

# Social perception of animacy: Preferential attentional orienting to animals links with autistic traits

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## ABSTRACT

Animate cues enjoy priority in attentional processes as they carry survival-relevant information and herald social interaction. Whether and in what way such an attention effect is associated with more general aspects of social cognition remains largely unexplored. Here we investigated whether the attentional preference for animals varies with observers' autistic traits — an indicator of autism-like characteristics in general populations related to one's social cognitive abilities. Using the dot-probe paradigm, we found that animal cues can rapidly and persistently recruit preferential attention over inanimate ones in observers with relatively low, but not high, autistic traits, as measured by Autism-Spectrum Quotient (AQ). Moreover, individual AQ scores were negatively correlated with the attentional bias toward animals, especially at the early orienting stage. These results were not simply due to low-level visual factors, as inverted or phase-scrambled pictures did not yield a similar pattern. Our findings demonstrate an automatic and enduring attentional bias beneficial to both rapid detection and continuous monitoring of animals and reveal its link with autistic traits, highlighting the critical role of animacy perception in the architecture of social cognition.

## 1. Introduction

Animacy is a foundational dimension when identifying and categorizing entities. The perception of animacy, or distinguishing animate from inanimate entities, has long been a fundamental ability for all species, humans included (Lorenzi & Vallortigara, 2021; Vallortigara, 2021; Wheatley et al., 2007). From ancient to modern times, detecting living creatures in the vicinity plays a crucial role in survival and propagation. It is our natural instinct and an innate disposition to readily perceive animacy in preparation to make proper responses (Di Giorgio et al., 2017; Di Giorgio et al., 2021; Vallortigara, 2021). It is thus reasonable to speculate that compared with non-living things, animate entities receive priority in human cognitive processing, amid which visual attention is an important aspect.

The animate monitoring hypothesis proposed by New and colleagues is the most influential theory regarding the privilege of animates in visual attention (New et al., 2007). In their study, participants were faster and more accurate at detecting changes in humans and animals, compared with non-living objects (see also Altman et al., 2016), supporting the hypothesis that due to the adaptive value of animate entities, the human attention system has evolved to spontaneously monitor

humans and non-human animals for changes in their state and location. This hypothesis was further supported by studies using various visual attention paradigms and animate stimuli, despite the presence of negative evidence (Hagen et al., 2018; Hagen & Laeng, 2016, 2017). For instance, animals are located faster than inanimate objects in visual search (He & Cheung, 2019; Jackson & Calvillo, 2013; Lipp et al., 2004), and they exhibit resistance to inattention blindness (Calvillo & Jackson, 2014) and attentional blink (Guerrero & Calvillo, 2016, but see Hagen & Laeng, 2017). In addition, animate motions also enjoy an advantage in visual search and are detected more quickly than inanimate motions (Abrams & Christ, 2003; Nguyen & Van Buren, 2023; Pratt et al., 2010; Shen et al., 2023; Wang et al., 2010).

Despite the abundant evidence, there is a significant but largely ignored aspect of the animacy advantage in attention regarding its relationship with social cognition. As social interaction usually occurs between living creatures, attending to animate beings is the first step for social interaction. A great amount of evidence shows that even visually naïve chicks and human newborns prefer to look at socially relevant animate stimuli, like faces and biological motion (Buiatti et al., 2019; Di Giorgio et al., 2017; Lemaire et al., 2022; Lemaire & Vallortigara, 2023; Lorenzi et al., 2017, 2019, 2021; Matsushima et al., 2022; Rosa-Salva

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et al., 2018, 2019, 2021; Sgadò et al., 2018). This leads to the assumption that preferential attending to animate stimuli may contribute to the development of the social brain, presumably by increasing the exposure to animate beings during sensitive periods of cortical development (Salva & Vallortigara, 2015). This account highlights the significance of animacy detection as a basic part of social cognition and raises a fundamental question regarding the ‘social’ nature of preferential attention to animals: whether and in what way is this effect associated with social cognition? Examining whether prioritized attention for animals varies with individual differences in social cognitive abilities may provide a clue to this issue.

