

2021, Vol. 47, No. 9, 1237-1246 https://doi.org/10.1037/xhp0000939

Social Attention Triggered by Eye Gaze and Walking Direction Is Resistant to Temporal Decay

Wenjie Liu, Xiangyong Yuan, Dingrui Liu, Li Wang, and Yi Jiang

State Key Laboratory of Brain and Cognitive Science, CAS Center for Excellence in Brain Science and Intelligence Technology,

Institute of Psychology, Chinese Academy of Sciences, Beijing, China

Department of Psychology, University of Chinese Academy of Sciences

Chinese Institute for Brain Research, Beijing, China

The attentional orienting induced by social cues, such as eye gaze and walking direction of biological motion, plays a vital role in human survival and interpersonal interactions. It has long been debated whether this indispensable ability is unique and intrinsically distinct from nonsocial attention. In the current study, we characterized the temporal profiles of the attentional orienting triggered by social cues (i.e., eye gaze and walking direction) and compared them with those induced by nonsocial cues (i.e., arrows) and exogenous cues using a covert orienting task. We calculated the attentional cuing effects in the early and the late periods of the task and further carried out a time course analysis to characterize their dynamic changes over trials. Whereas the cuing effect induced by nonsocial cues were similar and remained stable throughout the task, resembling that induced by reflexive exogenous cues. These results clearly demonstrate that the socially coordinated attentional orienting is a highly reflexive and temporally stable response, which is less susceptible to top-down cognitive control and substantially distinguished from the attentional orienting induced by nonsocial cues. These findings extend our understandings of the distinction between social and nonsocial attention and further substantiate the specificity of social attentional orienting from a temporal-stability perspective.

Public Significance Statement

Social attention is vital for human survival and interpersonal interactions, which may differ from nonsocial attention in many aspects. Here, we show from a novel, temporal-stability perspective that the social attentional orienting induced by eye gaze or biological motion remains temporally stable as the task proceeds, resembling reflexive attentional orienting induced by exogenous cues. By contrast, nonsocial attentional orienting induced by arrows exhibits a significant trend of decay. The findings extend our understandings of the distinction between social and nonsocial attention from a temporal view, and suggest a stricter criterion that takes temporal stability into consideration, when testing the reflexive nature of attentional orienting.

Keywords: social attention, biological motion, eye gaze, reflexive, top-down control

Xiangyong Yuan b https://orcid.org/0000-0002-8043-3601 Li Wang b https://orcid.org/0000-0002-2204-5192

This work is supported by the National Natural Science Foundation of China (31830037), the Strategic Priority Research Program (XDB32010300), the Key Research Program of Frontier Sciences (QYZDB-SSW-SMC030), the National Key Research and Development Project (2020AAA0105600), Beijing Municipal Science & Technology Commission, and the Fundamental Research Funds for the Central Universities.

All data have been made publicly available via the Institutional Knowledge Repository, Institute of Psychology, Chinese Academy of Sciences, and can be accessed at http://ir.psych.ac.cn/handle/311026/34075. The authors declare no competing financial interest.

Correspondence concerning this article should be addressed to Xiangyong Yuan or Yi Jiang, State Key Laboratory of Brain and Cognitive Science, CAS Center for Excellence in Brain Science and Intelligence Technology, Institute of Psychology, Chinese Academy of Sciences, 16 Lincui Road, Chaoyang District, Beijing 100101, China. Email: yuanxy@ psych.ac.cn or yijiang@psych.ac.cn

Humans, being social creatures, are ready to focus attention on the interests of their conspecifics via social cues (e.g., eye gaze) and make inferences regarding their intentions and actions (Hommel et al., 2001; Nummenmaa & Calder, 2009). This indispensable ability, which is known as social attention or joint attention, underpins the development of complex sociocognitive skills (for example, theory of mind, language; Baron-Cohen, 1995; Brooks & Meltzoff, 2005; Shepherd, 2010) and plays a fundamental role in daily social interactions. A modified central cuing paradigm, introduced by Friesen and Kingstone (1998), has been widely used to characterize the properties of social attention. Typically, a nonpredictive eye gaze cue is presented centrally (with valid cues in half of the trials and invalid cues in the other half), which would lead to more rapid responses to targets located in the same side directed by the eye gaze than those in the opposite location. This gaze cuing effect arises very rapidly (about 100-200 ms following the onset of the gaze cue; Friesen & Kingstone, 1998; Frischen & Tipper, 2004; Langton &

Yi Jiang D https://orcid.org/0000-0002-5746-7301

Bruce, 1999) and occurs even when gaze direction is counterpredictive of the target location (Downing et al., 2004; Driver et al., 1999; Friesen et al., 2004; Tipples, 2008), thus disclosing its reflexive nature.

Apparently, although social cues are always located in the center like traditional endogenous cues (Posner, 1980), social attention cannot be categorized as a type of endogenous attention, because of the cues' unpredictability. It seems that social attention parallels the well-known exogenous attention that is reflexively induced by spatially uninformative cues (Posner, 1980). However, unlike exogenous attention, social attention is not triggered by peripheral cues. More importantly, it persists over a fairly long interval and exhibits delayed inhibition of return (Frischen et al., 2007; Frischen & Tipper, 2004). Given these special properties, social attention challenges the traditional dichotomous categorization of covert attention and opens up new avenues for visual attention research.

In addition to social attention, the attention guided by some symbolic, nonsocial cues (e.g., arrows) cannot be classified according to the traditional dichotomy of attention either, since these nonpredictive nonsocial cues can also trigger attentional orienting (Hommel et al., 2001; Ristic et al., 2002; Ristic & Kingstone, 2006; Tipples, 2002). It is thus theoretically important to elucidate whether social attention is intrinsically different from nonsocial attention. There has been some evidence that supports the specificity of social attention. First, relative to nonsocial attentional orienting, social attentional orienting seems to be more reflexive and less susceptible to topdown cognitive control (Friesen et al., 2004; Ristic et al., 2007). Second, some neuroimaging studies have demonstrated differentiated neural activations in response to social and nonsocial attention. For instance, orienting to eye gaze activates the ventral frontoparietal attention network, whereas orienting to arrows activates the dorsal frontoparietal attention network (Hietanen et al., 2006, 2008; Joseph et al., 2015). However, other findings indicated that nonsocial attentional orienting was not only indistinguishable from the reflexive gaze orienting (Nummenmaa & Hietanen, 2009; Tipples, 2008), but also exhibited similar patterns in terms of brain activations (Sato et al., 2009; Tipples et al., 2013; Uono et al., 2014). Taken together, the specificity of social attention is still an open-to-debate question in the literature.

