differently compared to non-autistic children and whether animal-based picture books may enhance attention to gestures in ways that facilitate social learning. Addressing these questions can contribute to the development of more effective educational tools tailored to the unique cognitive and perceptual profiles of autistic children.

Understanding how autistic children engage with different types of characters in picture books is crucial for creating inclusive and effective educational materials. By exploring these differences, we can develop strategies to enhance the learning experiences of autistic children and support their development in ways that align with their unique strengths and preferences.

To address these gaps, the current study aimed to investigate the gaze characteristics of autistic children compared to non-autistic children when viewing picture books featuring human and animal characters. Using eye-tracking technology, the study sought to answer two main research questions: Do autistic and non-autistic children show similar visual attention to characters in picture books? Which types of characters and character areas (e.g., faces, hands) are more attractive to autistic children? Based on existing literature, it was hypothesized that, (1) autistic children would show less interest and attention to characters in picture books compared to non-autistic children, (2) autistic children would be more interested in animal characters compared to human characters, and (3) autistic children would pay more attention to socially relevant areas (e.g., faces and hands) in animal characters compared to human characters.

Results

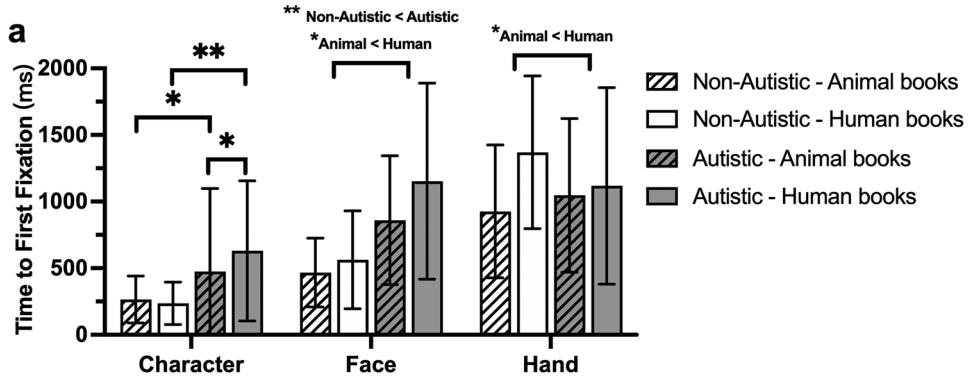
Time to first fixation

Character

There was a significant interaction between group and picture for time to first fixation at character areas ($F(1, 67) = 4.75$, $p = 0.03$, $\eta_p^2 = 0.07$; Fig. 1). Post-hoc analyses showed that autistic children fixated their first gaze to the animal characters significantly faster than the human characters (mean difference = 156 ms, $p = 0.02$), whereas non-autistic children showed no difference between the picture types ($p = 0.60$). Although autistic children were slower than non-autistic children to fixate on the characters, the difference between groups was smaller in the animal pictures (mean difference = 209 ms, $p = 0.047$) than in the human pictures (mean difference = 394 ms, $p < 0.001$).

Face

No significant interaction was found between group and picture for time to first fixation at face areas ($F(1, 67) = 1.63$, $p = 0.21$; Fig. 1). Overall, autistic children were slower than non-autistic children to show the first fixation ($F(1, 67) = 34.15$, $p < 0.001$, $\eta_p^2 = 0.34$). Children in both groups showed quicker first fixation at animal faces compared to human faces ($F(1, 67) = 6.25$, $p = 0.02$, $\eta_p^2 = 0.09$).



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		Character		Face		Hand	
		Mean	SD	Mean	SD	Mean	SD
Non-Autistic							
	Animal	264.67	176.44	467.37	258.40	926.28	498.02
	Human	236.11	159.54	562.60	367.21	1369.85	573.25
Autistic							
	Animal	474.60	624.02	859.64	483.53	1046.91	577.11
	Human	630.60	525.82	1153.21	735.26	1117.99	737.47

Fig. 1. Time to first fixation on different areas in the animal- and human-based picture books in autistic and non-autistic children. (**a**) Bar graphs are presented as mean ± standard deviation. (**b**) The table reports the mean and standard deviation of time to first fixation (ms) on each area of interest in each group. $^{*}p < 0.05$. $^{***}p < 0.001$.