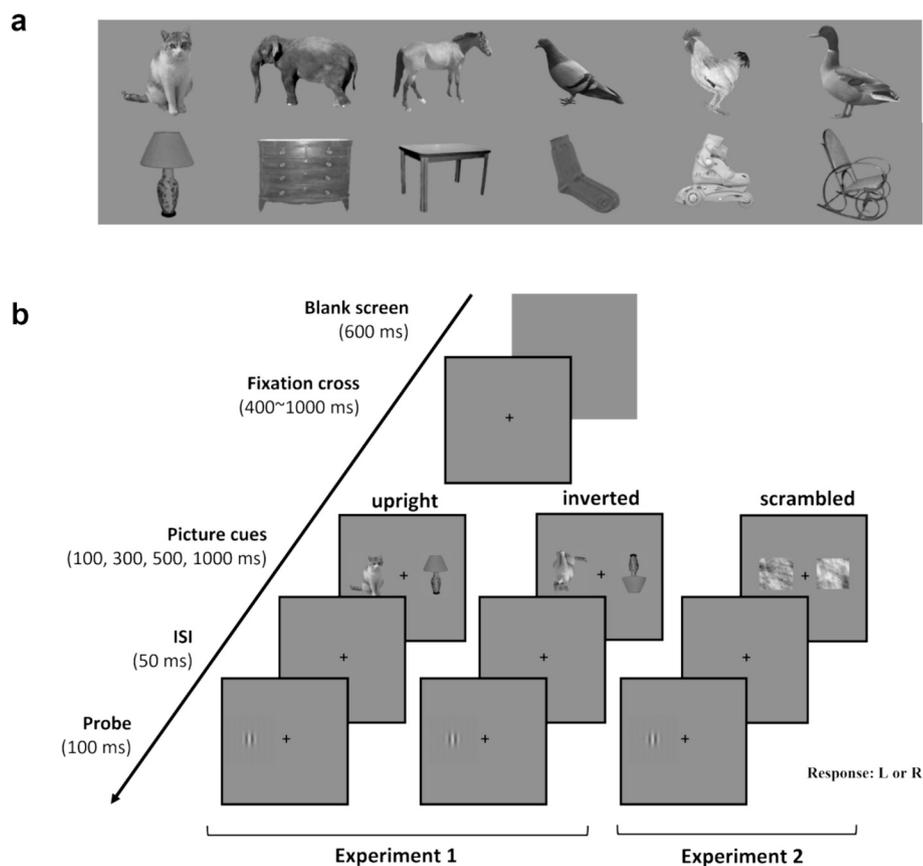
Autism spectrum disorder (ASD) is a neurodevelopmental disorder marked by severe social cognitive impairments. Moreover, there is a continuum between autism and neurotypicality, and any given individual, with normal intelligence, lies on this continuum with a certain degree of autistic traits (Baron-Cohen et al., 2001), making autistic traits a good indicator of social cognitive abilities in the general population. Based on this theoretical account, if prioritized attention to animacy relates to social cognition, it may be compromised in ASD and even non-clinical populations with high autistic traits. Indeed, individuals with ASD or high autistic traits and newborns with a high familial risk of autism exhibit aberrant processing of biological motion (e.g., Blake et al., 2003; Di Giorgio et al., 2016; Di Giorgio et al., 2021; van Boxtel et al., 2017; Wang et al., 2018, but see Cusack et al., 2015; Vanmarcke et al., 2017) and faces (English et al., 2017; Kikuchi et al., 2009; Moore et al., 2012). Nonetheless, given the complicated nature of these stimuli, it is hard to tell whether these results reflect the processing of animacy or that of social information. Beyond these findings, whether the attentional processing of animate cues with less social relevance, like animals, is compromised in ASD or varies with individual autistic traits

remains largely obscure.

To our knowledge, there is only one published study concerning animacy perception from static animal cues in ASD (New et al., 2010). Using a change detection task, the study found unimpaired prioritized attention to animals and humans within natural scenes in the autistic group, compared with the typical control, and therefore claimed that the scope of social attention deficits in ASD does not include categorical animacy perception. However, this conclusion might be premature because the change detection paradigm is insufficient to capture the early attentional orienting to animals, while this stage appears critical to evaluating attentional bias for animacy. As in studies on faces, autistic-related altered attentional behavior occurs mainly at the early attentional stage (i.e., when observers direct their first fixation or the face stimuli are presented briefly) (Guillon et al., 2016; Moore et al., 2012; Osterling & Dawson, 1994). Hence, to obtain a deeper understanding of the attentional bias for animals and its relation to autistic levels, here we examined the time course of this attention effect in observers with different levels of autistic traits.

To this end, the present study adopted a dot-probe task to assess the observers’ allocation of attention to pairs of animal and inanimate picture cues based on their reaction times to the probes following these cues (Fig. 1). The cue duration was set to 100, 300, 500, or 1000 ms. The short-duration conditions (i.e., 100 and 300 ms) mainly reflect the initial orienting of attention (Koster et al., 2005; Mogg & Bradley, 2006; Moore et al., 2012; Zvielli et al., 2014). Otherwise, the long-duration conditions (i.e., 500 and 1000 ms) measure the later attentional shifting and maintenance components, with enough time for attention to be disengaged from its initial locus (Bar-Haim et al., 2006; Mogg et al., 1997).

In Experiment 1, we sought to examine the temporal profile of the attentional bias toward animacy and the possible difference of such a



**Fig. 1. Materials and procedure of the experiments.** (a) Animal and object picture cues (one pair in each column). (b) The schematic representation of the experimental paradigm. The locations of animal and object cues (or phase-scrambled animals and objects) were non-predictive of the probe location. Observers were asked to monitor the screen for the target probe and to respond to its location (left or right) as quickly as possible while being accurate.

bias between individuals with relatively high and low levels of autistic traits. We expected to observe an overall attentional bias for animal images, with faster probe detection responses following the animal cues than following the object cues. Such an attentional effect, if existing, would be more likely to occur in individuals with low autistic traits but less evident in individuals with high autistic traits. Moreover, how the attentional bias toward animals and its link with autistic traits unfolds over time (i.e., across different cue duration conditions) remains an open question. Besides normal upright pictures, we employed upside-down stimuli to investigate whether stimulus orientation affects the allocation of attention to animals. Although inverted objects are often more difficult to recognize (Sumi, 1984; Yin, 1969), it remains unclear whether inversion would reduce the attention bias to animate stimuli (Bindemann & Burton, 2008; Olk & Garay-Vado, 2011). To further rule out the possibility that it was not animacy perception but some low-level image properties that led to the findings of Experiment 1, we used phase-scrambled images as the attentional cues in Experiment 2.