Here we aimed to investigate this issue from a novel perspective. It has been shown that humans can learn the cue's predictiveness for the location of target even without being explicitly instructed, and imbue the predictive cue with higher attention priority (Dodd & Wilson, 2009; Lin et al., 2016) or inhibit attention to the nonpredictive repeated cues (a phenomenon termed habituation; see Dukewich, 2009; Dukewich & Boehnke, 2008). These results suggest that as time goes on, observers may become gradually aware that some cues are not predictive of the probable target location, and can gradually refrain from attending to those cues through top-down cognitive control. However, this implicit strategy might be more effective for nonreflexive than for reflexive attentional orienting, as reflexive behaviors by definition are less susceptible to cognitive control (Giordano et al., 2009). In short, reflexive and nonreflexive attentional orienting might exhibit disparate profiles from a perspective of temporal stability. Of note, the temporal profile here refers to the dynamic cuing effect as the task proceeds rather than as a function of the stimulus onset asynchrony (SOA). As mentioned above, it remains controversial whether social and nonsocial attention are similarly reflexive in nature, or comparably amenable to top-down control (Friesen et al., 2004; Nummenmaa & Hietanen, 2009; Ristic et al., 2007; Tipples, 2008). If social attention is indeed more reflexive than nonsocial attention, we would expect to delineate their difference from the perspective of temporal stability.

To this end, we carried out a covert orienting task with more trials (for one SOA) compared with previous studies (Driver et al., 1999; Friesen & Kingstone, 1998; Shi et al., 2010) in order to characterize the temporal profiles of social and nonsocial attentional orienting effects over trials. We would most likely find similar attentional orienting triggered by eye gaze and arrow cues at the early period of the task, as in previous studies (Nummenmaa & Hietanen, 2009; Tipples, 2008). By contrast, for the late period of the task, we would expect to observe a substantial differentiation of the two effects (in terms of temporal decay).

To further delineate the specificity of social attention, we adopted another type of social cue, biological motion (BM), which is portrayed by a handful of moving point-light dots attached to the main joints of a person (Johansson, 1973). BM conveys critical social information about the person's intention, and it has been demonstrated that walking direction of BM, like eye gaze, can trigger reflexive attentional orienting effect (Shi et al., 2010; Yu et al., 2020). Moreover, such effects exist not only in adults (Hirai et al., 2011; Shi et al., 2010), but also in 4-year-old children (Zhao et al., 2014) and even 6-month-old infants (Bardi et al., 2015; Lunghi et al., 2019).

Finally, we conducted an additional experiment using the reflexive exogenous cuing paradigm (Posner, 1980) to illustrate the temporal profile for a typical reflexive attentional orienting in the same experimental settings. This would allow us to directly depict whether the cuing effects induced by social and nonsocial cues exhibit similar temporal profiles to that induced by reflexive exogenous cues (Bardi et al., 2015; Friesen et al., 2004; Friesen & Kingstone, 1998; Hirai et al., 2011; Langton & Bruce, 1999; Shi et al., 2010; Zhao et al., 2014).

General Method

Participants

A total of 80 participants (51 female, aged from 18 to 31) took part in the study, with 20 participants (13 females in Experiments 1, 2 and 4, and 12 females in Experiment 3) in each of the four experiments. The sample size was determined based on previous relevant studies (Hietanen et al., 2006; Ji et al., 2020; Shi et al., 2010), and a two-tailed power analysis using G*Power (Version 3.1.9.4; Faul et al., 2007) confirmed that a sample size of 15 participants would afford 80% power to detect an attentional effect induced by social or nonsocial cues (Cohen's d = .8, which is an average effect size found in previous studies; see Hietanen et al., 2006; Ji et al., 2020; Shi et al., 2010). Considering the primary aim of the study was to evaluate the dynamic change of the cuing effect, the sample size was increased to 20. All participants had normal or corrected-to-normal vision and gave written, informed consent in accordance with procedures and protocols approved by the institutional review board of the Institute of Psychology, Chinese Academy of Sciences. Of the 86 participants we originally recruited, 6 were excluded from further analysis due to the following reasons (see Results section for more details). Briefly, one was excluded from Experiment 3 as his mean response time fell beyond two standard deviations of the group mean, and 5 were excluded in the analysis of their temporal profiles over trials: Two (one in Experiment 1 and one in Experiment 4) had very poor goodness of fit (the R square was below two standard deviations of the mean), and the other 3 (2 in Experiment 1 and 1 in Experiment 4) had abnormal slope parameter of the fitted curve, which was beyond two standard deviations of the means.

Stimuli and Procedure

Stimuli were generated and displayed using MATLAB (Mathworks, Inc.) together with the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). All stimuli were presented in white

on a gray background, and the viewing distance was about 57 cm. A covert orienting (cue-probe) task with different cues was conducted in separate experiments (Figure 1). In Experiment 1, a face $(3.4^{\circ} \times 4.3^{\circ})$ image with gaze averted to the left or the right was taken from the Ekman and Friesen's Pictures of Facial Affect (Ekman & Friesen, 1976), and it was cropped to remove features outside of the face (e.g., hair and ears). The gaze direction was manipulated by Photoshop software. In Experiment 2, a left or right arrow $(1.7^{\circ} \times .5^{\circ})$ at the fixation was used as a central cue. In Experiment 3, a BM cue was used. The BM cue was a point-light walker adopted from Vanrie and Verfaillie (2004), walking either leftward or rightward. Each point-light walker, subtending