Hand

No significant interaction was found between group and picture for time to first fixation at hand areas ($F(1, 61) = 0.65$, $p = 0.42$; Fig. 1). Autistic and non-autistic children showed similar time to first fixation at hand areas ($F(1, 61) = 0.42$, $p = 0.52$). Children in both groups showed quicker first fixation at animal hands compared to human hands ($F(1, 61) = 5.04$, $p = 0.03$, $\eta_p^2 = 0.08$).

First fixation duration

Groups or pictures did not significantly affect the first fixation duration at character areas (group: $F(1, 67) = 0.41$, $p = 0.53$; picture: $F(1, 67) = 2.09$, $p = 0.15$; group* picture: $F(1, 67) = 1.26$, $p = 0.27$; Fig. 2), face areas (group: $F(1, 67) = 0.12$, $p = 0.73$; picture: $F(1, 67) = 0.09$, $p = 0.76$; group* picture: $F(1, 67) = 0.02$, $p = 0.89$; Fig. 2), or hand arears (group: $F(1, 61) = 3.36$, $p = 0.07$; picture: $F(1, 61) = 0.38$, $p = 0.54$; group* picture: $F(1, 61) = 2.93$, $p = 0.09$; Fig. 2).

Total fixation duration

Character

No significant interaction was found between group and picture for total fixation duration at character areas ($F(1, 67) = 0.34$, $p = 0.57$; Fig. 3). Autistic children showed shorter total fixation duration at characters compared to non-autistic children ($F(1, 67) = 28.81$, $p < 0.001$, $\eta_p^2 = 0.30$). Children in both groups fixated at the human characters for a longer duration compared to animal characters ($F(1, 67) = 7.55$, $p = 0.01$, $\eta_p^2 = 0.10$).

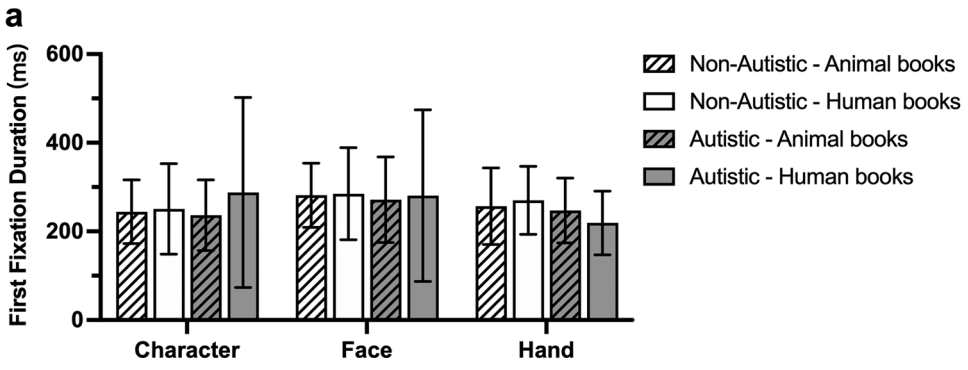
Face

Similar to total fixation duration at the whole character areas, no significant interaction was found between group and picture for total fixation duration at face areas ($F(1, 67) = 0.89$, $p = 0.35$; Fig. 3). Autistic children fixated at faces for a shorter duration compared to non-autistic children ($F(1, 67) = 32.86$, $p < 0.001$, $\eta_p^2 = 0.33$). However, different to the total fixation duration at the whole character areas, children in both groups fixated at animal faces for a longer duration compared to human faces ($F(1, 67) = 8.46$, $p = 0.001$, $\eta_p^2 = 0.11$).

Hand

No significant interaction was found between group and picture for total fixation duration at hand areas ($F(1, 61) = 0.001$, $p = 0.97$; Fig. 3). Autistic children spent a similar amount of time fixating at hand areas compared to non-autistic children ($F(1, 61) = 1.35$, $p = 0.25$). Children in both groups fixated at animal hands for a longer duration compared to human faces ($F(1, 61) = 18.34$, $p < 0.001$, $\eta_p^2 = 0.23$).