## 2. Method

### 2.1. Participants

A total of 120 participants aged between 18 and 29 years ( $M \pm SD = 22.52 \pm 2.67$ ) took part in the study, 60 (30 females) in Experiment 1 and 60 (34 females) in Experiment 2. All participants have normal or corrected-to-normal vision, with no history of mental or neurological diseases, and were naive to the purpose of the experiment. Before the experiment, each participant gave written informed consent in accordance with procedures and protocols approved by the institutional review board. A two-tailed power analysis using G\*Power (Faul et al., 2009) indicated that, to detect a small effect size of 0.25 and achieve a power of 0.80, at least 17 participants with low autistic level or high autistic level were needed for a two-factor mixed ANOVA analysis. We have further increased the sample size to approximately 30 participants per group in each experiment to adequately detect the potential difference between these groups in the current study.

### 2.2. Apparatus and material

Stimuli were generated and presented using MATLAB (The MathWorks, Natick, MA) together with the Psychtoolbox extensions (Brainard, 1997; Pelli, 1997) on a 20.8-in. Dell monitor (1920 × 1080 at 60 Hz). Participants' viewing distance was 60 cm. Stimuli were presented on a gray background (RGB: 128, 128, 128), within a black rectangle frame (19.8° × 19.8°, line width: 0.2°) centered on the screen.

The stimuli used in Experiment 1 were pictures of photographed animals and objects selected from an image set of Moreno-Martinez and Montoro (2012). There were 6 pairs of images in total. Each pair included one animal and one object with similar configurations (shown in Fig. 1a) and were presented simultaneously in the experiment. All images were resized to 400 × 300 pixels (8.3° × 7.8°) and changed into grayscale using SHINE Toolbox to match the luminance and contrast within each image pair (Willenbockel et al., 2010). Familiarity did not appear to be confounded with the experimental manipulation, as the animal and object images did not differ in familiarity ratings (averaged familiarity scores: 3.95 vs. 4.29,  $p = 0.249$ ), based on rating data derived from the original image set.

Materials used in Experiment 2 were the phase-scrambled images of those used in Experiment 1. Phase randomization was implemented by fast Fourier transform of the image. A random phase matrix was generated from a randomized image matrix ranged 0–1 and added to the original phases of the picture. An inverse Fourier transform then returned the data to a phase-scrambled image. The pairing relationship of the scrambled images was the same as in Experiment 1.

### 2.3. Procedure

In Experiment 1, each trial began with a fixation cross (0.8° × 0.8°) presented in the center of the screen. Participants were requested to fixate on the central cross while it was on the screen. After a randomized duration between 400 ms and 1000 ms, two images appeared on the left and right side of the fixation (5.3° away from the center). The duration of these picture cues was either 100, 300, 500 or 1000 ms. After an interstimulus interval (ISI) of 50 ms, a visually low-contrast Gabor patch (1.4° × 1.4°) was briefly presented for 100 ms as a probe either on the left or right side of the screen (5.3° from the central cross). Participants were asked to press the left or right arrow key to indicate the location of the probe as quickly as possible while being accurate. The fixation cross remained on the screen after the probe disappeared until a response was made. The intertrial interval was 600 ms with a blank screen (Fig. 1b).

Experiment 1 included 384 trials, separated into 4 blocks (two upright-image blocks and two inverted-image blocks arranged in an ABBA order). Half of the participants started with the upright block, and the other half started with the inverted block. In each block, the probe had an equal chance of appearing at the animal or the object location. The locations of animal and object cues were counterbalanced. There were four conditions of cue duration (100, 300, 500, and 1000 ms), which were mixed randomly within the block. Before starting the task, participants completed 32 practice trials. Experiment 2 consisted of 192 trials, following a procedure similar to that of the upright picture blocks in Experiment 1, except that the picture cues were changed into their phase-scrambled counterparts.