Figure 1

Schematic Diagram of the Experimental Paradigm



Note. (a) The trial procedure of Experiment 1. A fixation was showed 500 ms firstly in each trial, followed by a face with straight-ahead gaze (100 ms) and then with averted gaze (400 ms). After a 100-ms interstimulus interval (ISI), a small Gabor patch was presented briefly (100 ms) as a probe on the left or the right side of the fixation. Participants were required to press one of two buttons to indicate on which side the probe appeared, as quickly as possible. The experimental procedures of Experiment 2 (b), Experiment 3 (c), and Experiment 4 (d) were similar to Experiment 1 (a) except that different cues were used and no precue was presented. And in Experiment 4, the fixation was lengthened to 900 ms as the exogenous cue was flashed in a short time (100 ms).

approximately $3.7^{\circ} \times 5.3^{\circ}$ in visual angle, was presented around the fixation and refreshed at a rate of 30 Hz. One gait cycle of the point-light walker lasted 1 s, and the initial frame of the point-light walker was randomized in each trial to avoid participants' prediction. In Experiment 4, a white rectangular frame $(1.1^{\circ} \times 1.1^{\circ})$, which flashed on either the left or the right side of the fixation randomly (exactly around the probe), was used as a peripheral, exogenous cue.

In Experiment 1, each trial began with fixation on a central cross $(.5^{\circ} \times .5^{\circ})$ within a frame $(16.1^{\circ} \times 16.1^{\circ})$ that extended beyond the outer border of the stimuli. After 500 ms, a face with a straight-ahead gaze appeared in the center of the screen for 100 ms, followed by a 400-ms gaze cue (the same face but with leftward or rightward gaze). After the cue disappeared, there was a 100-ms interstimulus interval (ISI), followed by a small Gabor patch $(1.1^{\circ} \times 1.1^{\circ})$ that was presented briefly (100 ms) as a probe on the left or the right side, with an eccentricity of 4.2°. Throughout the experiment, participants were asked to stare at the fixation and to press one of two keys on a standard keyboard to indicate whether the probe appeared on the left or the right side, as quickly as possible while minimizing errors. The procedures of Experiments 2, 3, and 4 were similar to that of Experiment 1, except that a 500-ms arrow cue and point-light walker was employed as a central cue in Experiments 2 and 3, respectively. A white rectangular frame flashed in 100 ms was employed as a classical exogenous cue in Experiment 4. In order to match the trial duration (1200 ms) with other cues, the fixation period before the exogenous cue onset in Experiment 4 was prolonged to 900 ms (see Figure 1 for a schematic experimental procedure). There was a total of 300 trials for each experiment, with 150 trials for the valid Cue-Probe condition (the probe was presented on the same side of the cue indication) and invalid Cue-Probe condition (the probe was presented on the opposite side of the cue indication), respectively. Participants were not informed that the cues were nonpredictive of the targets (50% valid and 50% invalid trials). Short breaks were provided after every 50 trials.

Data Analysis

To examine how attentional orienting effects caused by different cues dynamically changed over trials, we extracted the RT (response time) in each trial for each participant. Only trials with correct responses were considered, and those trials with RTs shorter than 100ms, longer than 1s, or beyond two standard deviations of the mean were removed beforehand. The percentage of trials excluded from the analyses was 4.7% in Experiment 1, 4.0% in Experiment 2, 4.0% in Experiment 3, and 5.6% in Experiment 4. Next, we divided all trials into two parts in each experiment, the first and second half of trials, which respectively corresponded to the early- and the late-period condition. A 2×2 repeated-measures analysis of variance (ANOVA) with two within-subjects factors of Cue-Probe Validity (valid vs. invalid) and task Period (early vs. late) was carried out in each experiment (as drawn in Figure 2). A significant main effect of Cue-Probe Validity and an interaction effect, if both existed, would indicate that the cuing effect (invalid RTs minus valid RTs) significantly changes between the early and the late periods of the task. If only a significant main effect of Cue-Probe Validity was found, it then signified a temporally stable cuing effect.

Furthermore, to portray the dynamic changes of the cuing effect caused by different cues more precisely, we analyzed the temporal trend of the cuing effect over trials for each participant. This analysis was conducted using a sliding window method, which calculates the running average of the cuing effect across consecutive trials. First, we set 100 trials as a time bin, and applied the sliding window method across trials with a step size of one trial, consequently generating 201 time bins. For example, bin 1 included trials from the 1st to the 100th, bin 2 included trials from the 2nd to the 101st, and so forth. Second, we calculated the cuing effect using valid and invalid RTs of the 100 trials in each time bin, as drawn in Figure 3a–d (black curves). Third, we fitted the obtained temporal profile of the cuing effect via the function below (red[dark gray] curves in Figure 3a–d):

Cuing effect =
$$\sum_{i=1}^{2} A_i \times \sin(2 \times pi \times f_i(n+ph_i))$$

+ slope \times n + intercept,

in which *n* refers to the number of the time bin. For example, trials from 1 to 100 constitute the first bin so that n = 1. The *slope* parameter is of our most interest, as it specifically estimates the linear changes of the cuing effect as the task proceeds. In particular, a significantly negative slope value means that the cuing effect gradually vanishes over trials (i.e., temporal decay). Moreover, two sinusoidal fluctuations each with three parameters *A*, *f*, and *ph* are used to capture the slow and fast fluctuations of the cuing effect over trials, respectively (as illustrated by the rise and fall of the red (dark gray) curves in Figure 3a–d).

Results

Attentional Orienting in the Early and the Late Periods of the Task

In Experiment 1, where gaze cues were presented, the repeatedmeasures ANOVA revealed a significant main effect of Cue-Probe Validity (F(1, 19) = 6.02, p = .02, $\eta_p^2 = .24$; Figure 2a). RTs were significantly shorter in the valid condition (360.11 ± 34.95 ms) than in the invalid condition (367.69 ± 31.35 ms), which indicates that attention is reflexively attracted to the gaze direction, consistent with previous findings (Driver et al., 1999; Friesen & Kingstone, 1998). Moreover, the main effect of task Period was significant (F(1, 19) =7.73, p = .01, $\eta_p^2 = .29$). Notably, there was no significant interaction between these two factors (F(1, 19) = .32, p = .58, $\eta_p^2 = .02$). These results suggest that the gaze cuing effect remains stable throughout the task although participants have completed more trials (for one SOA) than previous studies using these uninformative gaze cues (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999).