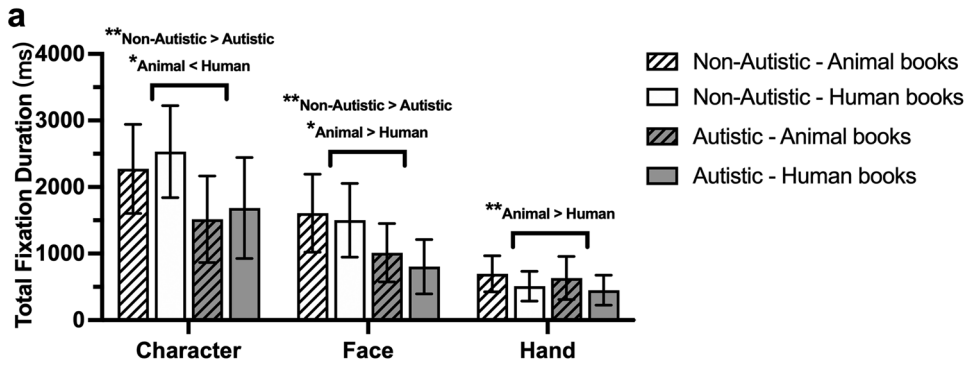
$^*p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.



b

		Character		Face		Hand	
		Mean	SD	Mean	SD	Mean	SD
Non-Autistic							
	Animal	244.29	71.95	281.49	72.53	256.75	86.28
	Human	250.79	101.97	284.99	103.94	270.05	76.52
Autistic							
	Animal	236.44	79.94	271.59	96.74	247.29	73.12
	Human	287.74	214.25	280.68	193.52	218.98	71.71

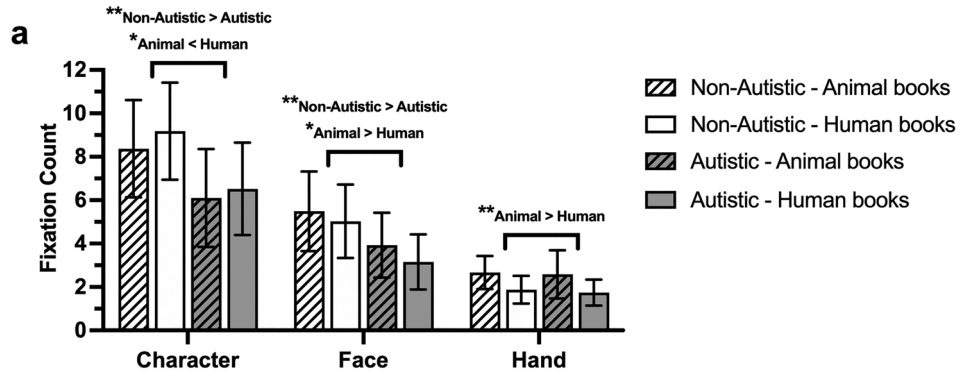
Fig. 2. First fixation duration on different areas in the animal- and human-based picture books in autistic and non-autistic children. (**a**) Bar graphs are presented as mean ± standard deviation. (**b**) The table reports the mean and standard deviation of first fixation duration (ms) on each area of interest in each group. $^*p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.



b

		Character		Face		Hand	
		Mean	SD	Mean	SD	Mean	SD
Non-Autistic							
	Animal	2272.96	670.05	1607.90	586.00	696.18	272.49
	Human	2532.24	690.77	1501.13	553.36	509.85	222.34
Autistic							
	Animal	1515.29	649.93	1012.38	438.40	633.26	324.95
	Human	1684.37	759.20	802.84	407.03	450.22	226.30

Fig. 3. Total fixation duration on different areas in the animal- and human-based picture books in autistic and non-autistic children. (**a**) Bar graphs are presented as mean ± standard deviation. (**b**) The table reports the mean and standard deviation of total fixation duration (ms) on each area of interest in each group.



b

		Character		Face		Hand	
		Mean	SD	Mean	SD	Mean	SD
Non-Autistic							
	Animal	8.37	2.24	5.49	1.83	2.67	0.76
	Human	9.18	2.23	5.03	1.69	1.87	0.64
Autistic							
	Animal	6.10	2.26	3.92	1.49	2.58	1.12
	Human	6.52	2.13	3.16	1.27	1.75	0.60

Fig. 4. Fixation count on different areas in the animal- and human-based picture books in autistic and non-autistic children. (**a**) Bar graphs are presented as mean ± standard deviation. (**b**) The table reports the mean and standard deviation of fixation counts on each area of interest in each group. $^{**}p < 0.01$. $^{***}p < 0.001$.