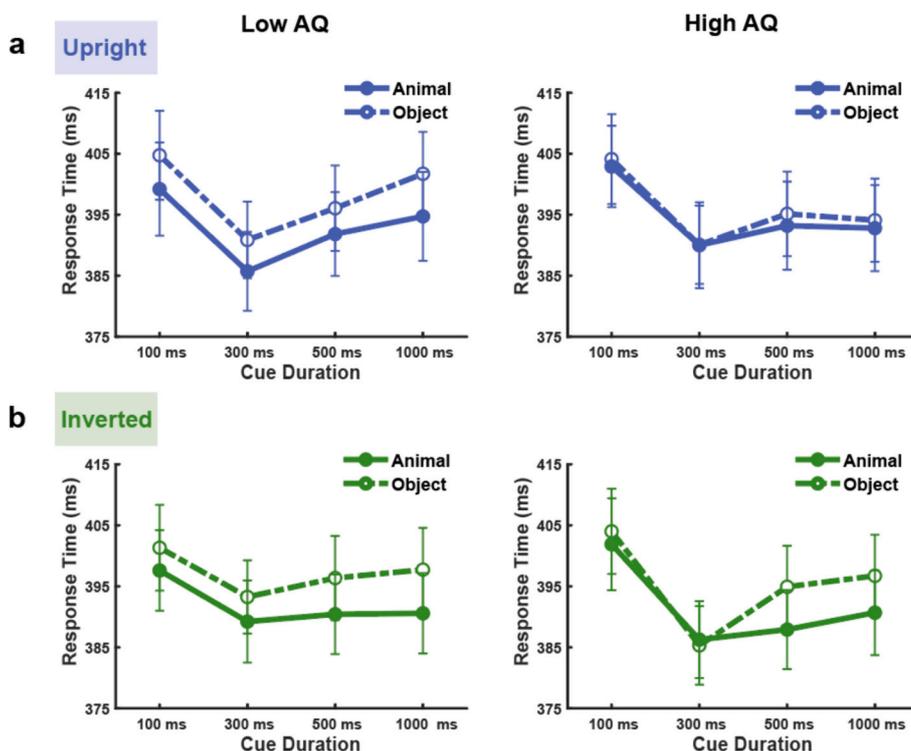
In both experiments, we measured the autistic traits of the participants using the Autism-Spectrum Quotient (AQ) questionnaire developed by Baron-Cohen et al. (2001). It is a brief assessment instrument for identifying the degree of autistic traits of an adult of normal intelligence. A review has supported the validity of the AQ in indexing autistic traits in non-clinical populations (Ruzich et al., 2015).

## 3. Results

### 3.1. Experiment 1

In Experiment 1, the overall accuracy was beyond 99%, both in the upright and inverted cue conditions. Trials with incorrect responses or RTs shorter than 100 ms or longer than 1800 ms were excluded from the statistical analyses, followed by trials with RTs beyond three standard deviations from each subject's own mean value (collapsed across experimental conditions). The percentage of trials excluded from the analyses was 2.2%. To assess the potential difference between participants with different autistic trait levels, we split the participants by the median AQ score (21) into two groups, the low AQ group (AQ ≤ 21, 31 individuals, 17 females) and the high AQ group (AQ > 21, 29 individuals, 13 females).

First, we conducted a 2 (cue type: animal vs. object) × 4 (cue duration: 100, 300, 500, 1000 ms) × 2 (cue orientation: upright vs. inverted) × 2 (AQ group: low AQ vs. high AQ) mixed ANOVA on the RTs (Fig. 2). Results revealed a significant main effect of cue type ( $F(1, 58) = 33.636, p < 0.001, \eta_p^2 = 0.367$ ), as the RTs in the animal-cued trials were faster than those in the object-cued trials, suggesting that participants' attention was overall biased toward the animal pictures. Moreover, there was a significant interaction between cue type and AQ group ( $F(1, 58) = 5.153, p = 0.027, \eta_p^2 = 0.082$ ), as the attentional bias for animals was stronger in the low AQ group than in the high AQ group. The cue type × duration × AQ group interaction was not significant ( $F(3, 174) = 0.502, p = 0.681, \eta_p^2 = 0.009$ ). However, the main effect of cue duration ( $F(3, 174) = 21.435, p < 0.001, \eta_p^2 = 0.270$ ) and the duration × orientation × AQ group interaction ( $F(3, 174) = 4.048, p = 0.008, \eta_p^2 = 0.065$ ) were significant, indicating the variation of RT over time modulated by stimulus- and observer-related factors. No other main effects or interactions were significant ( $ps > 0.17$ ).