In Experiment 2, we continued to explore whether such stable cuing effect observed in Experiment 1 was specific to social cues. To this end, arrows, which have directional property but without biological meaningfulness, were used. As seen in Figure 2b, the results also revealed a significant main effect of Cue-Probe Validity ($F(1, 19) = 6.29, p = .02, \eta_p^2 = .25$; valid RT: 379.75 ± 54.21 ms; invalid RT: 388.27 ± 50.12 ms), and a nonsignificant main effect of task Period ($F(1, 19) = .18, p = .67, \eta_p^2 = .01$). However, different from



Figure 2 *Results from Experiments 1–4*

Note. Participants' responses were significantly faster when probe was presented at the gaze direction (Experiment 1), the pointing direction of the arrows (Experiment 2), the walking direction of the point-light walkers (Experiment 3), and at the same position of the rectangular frames (Experiment 4). Remarkably, this cuing effect disappeared in the late period of the task (i.e., the second half of trials) when arrows were used as attentional cues (b), while persisting over the entire period of the task when the gaze (a), point-light walkers (c), or the rectangular frames (d) were used as cues. BM = biological motion. Error bars show standard errors.

Experiment 1, a significant interaction was found (F(1, 19) = 5.39, p = .03, $\eta_p^2 = .22$). For the first half of trials, participants were attracted by the uninformative arrow cues, responding significantly faster when the probe was presented at the direction indicated by the arrow than in the opposite direction (valid RT: 376.45 ± 53.81 ms; invalid RT: 389.27 ± 52.38 ms; t(19) = -3.47, p = .003, Cohen's d = .78, 95% CI [-20.54, -5.08]), but the cuing effect completely disappeared in the second half of trials (valid RT: 383.04 ± 55.82 ms; invalid RT: 387.27 ± 49.11 ms; t(19) = -1.05, p = .31, Cohen's d = .23, 95% CI [-12.66, 4.22]), indicating the attentional orienting induced by nonpredictive arrow cues exhibited significant temporal decay as the task proceeded. The sharp contrast between Experiments 1 and 2 provided compelling evidence that the attentional orienting induced by social cues, but not nonsocial cues, is resistant to temporal decay even without any target-informative clues.

In Experiment 3. where social cues were replaced by BM, the results were essentially the same as those of Experiment 1 (the main effect of Cue-Probe Validity: F(1, 19) = 9.10, p = .007, $\eta_p^2 = .32$; the main effect of task Period: F(1, 19) = .001, p = .97, $\eta_p^2 < .001$; the interaction: F(1, 19) = 1.59, p = .22, $\eta_p^2 = .08$; Figure 2c). Like Experiment 1, the finding of Experiment 3 confirms a temporally stable cuing effect toward the walking direction of the point-light walkers (valid RTs: 390.88 ± 48.43 ms; invalid RTs: 396.82 ± 49.48 ms).

If social cues can induce reflexive attentional orienting, the temporal trend of the cuing effect induced by gaze and BM is expected to be similar to that of the classical exogenous attentional orienting, which is intrinsically reflexive (Giordano et al., 2009). Therefore, in Experiment 4, we used a rectangular frame flashed briefly as an exogenous, peripheral cue. We found that the results, illustrated in Figure 2d, were identical to those observed in Experiments 1 and 3. There was a significant effect of Cue-Probe Validity ($F(1, 19) = 14.95, p = .001, \eta_p^2 =$.44), with valid RTs significantly shorter (369.11 \pm 31.17 ms) than invalid RTs (385.68 \pm 38.28 ms), but neither the main effect of task Period ($F(1, 19) = 1.18, p = .29, \eta_p^2 = .06$) nor their interaction ($F(1, 19) = 1.36, p = .26, \eta_p^2 = .07$) was significant. The results from Experiments 1, 3, and 4 substantiated that the temporal trend of attentional orienting induced by social cues was indeed similar to that induced by reflexive exogenous cues.

The temporal trends of attentional orienting across the early and the late periods in Experiments 1–4 were further highlighted by the normalized cuing effects (i.e., invalid RTs – valid RTs/invalid RTs + valid RTs). Consistently, the normalized cuing effect induced by arrows decreased significantly more in the late period than that in the early period (t(19) = -2.42, p = .03, Cohen's d =



Temporal Trends of the Cuing Effects (Invalid RTs Minus Valid RTs) from Experiments 1-4

Note. Panels (a), (b), (c), and (d) show the temporal trend of the average cuing effect across participants for gaze (Experiment 1), arrow (Experiment 2), BM (Experiment 3), and exogenous cue (Experiment 4), respectively. In each panel, the observed cuing effect over trials was plotted in black and the fitted curve was plotted in red (dark gray). The shaded areas represent standard errors. RT = response time. See the online article for the color version of this figure.

.54, 95% CI [-.02, -.001]), while the normalized cuing effect induced by gaze, BM, and exogenous cues showed no significant change throughout the task (|ts| < 1.15, ps > .26).

Temporal Trend in Attentional Orienting Over the Task

The mean *R* squares of the fitted curves were .84 \pm .10, .85 \pm .09, .84 \pm .10, and .86 \pm .09 for the gaze, arrow, BM, and exogenous cues, respectively. In other words, the fitted curve on average could explain more than 80% variance of the cuing effect. Even at the individual level, the lowest *R* square was above .67. Given the complexity of the spontaneous fluctuation of the cuing effect, the goodness of fitting was considered acceptable for further analysis of the parameters of the fitted curve. A one-way ANOVA found no significant effect of Cue Types for the fitted *R* squares, *F*(3, 76) = .21, *p* = .89, η_p^2 = .01, demonstrating comparable goodness of fitting between participants from different experiments.