Fixation count

Character

No significant interaction was found between group and picture for fixation count at character areas ($F(1, 67) = 0.55$, $p = 0.46$; Fig. 4). Autistic children showed less gaze points at characters compared to non-autistic

children ($F(1, 67) = 27.14$, $p < 0.001$, $\eta_p^2 = 0.29$). Children in both groups showed more gaze points at human characters compared to animal characters ($F(1, 67) = 5.40$, $p = 0.02$, $\eta_p^2 = 0.08$).

Face

Similar to the fixation count at the whole character areas, no significant interaction was found between group and picture for fixation count at face areas ($F(1, 67) = 0.59$, $p = 0.45$; Fig. 4). Autistic children showed less fixation points compared to non-autistic children ($F(1, 67) = 25.55$, $p < 0.001$, $\eta_p^2 = 0.28$). However, different to the fixation count at the whole character areas, children in both groups showed more fixation points at animal faces compared to human faces ($F(1, 67) = 9.50$, $p = 0.003$, $\eta_p^2 = 0.12$).

Hand

No significant interaction was found between group and picture for fixation count at hand areas ($F(1, 61) = 0.03$, $p = 0.87$; Fig. 4). Autistic children showed a similar number of fixation points at hand areas compared to non-autistic children ($F(1, 61) = 0.45$, $p = 0.51$). Children in both groups showed more fixation points at animal hands compared to human faces ($F(1, 61) = 40.18$, $p < 0.001$, $\eta_p^2 = 0.40$).

Discussion

The current study demonstrated distinct viewing patterns between autistic and non-autistic children when engaging with picture books. Autistic children exhibited less overall attraction to the illustrative characters, as evidenced by longer time to first fixation, shorter total fixation time, and fewer fixation counts compared to non-autistic children. However, no group differences were found in first fixation duration, suggesting that the early stages of stimulus processing were intact in autistic children. Notably, autistic children noticed animal characters more quickly than human characters, which was not observed in non-autistic children. Despite this, both groups fixated longer and more frequently on human characters than on animal characters. Additionally, both groups demonstrated more attention toward socially-relevant areas, e.g., faces and hands, in animal-based books compared to human-based books, evidenced by faster time to first fixation, longer total fixation time, and more fixation counts. In summary, autistic children demonstrated reduced visual attention to picture books compared to non-autistic children, but this was partially mitigated by the inclusion of animal characters. These findings highlight the potential of animal-based picture books as educational and intervention tools, particularly for social learning in autistic children.

Autistic children were less engaged during picture book viewing compared to non-autistic children. The current study found that autistic children took a longer time to allocate their first fixation onto characters in general or the faces of characters compared to non-autistic children. Autistic children also fixated on these two regions for a shorter duration and less frequently compared to non-autistic children. This finding is consistent with previous research that found reduced fixation on faces[34], eyes[24,35], and social scenes[36–38] in autistic children during natural scene viewing. Together, our findings suggest that reduced engagement of visual attention observed in autistic children could be generalized from social scenarios to picture book viewing.

Autistic children may benefit from simplistic designs in picture books. The current study did not find group differences in gaze patterns on hand areas, possibly because hand areas have simpler features (e.g., less lines and colors) compared to character or face areas. Consistent with this suggestion, a recent study found that autistic children showed longer fixation time in simplified researcher-designed picture books than in picture books obtained from the market[28]. Another study also found that when viewing side-by-side geometric and social images, autistic toddlers showed stronger preference for fixating on the geometric images over social images compared to non-autistic toddlers[39]. These findings suggest that autism-friendly picture books, particularly those with simplified illustrations, could enhance engagement and learning.