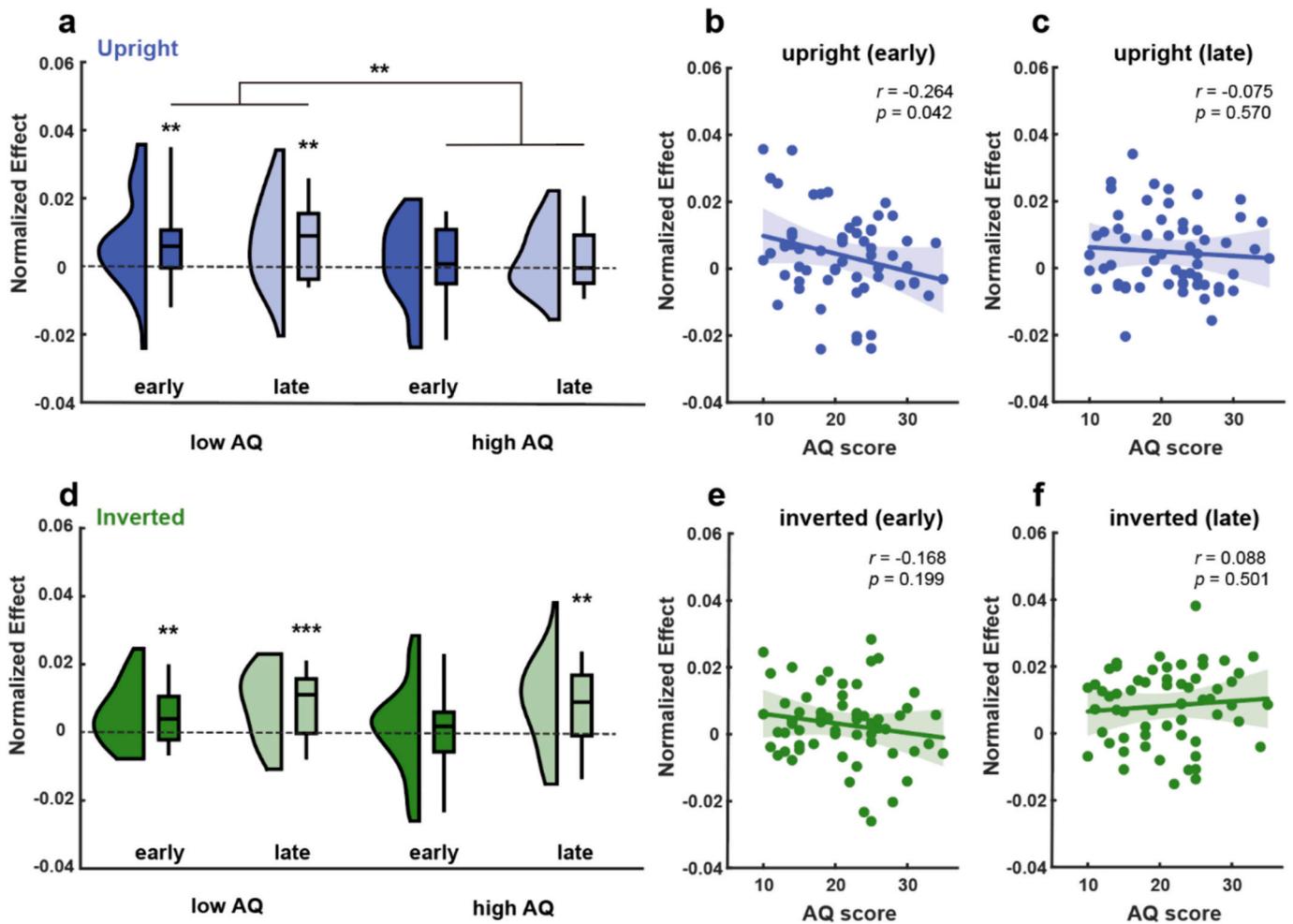
**Fig. 2.** Mean response times in upright (a) and inverted (b) picture cue conditions for low-AQ and high-AQ groups in Experiment 1. Filled lines indicate animal-cued trials, and dashed lines indicate object-cued trials. Error bars show the standard errors of means.

To eliminate the potential influence of the variation of RT over time on the attentional effect, we obtained a normalized attentional bias effect, as the difference of the mean RTs for the object-cued and animal-cued trials divided by their sum, i.e.,  $(RT_{\text{object}} - RT_{\text{animal}}) / (RT_{\text{object}} + RT_{\text{animal}})$ . Positive bias effects indicate a bias toward the animal images, wherein the observers respond faster to probes following the animal cues than to those following the object cues, and negative effects suggest a bias away from the animal images, wherein the observers respond more slowly to probes following the animal cues. Moreover, we combined the first two time points (100 ms and 300 ms) into the early phase, the later ones (500 ms and 1000 ms) into the late phase, to extract more concise rules about the time course of observed attentional effect. Based on these normalized effects, we then examined the early and late attentional biases for each participant group in the upright and inverted picture conditions, respectively (Fig. 3).

One-sample *t*-tests revealed that, in the low AQ group, the normalized bias effect was significantly above zero in all processing phase and picture orientation conditions (early upright:  $t(30) = 2.867, p = 0.008$ ; late upright:  $t(30) = 3.238, p = 0.003$ ; early inverted:  $t(30) = 3.233, p = 0.003$ ; late inverted:  $t(30) = 4.657, p < 0.001$ ). By contrast, the high AQ group showed no attentional effects for upright animal stimuli (early:  $t(28) = 0.350, p = 0.729$ ; late:  $t(28) = 1.281, p = 0.211$ ) and at the early phase of the inverted condition ( $t(28) = 0.337, p = 0.739$ ), while exhibiting an attentional effect in the late phase for inverted animals ( $t(28) = 3.549, p = 0.001$ ). A 2 (processing phase: early vs. late)  $\times$  2 (cue orientation: upright vs. inverted)  $\times$  2 (AQ group: low vs. high) ANOVA on the normalized attentional effect yielded a significant main effect of AQ group on the overall attentional effect ( $F(1, 58) = 5.025, p = 0.029, \eta_p^2 = 0.080$ ). Besides, the attentional effect was significantly larger in the late phase than in the early phase ( $F(1, 58) = 4.714, p = 0.034, \eta_p^2 = 0.075$ ). While none of the two-way or three-way interactions reached significant levels, there was a tendency of the image orientation  $\times$  AQ group interaction ( $p = 0.143$ ) and a image orientation  $\times$  time course interaction ( $p = 0.162$ ), suggesting a possible distinction between the two cue orientation conditions regarding the attentional effect.