According to the results in the section Attentional Orienting in the Early and the Late Periods of the Task above, we expected similar evidence from the temporal trend of the cuing effect over trials, specifically revealed by the slope parameter. There should be no significant difference between the slope and 0 in Experiments 1, 3, and 4,

indicating no changes of the cuing effects as tasks proceeded, but the slope should be significantly more negative compared with 0 in Experiment 2, as the cuing effect gradually reduced as the task proceeded (i.e., temporal decay). Thus, the slopes were entered into a one-sample t-test in each experiment. As drawn in Figures 3–4, the mean slope was neither significantly different from 0 for the social cues (gaze: .016 ± .11, t(19) = .67, p = .51, Cohen's d = .15, 95% CI [-.03, .07], $BF_{10} = .28$; BM: .003 ± .10, t(19) = .15, p = .89, Cohen's d = .03, 95% CI [-.04, .05], $BF_{10} = .23$), nor for the exogenous cues (.042 ± .11, t(19) = 1.77, p = .09, Cohen's d = .39, 95% CI [-.01, .09], $BF_{10} = .86$). However, the mean slope for the arrow cues was significantly different from 0 (-.08 ± .13, t(19) = -2.67, p = .01, Cohen's d = .60, 95% CI [-.14, -.02], $BF_{10} = 3.66$). The results thus confirmed our hypothesis.

In order to further compare the dynamic changes of the cuing effect in different experiments quantitatively, the slopes from the four experiments were entered into a one-way ANOVA with a between-subjects factor of Cue Types. A significant effect was found (F(3, 76) = 4.19, p = .008, $\eta_p^2 = .14$). Post hoc pairwise comparisons (LSD method) showed no significant difference between the slope from the gaze cues, BM cues, and the exogenous cues (|ts| < 1.1, ps > .27); however, the mean slope from the arrow cues

Figure 3

1243

Figure 4 *The Mean Slopes of the Curves Fitted in Each Experiment*



Note. Only the slope of arrow cues was significantly different from zero, in contrast with the slopes of gaze, biological motion (BM), and exogenous cues. Error bars show standard errors. *p < 0.05. **p < 0.01.

was more negative than that from the gaze cues (t(76) = -2.62, p = .01, Cohen's d = .83, 95% CI [-.16, -.02]), the BM cues (t(76) = -2.26, p = .03, Cohen's d = .71, 95% CI [-.15, -.01]) and the exogenous cues (t(76) = -3.36, p = .001, Cohen's d = 1.06, 95% CI [-.19, -.05]). Taken together, these results demonstrated that the cuing effect induced by the social cues was temporally stable and in a similar pattern with the reflexive cuing effect induced by the exogenous cues, which was substantially distinguished from the cuing effect induced by the arrow cues.

Attentional Orienting Induced by a Group of Arrow Cues Occupying a Larger Area

As the size of the arrow cue was smaller than the gaze and BM cues, it may be less visually dominant and easier to be ignored, which might account for the temporal decay of the cuing effect by arrow cues in Experiment 2. To rule out this possibility, we conducted an additional experiment (20 participants) with a group of arrows covering approximately $3.7^{\circ} \times 4.2^{\circ}$ in visual angle, similar to the gaze and BM cues in Experiments 1 and 3 (Figure 5a). Moreover, 30 catch trials in which no target was presented were added to avoid the influence of anticipatory responses as the ISI was kept constant in the current study (false alarm rate: $3.67 \pm 6.20\%$).

As expected, the results of this experiment essentially replicated those of Experiment 2 (the main effect of Cue-Probe Validity: F(1, 19) = 12.29, p = .002, $\eta_p^2 = .39$; the main effect of task Period: F(1, 19) = .59, p = .45, $\eta_p^2 = .03$; the interaction: F(1, 19) = 6.13, p = .02, $\eta_p^2 = .24$; Figure 5b). For the first half of trials, there was a significant cuing effect induced by arrow cues, (valid RT: 376.55 ± 49.18 ms; invalid RT: 386.86 ± 54.16 ms; t(19) = -4.20, p < .001, Cohen's d = .94, 95% CI [-15.46, -5.17]), but the cuing effect disappeared in the second half of trials (valid RT: 377.49 ± 45.89 ms;

invalid RT: 381.82 ± 53.30 ms; t(19) = -1.83, p = .08, Cohen's d = .41, 95% CI [-9.29, .62]). The temporal profile of the cuing effect was also fitted via the function shown in section Data Analysis above (Figure 5c), and the mean slope of the fitted curve was significantly different from 0 (-.05 ± .08, t(19) = -3.10, p = .006, Cohen's d = .69, 95% CI [-.09, -.02], $BF_{10} = 7.97$, as shown in Figure 5d). These results thus clearly demonstrated that the temporal decay of the cuing effect induced by nonsocial cues was not much influenced by the cue size or by the anticipatory responses.

Discussion

The current study aimed to examine the specificity of social attention from a temporal-stability perspective. To this end, we characterized and compared the temporal profiles of attentional orienting effects caused by social, nonsocial, and exogenous cues. Results showed that the cuing effects induced by different social cues (i.e., eye gaze and walking direction), similar to that induced by reflexive exogenous cues, remained stable for a relatively long time, while the cuing effect induced by nonsocial cues (i.e., arrow) gradually decreased during the task. From a temporal-stability perspective, these findings substantiate the specificity of social attentional orienting induced by eye gaze and walking direction, distinguishing social attentional orienting.

To characterize the temporal trend of social attentional orienting. trial number in each Cue-Type \times SOA condition was increased from 8-80 trials in previous studies (Bardi et al., 2015; Driver et al., 1999; Friesen & Kingstone, 1998; Hirai et al., 2011; Langton & Bruce, 1999; Lunghi et al., 2019; Shi et al., 2010; Zhao et al., 2014) to 150 trials in the current one. The persistent effect of the social attentional orienting over relatively more trials, especially considering the unpredictability of the cues (half valid and half invalid) to the subsequent target, unambiguously proved its reflexive property. This reflexiveness of attentional orienting to eye gaze and biological motion ought to rely on automatic extraction of the cue's direction, which has already been evidenced by findings that the direction of social cues can be extracted without focused attention (Langton, 2000; Thompson & Parasuraman, 2012; Thornton & Vuong, 2004; Zorzi et al., 2003) or even without explicit recognition of its biological nature (Sato et al., 2007; Wang et al., 2014). More strikingly, such automatic decoding can take place to visually inexperienced chicks: The newly hatched chicks are inclined to align their bodies with the hen's walking direction (Vallortigara & Regolin, 2006). Combined with these studies, our finding recommends a much stricter criterion fulfilled for a genuine reflexive orienting controlled by an automatic system, that the cuing effect should be temporally stable despite the cues are target uninformative.