The current study extends current knowledge of autism-friendly picture books by comparing the preferences of autistic children for viewing animal versus human-based picture books. We found that autistic children noticed the animal characters more quickly than the human characters, whereas non-autistic children showed no difference in noticing these two types of characters. Similarly, previous research has shown that autistic people have a preference for interacting with animals than with humans or inanimate objects[40]. The presence of animals has also been reported to be a source of comfort and support for autistic people to cope with life stressors[41–44]. Therefore, our findings indicate that animal characters could be used to attract the attention of autistic children during picture book viewing. It is noted, however, that animal characters did not help to sustain the attention of both autistic and non-autistic children, indicated by similar first fixation duration, shorter total fixation duration, and less fixation counts compared to human characters. It is possible that autistic children were easily attracted by the animal characters, but their interest quickly decreased once they had noticed the animal characters. The change of interest and attention in animal characters over reading duration and the underlying mechanisms needs to be further investigated in both autistic and non-autistic children.

The error bars in Figs. 1 and 2 highlight considerable variability in autistic children's gaze patterns, particularly in measures such as time to first fixation and total fixation duration. This variability reflects the diverse cognitive, sensory, and social profiles within the autism spectrum[5,25]. For instance, some autistic children may show a strong preference for specific stimuli (e.g., animal characters or simpler designs), while others may not exhibit the same level of engagement. Factors such as sensory sensitivities, cognitive abilities, and individual interests likely contribute to these differences. This variability has important implications for designing educational materials. While animal-based picture books may effectively capture initial attention, a one-size-fits-all approach is insufficient. Personalized strategies that account for individual preferences and sensory profiles are essential for sustaining engagement and facilitating social learning. For example, incorporating a variety of visual stimuli, such as simplified designs or interactive elements, could better accommodate the diverse needs of autistic children.

The effect sizes observed in this study provide further insight into the magnitude of differences in gaze patterns between autistic and non-autistic children. For instance, the interaction between group and picture type for time to first fixation at character areas yielded a partial η^2 of 0.07, indicating a small to medium effect size. While statistically significant, this suggests that the practical difference in how quickly autistic children fixate on animal characters may be modest. In contrast, larger effect sizes were observed for total fixation duration at character areas (partial $\eta^2 = 0.30$) and face areas (partial $\eta^2 = 0.33$), highlighting a substantial reduction in sustained attention among autistic children. Similarly, fixation counts at character areas (partial $\eta^2 = 0.29$) and face areas (partial $\eta^2 = 0.28$) showed medium to large effect sizes, reinforcing the finding that autistic children engage less frequently with socially relevant areas. Smaller effect sizes for hand areas (partial $\eta^2 = 0.08$ for time to first fixation and partial $\eta^2 = 0.23$ for total fixation duration) suggest that differences in attention to hands are less pronounced. This may be due to the simpler visual features of hands, which are less socially demanding and thus more accessible to autistic children. These effect sizes underscore the importance of considering both statistical significance and practical relevance when interpreting results. They also highlight the potential of animal-based picture books to improve initial engagement, though additional strategies are needed to sustain attention over time.

The distinction between first fixation and total fixation is crucial for understanding how autistic children engage with picture books. First fixation measures the speed of initial attention allocation, while total fixation reflects sustained engagement. Autistic children's faster first fixation to animal characters suggests that these stimuli may serve as an accessible entry point for social engagement. However, their shorter total fixation durations indicate challenges in maintaining attention, particularly with human characters that require more complex social processing. This dual perspective underscores the need for educational materials that not only capture initial attention but also sustain engagement. For example, combining animal characters with interactive or simplified elements may help maintain interest and facilitate deeper social learning.

Consistent with these results, several eye-tracking studies found that autistic children tended to gaze more or longer at animal faces than to human faces[21,30,45]. A neuroimaging study also reported that autistic adolescents demonstrated reduced activation in brain regions involved in face processing in response to human images but not animal images[31]. This study also showed that autistic adolescents may feel more socially rewarded and motivated when viewing animal faces compared to human faces, as indicated by increased activation in the amygdala and putamen[31]. Collectively, the existing evidence suggests that atypical face processing may be specific to human but not animal stimuli in autistic people. In terms of hand viewing, previous research found deficient recognition of human hand gestures in autistic people[32,33], but no studies on autistic people have compared differences in viewing animal versus human hands. The current study extends the existing literature by showing that animal illustrations elicit greater visual attention to social areas in autistic children, highlighting the possibility of enhancing face and gesture learning in autistic children through the use of animal picture books.