Thus, we conducted a two-way ANOVA of the AQ group  $\times$  processing phase for the upright and inverted cue conditions, respectively. In the upright condition (Fig. 3a), individuals with lower autistic traits showed a larger attentional effect than those with higher autistic traits ( $F(1, 58) = 7.228, p = 0.009$ ). The attentional effect did not differ between the early and late phases ( $F(1, 58) = 0.140, p = 0.710$ ), without significant interaction between the processing phase and the AQ group ( $F(1, 58) = 0.073, p = 0.788$ ). In the inverted picture condition (Fig. 3d), however, the low and high AQ groups did not differ in the overall attentional effect ( $F(1, 58) = 0.945, p = 0.335$ ), while the attentional effect was significantly larger in the late phase than in the early phase ( $F(1, 58) = 7.340, p = 0.009$ ). The processing phase by AQ group interaction was not significant ( $F(1, 58) = 1.243, p = 0.269$ ).

Apart from group analysis, correlation analysis could provide a more direct way to evaluate the relationship between the attentional bias for animacy and individuals' autistic traits. Therefore, we performed Pearson correlation analyses and summarized the results in Table 1. In the upright condition, the observers' AQ scores negatively correlated with the overall attentional effects ( $r = -0.253, p = 0.051$ ), such correlation was significant for the early attentional effect ( $r = -0.264, p = 0.042$ ) but not for the late attentional effect ( $r = -0.075, p = 0.570$ ). By contrast, in the inverted condition, none of the correlations were significant ( $ps > 0.19$ ). The correlation scatters of the early- and late-phase effects under each orientation were shown in Fig. 3. Further comparison revealed that the correlation in the upright-cue condition was stronger than that in the inverted-cue condition ( $p = 0.020$  without cat trials,  $p = 0.089$  for all trials, see the *Rating Experiment and supplementary data analyses* session below for more details), although the correlation difference between the early phase and the late phase attention effects in the upright-cue condition did not reach significance ( $p = 0.139$  without cat trials;  $p = 0.154$  for all trials). Together, these results verify the finding that higher autistic traits lead to less attentional bias toward animacy, and suggest that such link primarily roots in the early attentional orienting process and is sensitive to the stimulus orientation.



**Fig. 3.** Normalized attentional effects and its correlation with the AQ score in Experiment 1. The early and late attentional effects in the two AQ groups for the upright (a) and inverted (d) conditions, with distributions of samples shown by the smoothed density plot, as well as the quantiles and median scores shown by the boxplot. The correlation scatters of AQ and the normalized attentional effects under the upright (b, c) and inverted (e, f) cue conditions. Error bars show the standard errors of means. \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ .

**Table 1**

Pearson's Correlations Between the AQ Scores and the Attentional Effects.

	Attention bias to animacy	Upright cue			Inverted cue		
		Early	Late	Overall	Early	Late	Overall
AQ	Pearson's $r$	-0.264*	-0.075	-0.253 <sup>+</sup>	-0.168	0.088	-0.054
	$p$	0.042	0.570	0.051	0.199	0.501	0.681

Note: <sup>+</sup>,  $0.05 < p < 0.1$ ; \*,  $p < 0.05$ .

### 3.2. Rating Experiment and supplementary data analyses on the influence of social information

To further examine to what extent the current results were influenced by the potential social information conveyed by animals, we performed an additional rating experiment, collecting the social property rating scores of the animal stimuli in a new group of participants (detailed results and additional analyses were presented in Supplementary Information). In brief, the animal images were perceived as agents with low social properties in general (with an average score of 2.72 on a 1–7 scale), except that the cat has a medium level of social information (scoring around 4). There was no significant correlation between the social property rating score and the attentional effect across animal images (Spearman's  $r = 0.638$ ,  $p = 0.173$ ). Moreover, additional analyses based on data excluding the cat yielded essentially consistent

results with those from Experiment 1. These findings suggest that the observed results can not be accounted for by the social information conveyed by animals but may reflect the processing of animacy.

### 3.3. Experiment 2

In experiment 1, we observed attentional effects both in the upright and inverted cue conditions in the low AQ group, leading to two potential accounts. One was that the animacy nature of inverted animal images could still be perceived and cause attentional bias. The other was that some confounding low-level properties led to this result. Thus, in Experiment 2, we employed phase-scrambled animal and object images to disentangle these accounts. We recruited another 60 participants and divided them into the low AQ group ( $n = 30$ , AQ score:  $15.43 \pm 3.56$ , 17 females) and the high AQ group ( $n = 30$ , AQ score:  $26.90 \pm 4.68$ , 17

females), according to the same criterion that distinguished the two groups (the median AQ score: 21) in Experiment 1.

The trial exclusion criteria in Experiment 2 were the same as Experiment 1. The percentage of trials excluded from the analyses was 2.0%. Mean RTs of each condition are shown in Fig. 4a.