In the same vein, although arrows are able to induce attentional orienting in Experiment 2 and in many previous studies (Nummenmaa & Hietanen, 2009; Ristic et al., 2002; Tipples, 2002, 2008), its descending trend as the task proceeds, according to the above criterion, implies that the nonsocial attentional orienting is largely regulated by top-down control and cannot be deemed a truly reflexive response (Downing et al., 2004; Friesen et al., 2004; Ristic et al., 2007). Noteworthy, this descending temporal trend may also explain why some other studies, which employed remarkably less trials, found a reflexive nonsocial attentional orienting triggered by arrows (Ristic et al., 2002; Tipples, 2002). Therefore,



Figure 5 Schematic Diagram and Results for the Experiment With a Group of Arrow Cues

Note. (a) A snapshot of the group of arrow cues that covered a larger area. (b) The nonsocial attentional orienting effect induced by the arrow group. The cuing effect only existed in the early period of the task, but disappeared in the late period. Error bars show standard errors. (c) The temporal trend of the average cuing effect across participants. The observed cuing effect over trials was plotted in black and the fitted curve was plotted in red (dark gray). The shaded areas represent standard errors. (d) The mean slope of the fitted curve. The slope was significantly more negative than zero. Error bars show standard errors. ** p < 0.01. See the online article for the color version of this figure.

applying a stricter criterion from a temporal-stability perspective can help us separate the nonsocial attentional orienting induced by arrows from the social attentional orienting induced by gaze and BM. This temporal-stability perspective would then be helpful to reassess the disputable attentional orienting induced by nonsocial, counterpredictive cues (Downing et al., 2004; Friesen et al., 2004; Tipples, 2008), which encourages future investigation.

The distinct temporal trend of the attentional orienting induced by social cues and arrows may be attributed to their different evolutionary roots. As it is critical for a living organisms' survival to rapidly and accurately identify the focus of other animate entities (e.g., conspecifics, prey and predators), social attentional orienting induced by gaze and BM emerges in the early development period (Bardi et al., 2015; Farroni et al., 2004; Hood et al., 1998; Lunghi et al., 2019; Zhao et al., 2014). Such social ability appears also in some nonhuman species (Deaner & Platt, 2003; Leadner et al., 2020). These observations imply an evolutionary basis for the ability of social attentional orienting. A recent study unequivocally confirms that the attentional orienting induced by social cues (gaze and BM) is highly heritable (Wang et al., 2020). Due to such an innate property of the social attentional orienting, it is plausible that even if participants are gradually aware of the uselessness of the social cues as the task proceeds, they cannot refrain from decoding and orienting to the direction of these cues (or in other words, hardly habituate to the orienting effect brought by these cues). That is why the attentional orienting induced by gaze and BM is resistant to change over time. By contrast, an arrow, without any biological meaningfulness, is an overlearned symbol often used as indication signs (e.g., road signs) in daily life (Ristic & Kingstone, 2006, 2012). Not surprisingly, attentional orienting to such nonsocial cues is not heritable and chiefly shaped by environmental effects (Wang et al., 2020). Perhaps the attentional orienting response to an overlearned cue in daily life can be dynamically modulated or relearned according to the validity of the cues, so that participants' attentional orienting to arrows gradually declines over time.

The finding that social attentional orienting is resistant to temporal decay compared with nonsocial attentional orienting, provides another supportive evidence about the specificity of social attentional orienting, the idea of which is proposed by many previous studies (Akiyama et al., 2008; Friesen et al., 2004; Marotta et al., 2012; Ristic et al., 2007) and robustly supported in a recent crosscategory adaptation study (Ji et al., 2020). After adaptation to social cues (e.g., BM), participants were less inclined to shift their attention to the direction of the same (BM) or another (eve gaze) type of social cues that had same direction with the adaptors. In other words, a cross-category adaptation exists for the social attentional system. By contrast, after adaptation to nonsocial cues (arrows), the social attentional orienting was not influenced (Ji et al., 2020). In addition to behavioral evidence, so far there have been many findings that imply a differential neural mechanism underlying social relative to nonsocial attentional orienting. First, ERP studies found that early directing attention negativity (EDAN) induced by both eye gaze and BM occur on in earlier time window (e.g., 100-160 ms), while EDAN induced by arrows occurs in a later period (220-260 ms) after the cue onset (Brignani et al., 2009; Hietanen et al., 2008; Wang et al., 2014). Second, some brain imaging studies showed that social attentional orienting activates the ventral attention network while orienting to arrows activates the dorsal attentional network (Hietanen et al., 2006, 2008; Joseph et al., 2015; but see Sato et al., 2009; Tipples et al., 2013).

To conclude, the current study highlights that the temporal stability of social attentional orienting induced by gaze and BM is intrinsically distinct from that of the nonsocial attentional orienting induced by arrow cues. Our results not only provide novel evidence from a temporal trend perspective for the specificity of social attentional orienting induced by gaze and BM, but also call for a stricter criterion of temporal stability when considering the reflexive nature of social and nonsocial attentional orienting.