The illustrations in picture books provide concrete representations of abstract social concepts, making it easier for children with ASD to process and internalize the information. The repetitive and predictable structure of social stories in picture books helps reinforce desired behaviors, providing a sense of security and reducing anxiety, which is often a trigger for inappropriate behaviors in autistic children[46]. This is particularly important given the difficulties many autistic children face in interpreting and responding to social cues in real-life situations[7]. The use of animal characters may further enhance these benefits by reducing the social complexity and emotional intensity associated with human characters[20]. The findings from Khantreejitranon's[13] study, combined with the results of the current research, underscore the potential of picture books as a valuable educational and intervention tool for preschool autistic children. Future research should explore specific features of picture books—such as animal characters, simplified illustrations, and structured narratives—to optimize their effectiveness in autism education and therapy. By tailoring materials to the unique strengths and preferences of autistic children, educators and researchers can better support their social and emotional development.

Limitations

The free-viewing task in this study had low cognitive demands, and no participants struggled with the task rules. However, future research could improve precision by accounting for participants' mental age and intelligence. Convenience sampling was used to maximize sample size within a limited timeframe, potentially limiting the representation of the heterogeneous autistic population. While all autistic participants had a confirmed DSM-5[1] diagnosis, details such as age of diagnosis, language skills, and support needs were not collected. There is also a significant gender difference between groups which may affect the results. Additionally, given that some assumptions of ANOVA were not met, we should employ Mixed Effects Models (MEMs) instead, unfortunately however, some models did not converge or meet key assumptions, even after various attempts to address these issues. Besides, the study did not explore differences between physical and digital picture books. Physical books allow tactile interaction, fostering sensory and motor skills, while digital formats often limit interaction to swiping or tapping. Future studies could investigate these differences further. Additionally, instructing children to remain still may have impacted attention and immersion, particularly for those using physical books, as their natural inclination to interact was restricted. Age also likely played a role, as younger children may benefit more from tactile experiences, while older children might adapt better to digital formats. The number of picture presentations was limited due to the challenge of maintaining young children's attention. Multiple testing sessions with a larger and more varied set of pictures could yield more robust results. Eleven autistic children were excluded due to insufficient gaze data, which may have influenced findings. The study aimed to authentically represent the autistic population by recruiting age-matched participants, reflecting the inherent variability in social attention. Finally, the study did not examine gaze patterns on non-character areas, leaving

Demographic variable		Autistic ($n=29$)	Non-autistic ($n=40$)	Group comparison
Gender, *n* (%)	Male Female	25 (86.2) 4 (13.8)	24 (60) 16 (40)	$x^2(1)=5.61$, $p=0.02$
Chronological age (months)	Mean (*SD*) Range	52.32 (9.89) 42.43–62.21	49.56 (7.88) 41.68–57.44	$t(67)=1.29$, $p=0.20$

Table 1. Participant demographic variables and group comparisons. The autistic and non-autistic groups were matched on chronological age.

it unclear whether autistic children exhibit different basic visual processing when social understanding is not required. Future research could address this gap.

Methods

Participants

Twenty-nine autistic children (25 male; *M*age = 52.32 months, *SD* = 9.89, range = 42.43–62.21 months) and 40 non-autistic children (24 male; *M*age = 49.56 months, *SD* = 7.88, range = 41.68–57.44 months) participated in this study. The autistic and non-autistic groups were matched on chronological age. All autistic participants were diagnosed by experienced psychologists and clinicians based on the Psychoeducational Profile, Third Edition (PEP-3[47]) and the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5[1]) criteria. All non-autistic participants reported no family history of autism, mental disorders, or physical disorders to minimize confounding variables that could affect gaze patterns. Thirty-five autistic children were recruited from an autism service center in Tianjin. Five other autistic children and the 40 non-autistic children were recruited from a local kindergarten. Exclusion criteria for study participation included the inability to complete the study, such as being unable to sit still during the experiment, or the collection of less than 80% valid gaze data. Eleven autistic children were excluded due to insufficient gaze data. The age range of 42–62 months was selected because this period is critical for early social and cognitive development, and it aligns with previous studies on picture book viewing in young children[11]. Participants' demographic characteristics are shown in Table 1. All experimental procedures performed in studies involving human participants were in accordance with the ethical standards of and approved by the institutional research committee (Nankai University Faculty of Science and Technology Ethics Committee, reference number: NKUIRB2021065).