A 2 (cue type: animal vs. object)  $\times$  4 (cue duration: 100, 300, 500, 1000 ms)  $\times$  2 (AQ group: low AQ vs. high AQ) ANOVA on the RTs yielded no significant main effect of cue type ( $F(1, 58) = 0.298, p = 0.587$ ) or AQ group ( $F(1, 58) = 0.119, p = 0.731$ ), but a significant main effect of cue duration ( $p < 0.001$ ). None of the two-way or three-way interactions were significant,  $p_s > 0.37$ .

We then calculated the early and late normalized attentional effects for the two AQ groups in the same way as in Experiment 1 (Fig. 4b). The attentional effect did not differ from zero in either the early or late processing phase in both groups ( $p_s > 0.23$ ). Moreover, a two-way ANOVA revealed no significant main effect of AQ groups ( $F(1, 58) = 0.821, p = 0.369$ ), processing phases ( $F(1, 58) = 1.283, p = 0.262$ ), or the phase  $\times$  AQ group interaction ( $F(1, 58) = 0.254, p = 0.616$ ). Correlation analyses also showed that AQ score did not correlate with the early ( $r = -0.057, p = 0.664$ ), late ( $r = -0.030, p = 0.820$ ), or overall ( $r = -0.059, p = 0.653$ ) attentional effect. The absence of the attentional bias for phase-scrambled animal pictures and its lack of correlation with AQ exclude the possibility that low-level image properties lead to the findings from Experiment 1.

#### 4. General Discussion

Animacy is an important attribute that affects attention selection. The current study investigated the attentional bias toward animate stimuli and its time course in observers with different levels of autistic traits. In Experiment 1, observers with low AQ scores exhibited a significant and enduring attentional bias for upright animal pictures over object pictures, while the high AQ group showed no such bias. The

observed attentional effect was not due to the familiarity of picture stimuli, because the animal and object pictures had comparable familiarity ratings. Moreover, in Experiment 2, when using phase-scrambled pictures that disrupted the animacy information but not low-level properties of the image, both the low and high AQ groups exhibited no attentional bias, suggesting that the attentional effect observed in Experiment 1 should be attributed to the living nature rather than the low-level properties of animal images.

These findings provide fresh evidence for the animate monitoring hypothesis and extend our knowledge about the attention bias for animacy in the temporal dimension. Existing studies regarding the priority of animacy in attention processing have mostly focused on whether animate stimuli engage attention more than inanimate ones (Altman et al., 2016; Calvillo & Jackson, 2014; Guerrero & Calvillo, 2016; Lipp et al., 2004) while ignoring the temporal properties of the attention process. While there has been a study showing that human faces can steadily attract observers' attention more than non-living objects at 100 ms, 500 ms, and 1000 ms from the stimuli onset (Bindemann et al., 2007), such effects may not arise entirely from the attention to animacy, given that faces have special social meanings. The current study demonstrated for the first time that the attentional bias to general animate stimuli (i.e., animal images) unfolds over time at both the early (orienting) and late (maintenance) attentional phases, particularly in individuals with lower autistic traits. Consistent with the results of faces, these findings suggest the attentional bias to animacy could remain stable over time, which is beneficial to both rapid detection and continuous monitoring of animals.

Although sensitivity to animate information is an important part of the human cognitive system, not everyone is equally equipped with this ability. It remains controversial whether preferential attentional processing of static animate cues links with social perception and whether this attention effect is compromised in autistic populations or people with high autistic traits (Guillon et al., 2016; New et al., 2010). Our