References

- Akiyama, T., Kato, M., Muramatsu, T., Maeda, T., Hara, T., & Kashima, H. (2008). Gaze-triggered orienting is reduced in chronic schizophrenia. *Psychiatry Research*, 158(3), 287–296. https://doi.org/10.1016/j.psychres.2006 .12.004
- Bardi, L., Di Giorgio, E., Lunghi, M., Troje, N. F., & Simion, F. (2015). Walking direction triggers visuo-spatial orienting in 6-month-old infants and adults: An eye tracking study. *Cognition*, 141, 112–120. https://doi .org/10.1016/j.cognition.2015.04.014
- Baron-Cohen, S. (1995). Mindblindness: An essay on autism and theory of mind. The MIT Press. https://doi.org/10.7551/mitpress/4635.001.0001
- Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, *10*(4), 433–436. https://doi.org/10.1163/156856897X00357
- Brignani, D., Guzzon, D., Marzi, C. A., & Miniussi, C. (2009). Attentional orienting induced by arrows and eye-gaze compared with an endogenous cue. *Neuropsychologia*, 47(2), 370–381. https://doi.org/10.1016/j .neuropsychologia.2008.09.011
- Brooks, R., & Meltzoff, A. N. (2005). The development of gaze following and its relation to language. *Developmental Science*, 8(6), 535–543. https://doi.org/10.1111/j.1467-7687.2005.00445.x
- Deaner, R. O., & Platt, M. L. (2003). Reflexive social attention in monkeys and humans. *Current Biology*, 13(18), 1609–1613. https://doi.org/10 .1016/j.cub.2003.08.025
- Dodd, M. D., & Wilson, D. (2009). Training attention: Interactions between central cues and reflexive attention. *Visual Cognition*, 17(5), 736–754. https://doi.org/10.1080/13506280802340711
- Downing, P., Dodds, C., & Bray, D. (2004). Why does the gaze of others direct visual attention? *Visual Cognition*, 11(1), 71–79. https://doi.org/ 10.1080/13506280344000220
- Driver, I. J., Davis, G., IV, Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual Cognition*, 6(5), 509–540. https://doi.org/10.1080/ 135062899394920
- Dukewich, K. R. (2009). Reconceptualizing inhibition of return as habituation of the orienting response. *Psychonomic Bulletin & Review*, 16(2), 238–251. https://doi.org/10.3758/PBR.16.2.238

- Dukewich, K. R., & Boehnke, S. E. (2008). Cue repetition increases inhibition of return. *Neuroscience Letters*, 448(3), 231–235. https://doi.org/10 .1016/j.neulet.2008.10.063
- Ekman, P., & Friesen, W. V. (1976). Pictures of facial affect. Consulting Psychologists Press.
- Farroni, T., Massaccesi, S., Pividori, D., & Johnson, M. H. (2004). Gaze following in newborns. *Infancy*, 5(1), 39–60. https://doi.org/10.1207/ s15327078in0501_2
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. https://doi.org/10.3758/BF03193146
- Friesen, C. K., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review*, 5(3), 490–495. https://doi.org/10.3758/BF03208827
- Friesen, C. K., Ristic, J., & Kingstone, A. (2004). Attentional effects of counterpredictive gaze and arrow cues. *Journal of Experimental Psychology: Human Perception and Performance*, 30(2), 319–329. https:// doi.org/10.1037/0096-1523.30.2.319
- Frischen, A., Smilek, D., Eastwood, J. D., & Tipper, S. P. (2007). Inhibition of return in response to gaze cues: The roles of time course and fixation cue. *Visual Cognition*, 15(8), 881–895. https://doi.org/10.1080/ 13506280601112493
- Frischen, A., & Tipper, S. P. (2004). Orienting attention via observed gaze shift evokes longer term inhibitory effects: Implications for social interactions, attention, and memory. *Journal of Experimental Psychology: General*, 133(4), 516–533. https://doi.org/10.1037/0096-3445.133.4.516
- Giordano, A. M., McElree, B., & Carrasco, M. (2009). On the automaticity and flexibility of covert attention: A speed–accuracy trade-off analysis. *Journal of Vision*, 9(3), Article 30. https://doi.org/10.1167/9.3.30
- Hietanen, J. K., Leppänen, J. M., Nummenmaa, L., & Astikainen, P. (2008). Visuospatial attention shifts by gaze and arrow cues: An ERP study. *Brain Research*, 1215, 123–136. https://doi.org/10.1016/j.brainres .2008.03.091
- Hietanen, J. K., Nummenmaa, L., Nyman, M. J., Parkkola, R., & Hämäläinen, H. (2006). Automatic attention orienting by social and symbolic cues activates different neural networks: An fMRI study. *Neuro-Image*, 33(1), 406–413. https://doi.org/10.1016/j.neuroimage.2006.06.048
- Hirai, M., Saunders, D. R., & Troje, N. F. (2011). Allocation of attention to biological motion: Local motion dominates global shape. *Journal of Vision*, 11(3), Article 4. https://doi.org/10.1167/11.3.4
- Hommel, B., Pratt, J., Colzato, L., & Godijn, R. (2001). Symbolic control of visual attention. *Psychological Science*, 12(5), 360–365. https://doi .org/10.1111/1467-9280.00367
- Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science*, 9(2), 131–134. https://doi.org/10.1111/1467-9280.00024
- Ji, H., Wang, L., & Jiang, Y. (2020). Cross-category adaptation of reflexive social attention. *Journal of Experimental Psychology: General*, 149(11), 2145–2153. https://doi.org/10.1037/xge0000766
- Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics*, 14(2), 201–211. https://doi .org/10.3758/BF03212378
- Joseph, R. M., Fricker, Z., & Keehn, B. (2015). Activation of frontoparietal attention networks by non-predictive gaze and arrow cues. *Social Cognitive and Affective Neuroscience*, 10(2), 294–301. https://doi.org/ 10.1093/scan/nsu054
- Langton, S. R. H. (2000). The mutual influence of gaze and head orientation in the analysis of social attention direction. *The Quarterly Journal* of Experimental Psychology, 53(3), 825–845. https://doi.org/10.1080/ 713755908
- Langton, S. R. H., & Bruce, V. (1999). Reflexive visual orienting in response to the social attention of others. *Visual Cognition*, 6(5), 541–567. https://doi.org/10.1080/135062899394939