A power analysis was conducted to determine the adequacy of the sample size for detecting differences in gaze measures between autistic and non-autistic children. Using G*Power 3.1, a repeated-measures ANOVA with a moderate effect size (f = 0.25), alpha = 0.05, and power = 0.80 indicated that a total sample size of approximately 54 participants was required. Our study included 69 participants, suggesting sufficient power to detect medium to large effects but potentially limited sensitivity for detecting small effects.

Table 1 presents the demographic characteristics of the participants and statistical comparisons between autistic and non-autistic groups. An independent-samples t-test was conducted to compare the chronological age of the two groups, showing no significant difference ($p = 0.20$). However, a chi-square test revealed a significant gender difference between groups ($p = 0.02$), with the autistic group comprising a higher proportion of male participants. Given this imbalance, gender was controlled for in all subsequent analyses. These group comparisons ensure that differences in gaze patterns are not confounded by age differences and help interpret findings in the context of gender differences in autism research.

Materials

Picture books

Twelve pictures were selected from four picture books. Six pictures featured humans as the main characters, and the other six pictures featured animals as the main characters. The selection criteria for the pictures were as follows: (a) the background was either blank or contained a simple natural scene (e.g., forest) or life scene (e.g., door). This ensured that the backgrounds were not overly complex and did not distract from the main characters. (b) the facial expressions and actions of the characters were not obstructed, allowing for clear visibility of social cues such as emotions and gestures. (c) the colors were as vivid as possible to attract children's attention, ensuring that both animal and human characters were visually engaging; and (d) there was no text or only short sentences in Chinese or English outside the picture, minimizing the influence of written language on the children's visual attention. All the selected characters avoided direct gaze with the viewers to minimize the confounding effects of atypical gaze processing in autistic children[48,49],Von Dem[50]. The human and animal pictures were matched for complexity, background, and the presence of social cues (e.g., facial expressions, hand gestures). The human characters were depicted in various social scenarios, such as interacting with others or performing everyday activities. The characters avoided direct gaze with the readers to minimize the confounding effects of atypical gaze processing in autistic children. The facial expressions and hand gestures of the human characters were clearly visible, allowing for the study of attention to socially relevant areas (e.g., faces and hands). The animal characters were anthropomorphic, meaning they were depicted with human-like traits, such as standing on two legs, wearing clothes, or engaging in human-like activities. This allowed for a direct comparison with human characters in terms of social relevance. Similar to the human characters, the animal characters also avoided direct gaze with the readers and displayed clear facial expressions and hand gestures. The human and animal pictures were matched for complexity, background, and the presence of social cues (e.g., facial expressions, hand gestures). This ensured that the only significant difference between the two types of pictures was the

nature of the characters (human vs. animal), allowing for a fair comparison of how autistic and non-autistic children responded to each type. Prior to the experiment, the selected pictures were digitally processed to ensure consistency in colors, contrast, sharpness, size, and brightness across all pictures to ensure equivalence across the selected stimulus materials. These standardizations ensure that any observed differences in gaze patterns arise from the nature of the characters (human vs. animal) rather than variations in image composition. By carefully controlling these factors, the study ensured that the differences in gaze patterns observed between the two types of picture books could be attributed to the nature of the characters (human vs. animal) rather than other visual or contextual factors.