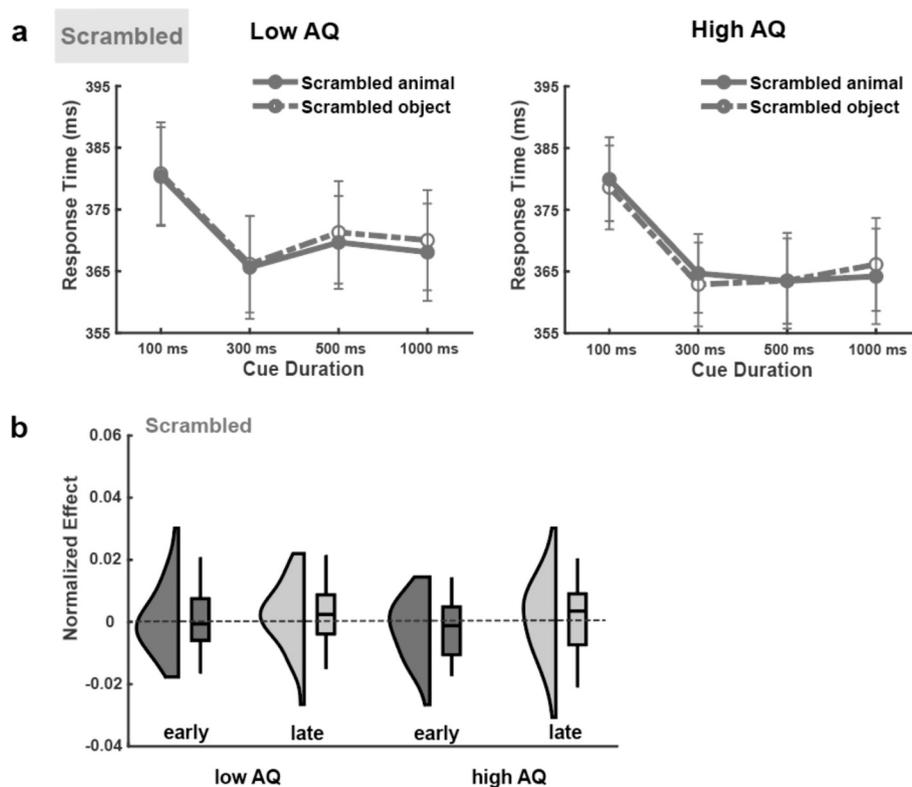


Fig. 4. Mean response times (a) and the normalized attentional effects (b) obtained with scrambled picture cues for low-AQ and high-AQ groups in Experiment 2. (a) Filled lines indicate scrambled-animal-cued trials, and dashed lines indicate scrambled-object-cued trials. (b) Distributions of samples as well as the quantiles and median scores under each condition. Error bars represent the standard errors of means.

results provide compelling evidence for this issue. Using a time-sensitive probe paradigm, we found reduced attentional orienting to animate pictures in the high AQ group relative to the low AQ group. This effect mainly occurs at the early orienting phase (100 and 300 ms), with individual AQ scores significantly correlated with the early attentional effects, although there is a negative but nonsignificant correlation at the late attentional phase. As an exploration, our study indicates a possible pattern about how the attentional processing of animacy may alter in ASD populations, which is worth further research. Contrasting the attentional effects between individuals diagnosed with ASD and non-clinical populations in future studies may help elucidate this issue. In addition, the discrepancy between the current findings and the negative results of New et al. (2010) obtained from the change detection paradigm indicates that time is an essential variable to consider when evaluating the individual differences in attentional bias to animacy, which somewhat echoes previous findings of reduced early attentional orientation to faces in ASD individuals (Guillon et al., 2016; Moore et al., 2012).

In addition, our research on static animate cues, together with studies showing defects in animate motion recognition in ASD (Congiu et al., 2010; Rasmussen & Jiang, 2019; Rutherford et al., 2006), broaden our understanding of the scope of the social cognitive impairments in autistic populations. The impairment may not be confined to the pure “social” range — the processing of less direct socially-relevant information (i.e., animacy) is involved as well. Animacy is a basic property of social agents, the perception of which could pave the way for social interaction. Based on the large amount of evidence for the inborn predispositions to orient toward animate entities (e.g., Di Giorgio et al., 2017; Lemaire et al., 2022; Rosa-Salva et al., 2018, 2021), it is assumed that the animacy detection mechanism is related to the emergence of the social brain (Salva & Vallortigara, 2015). Our findings are in favor of this perspective, supporting the connection between animacy processing and social cognitive abilities. From a developmental view, this connection could be explained by several accounts beyond the domain-general factors (Van De Cruys et al., 2014). One is that the aberrant attention to animate stimuli results in less exposure to social settings, and therefore less reinforcement of the brain circuits underlying the social cognitive abilities, causing autistic-like behaviors. Whereas the reverse also makes sense. It is also possible that there is a long-term mutual influence between the attentional processing of animacy and social cognitive abilities during development. Further investigation could explore the developmental and evolutionary origin of the animal advantage in selective attention.

In the current study, the attentional bias for animal pictures was also present in the inverted picture condition. Although the “inversion effect” is typical in stimuli with biological relevance, such as faces and biological motion (i.e., turning these stimuli upside-down resulted in impaired perception), inverted faces could still gain more attention when presented simultaneously with inverted objects (Bindemann & Burton, 2008). These findings indicate that some high-level visual attributes guiding attention could be available in both upright and inverted orientations, which is in accordance with our results. However, the attentional effects induced by inverted pictures may not share the same underlying mechanism as that for the upright condition, given that the AQ scores correlated solely with the attentional bias to upright animal pictures. Probably more top-down processing is needed to extract animacy information from inverted animal pictures, and this cognitive control may act as a compensatory yet time-consuming mechanism in high AQ individuals to induce attention bias for animacy in the late attentional phase.

In general, due to the adaptive value of animacy and its fundamental role in human life, our attention system is automatically biased toward animals, rapidly orienting to and constantly monitoring the presence of living entities. Yet this capacity is not uniformly distributed among individuals and may constitute a basis for social cognition. One’s autistic traits, commonly assumed to reflect the ability and willingness to

socialize, associate with the attentional bias to animacy.

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## CRediT authorship contribution statement

**Geqing Yang:** Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Ying Wang:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Yi Jiang:** Writing – review & editing, Funding acquisition.

## Declaration of competing interest

The authors declared no conflicts of interest with respect to the authorship or the publication of this article.

## Data availability

All data generated in the current study are made available at <http://ir.psych.ac.cn/handle/311026/45051>.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cognition.2024.105900>.

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