- Leadner, K., Sekely, L., Klein, R. M., & Gabay, S. (2020). Evolution of social attentional cues: Evidence from the archerfish. *Cognition*, 207, Article 104511. https://doi.org/10.1016/j.cognition.2020.104511
- Lin, Z., Lu, Z. L., & He, S. (2016). Decomposing experience-driven attention: Opposite attentional effects of previously predictive cues. *Attention, Perception, & Psychophysics*, 78(7), 2185–2198. https://doi.org/10 .3758/s13414-016-1101-z
- Lunghi, M., Piccardi, E. S., Richards, J. E., & Simion, F. (2019). The neural correlates of orienting to walking direction in 6-month-old infants: An ERP study. *Developmental Science*, 22(6), Article e12811. https:// doi.org/10.1111/desc.12811
- Marotta, A., Lupiáñez, J., Martella, D., & Casagrande, M. (2012). Eye gaze versus arrows as spatial cues: Two qualitatively different modes of attentional selection. *Journal of Experimental Psychology: Human Perception and Performance*, 38(2), 326–335. https://doi.org/10.1037/ a0023959
- Nummenmaa, L., & Calder, A. J. (2009). Neural mechanisms of social attention. *Trends in Cognitive Sciences*, 13(3), 135–143. https://doi.org/ 10.1016/j.tics.2008.12.006
- Nummenmaa, L., & Hietanen, J. K. (2009). How attentional systems process conflicting cues: The superiority of social over symbolic orienting revisited. *Journal of Experimental Psychology: Human Perception and Performance*, 35(6), 1738–1754. https://doi.org/10.1037/a0016472
- Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*(4), 437–442. https://doi.org/10.1163/156856897X00366
- Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology*, 32(1), 3–25. https://doi.org/10.1080/00335 558008248231
- Ristic, J., Friesen, C. K., & Kingstone, A. (2002). Are eyes special? It depends on how you look at it. *Psychonomic Bulletin & Review*, 9(3), 507–513. https://doi.org/10.3758/BF03196306
- Ristic, J., & Kingstone, A. (2012). A new form of human spatial attention: Automated symbolic orienting. *Visual Cognition*, 20(3), 244–264. https://doi.org/10.1080/13506285.2012.658101
- Ristic, J., & Kingstone, A. (2006). Attention to arrows: Pointing to a new direction. The Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 59(11), 1921–1930. https://doi.org/10.1080/ 17470210500416367
- Ristic, J., Wright, A., & Kingstone, A. (2007). Attentional control and reflexive orienting to gaze and arrow cues. *Psychonomic Bulletin & Review*, 14(5), 964–969. https://doi.org/10.3758/BF03194129
- Sato, W., Kochiyama, T., Uono, S., & Yoshikawa, S. (2009). Commonalities in the neural mechanisms underlying automatic attentional shifts by gaze, gestures, and symbols. *NeuroImage*, 45(3), 984–992. https://doi .org/10.1016/j.neuroimage.2008.12.052
- Sato, W., Okada, T., & Toichi, M. (2007). Attentional shift by gaze is triggered without awareness. *Experimental Brain Research*, 183(1), 87–94. https://doi.org/10.1007/s00221-007-1025-x
- Shepherd, S. V. (2010). Following gaze: Gaze-following behavior as a window into social cognition. *Frontiers in Integrative Neuroscience*, 4, Article 5. https://doi.org/10.3389/fnint.2010.00005

- Shi, J., Weng, X., He, S., & Jiang, Y. (2010). Biological motion cues trigger reflexive attentional orienting. *Cognition*, 117(3), 348–354. https:// doi.org/10.1016/j.cognition.2010.09.001
- Thompson, J., & Parasuraman, R. (2012). Attention, biological motion, and action recognition. *NeuroImage*, 59(1), 4–13. https://doi.org/10 .1016/j.neuroimage.2011.05.044
- Thornton, I. M., & Vuong, Q. C. (2004). Incidental processing of biological motion. *Current Biology*, 14(12), 1084–1089. https://doi.org/10 .1016/j.cub.2004.06.025
- Tipples, J. (2002). Eye gaze is not unique: Automatic orienting in response to uninformative arrows. *Psychonomic Bulletin & Review*, 9(2), 314–318. https://doi.org/10.3758/BF03196287
- Tipples, J. (2008). Orienting to counterpredictive gaze and arrow cues. Perception & Psychophysics, 70(1), 77–87. https://doi.org/10.3758/pp.70.1.77
- Tipples, J., Johnston, P., & Mayes, A. (2013). Electrophysiological responses to violations of expectation from eye gaze and arrow cues. *Social Cognitive and Affective Neuroscience*, 8(5), 509–514. https://doi .org/10.1093/scan/nss024
- Uono, S., Sato, W., & Kochiyama, T. (2014). Commonalities and differences in the spatiotemporal neural dynamics associated with automatic attentional shifts induced by gaze and arrows. *Neuroscience Research*, 87, 56–65. https://doi.org/10.1016/j.neures.2014.07.003
- Vallortigara, G., & Regolin, L. (2006). Gravity bias in the interpretation of biological motion by inexperienced chicks. *Current Biology*, 16(8), R279–R280. https://doi.org/10.1016/j.cub.2006.03.052
- Vanrie, J., & Verfaillie, K. (2004). Perception of biological motion: A stimulus set of human point-light actions. *Behavior Research Methods*, *Instruments, & Computers*, 36(4), 625–629. https://doi.org/10.3758/ BF03206542
- Wang, L., Wang, Y., Xu, Q., Liu, D., Ji, H., Yu, Y., Hu, Z., Yuan, P., & Jiang, Y. (2020). Heritability of reflexive social attention triggered by eye gaze and walking direction: Common and unique genetic underpinnings. *Psychological Medicine*, 50(3), 475–483. https://doi.org/10.1017/ S003329171900031X
- Wang, L., Yang, X., Shi, J., & Jiang, Y. (2014). The feet have it: Local biological motion cues trigger reflexive attentional orienting in the brain. *NeuroImage*, 84, 217–224. https://doi.org/10.1016/j.neuroimage.2013 .08.041
- Yu, Y., Ji, H., Wang, L., & Jiang, Y. (2020). Cross-modal social attention triggered by biological motion cues. *Journal of Vision*, 20(10), Article 21. https://doi.org/10.1167/jov.20.10.21
- Zhao, J., Wang, L., Wang, Y., Weng, X., Li, S., & Jiang, Y. (2014). Developmental tuning of reflexive attentional effect to biological motion cues. *Scientific Reports*, 4, Article 5558. https://doi.org/10.1038/srep05558
- Zorzi, M., Mapelli, D., Rusconi, E., & Umiltà, C. (2003). Automatic spatial coding of perceived gaze direction is revealed by the Simon effect. *Psychonomic Bulletin & Review*, 10(2), 423–429. https://doi.org/10 .3758/BF03196501

Received January 10, 2021

Revision received April 28, 2021

Accepted May 18, 2021 ■