Eye-tracking apparatus

Eye-tracking technology has been utilized as a powerful tool to analyze visual attention and neural processing by recording gaze shifting, gaze points, and duration of fixation at various areas of interest[51–53]. A Tobii TX300 Eye Tracker was employed to present the experimental materials to participants and to monitor and record the eye movement data. A Lenovo ThinkBook 14 with a resolution of 1024×768 was used to run the experimental programs and operate the eye-tracking device. No equipment was employed to restrain head or body movements.

Procedure

Each participant was instructed to sit in front of an eye-tracking monitor. A familiar teacher was seated next to them, and a researcher was seated next to the monitor, facing the participant. The presence of a familiar teacher during the study was likely a deliberate choice to ensure the children's comfort, facilitate their participation, and maintain ethical standards. This approach aligns with best practices in research involving children, particularly those with autism, and helps create a supportive and naturalistic environment for the study. At the beginning of the experiment, gaze point calibration was conducted until the participant successfully passed the 5-point calibration. The researcher then instructed the participant to prepare and initiated the task by pressing a button. The 12 pictures selected from the picture books were sequentially presented in a random order, with each picture remaining on the screen for four seconds. A blank screen was displayed for two seconds between each picture presentation. The experiment ended after all 12 pictures had been presented, totaling 72 s. The researcher instructed the participant to keep their head and body still before the commencement of the experiment. The teacher reminded the participants to maintain the same position throughout the experiment with short verbal prompts.

Data preparation

The areas of interest (AOIs) for each picture included the character as a whole, the character's face area, and the character's hand area. Four gaze indicators—time to first fixation, first fixation duration, total fixation duration, and fixation count—were recorded for each participant. Time to first fixation refers to the duration between the onset of the picture and the first gaze at a specific AOI, reflecting the speed of awareness of a particular object or situation. First fixation duration refers to the duration of the first gaze at the AOI, reflecting the early stages of stimulus processing. Total fixation duration is the total duration of all gaze points at the AOI, reflecting the temporal distribution of attention to a specific object or situation. Fixation count is the sum of all gaze points at the AOI, reflecting the extent to which the participant was attracted to a specific object or situation.

If a picture contains more than one AOI (e.g., two characters), the time to first fixation and the first fixation duration were calculated based on the first fixated AOI, and the total fixation and the fixation count were calculated using the sum of data from all AOIs. Data from all pictures from the same type of book (i.e., animal or human) were then averaged.

Data analysis

To investigate general gaze patterns, analyses were first conducted on the areas in which a character was present. Due to the interest in autistic children's gaze patterns on highly socially relevant areas, the face and hand regions were then analyzed separately. For each type of AOI (i.e., character, face, and hand), repeated-measures ANOVAs were conducted for each gaze measure (i.e., time to first fixation, first fixation duration, total fixation duration, and fixation count), with participant group (autistic versus non-autistic) as the between-group factor and type of book (animal versus human) as the within-group factor. Normality of the four gaze measures was assessed using the Shapiro–Wilk test and histograms. The sphericity assumption was tested using Mauchly's test. The data for all four gaze measures met the assumption of sphericity but not normality. As ANOVA is robust to violations of normality when the sphericity assumption is met[54], it was deemed appropriate for the current study. Where there was a significant interaction effect, post-hoc comparisons were conducted with the Bonferroni correction. Hypotheses were tested using p values with alpha set at $p < 0.05$. Effect size (i.e., partial η_p^2) was calculated for significant results. Data were analyzed using IBM SPSS Statistics 29.0.

Conclusion

The current study demonstrated different viewing patterns on picture books between autistic and non-autistic children. Overall, autistic children showed less interest and attention to characters in the picture books compared to non-autistic children. Autistic children were faster to focus on the characters when viewing animal picture books compared to human picture books, which was not found in non-autistic children. Animal picture books also attracted and maintained visual attention to socially relevant areas (faces and hands) in both autistic and non-autistic children better than human picture books. These findings, therefore, support further investigation of the effectiveness of using animal books as an education and intervention tool especially for social learning in autistic children.

Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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Author contributions

PA and CW co-designed the study. PA conducted the experiment testing and data analysis. PA and CW contributed equally to the writing of the paper.

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Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (Nankai University Faculty of Science and Technology Ethics Committee, reference number: NKUIRB2021065) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants' parents included in the study.

Additional information

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