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Attentional shift by eye gaze requires joint attention: Eye gaze cues are unique to shift attention[1]

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Abstract: Researchers have demonstrated that attentional shift triggered by gaze direction is reflexive. However, here we show that attentional shift by gaze direction was not always reflexive, but could be modulated by another's perspective. In Experiment 1, a schematic face's line of sight to a peripheral target was obstructed by a vertical barrier located between the face and the target under two conditions. However, the line of sight of the face was clear under another two conditions, in which the barrier was located *behind* the line of sight by utilizing a depth cue. The gaze cue shifted attention only when the line of sight was not blocked (i.e. joint attention was attained). The arrow cue did not shift attention regardless of the obstruction conditions in Experiment 2. These results suggest that attentional shift by gaze cues, but not arrow cues, involve a higher social cognitive process such as interpretation of the gaze.

Key words: attentional shift, eye gaze, arrow cues, reflexive orienting, joint attention.

Humans tend to pay attention to where someone else is looking (Kawai, 2008; Okamoto & Kawai, 2006; Ristic & Kingstone, 2005). In typical experiments (Friesen & Kingstone, 1998, 2003), participants respond more quickly to a target appearing at a location gazed at by a centrally presented face image (i.e. valid cues) than to one appearing at a location that is not gazed at (i.e. invalid cues). This facilitation effect occurs even though the gaze direction does not predict the location at which the target stimulus will appear (Driver, Davis, Ricciardelli, Kidd, Maxwell, & Baron-Cohen, 1999; Ristic, Friesen, & Kingstone, 2002), indicating that this gaze cuing effect is reflexive in nature.

A controversial issue in this area has been whether "eyes are special" in producing reflexive shifts of attention (Friesen, Ristic, & Kingstone, 2004; Ristic et al., 2002; Tipples, 2002). Many studies (Akiyama, Kato, Muramatsu, Saito, Umeda, & Kashima, 2006; Ristic et al., 2002; Ristic & Kingstone, 2005; Ristic, Wright, & Kingstone, 2007) have indicated that eyes are special in producing attentional shift (see Friesen & Kingstone, 2003, for more details). However, some other studies have demonstrated that nonsocial directional cues (arrows) also lead to reflexive shifts of attention (Ristic et al., 2002; Tipples, 2002), suggesting that gaze cues are not special. In contrast, Friesen et al. (2004) suggested that gaze and arrow cues could trigger qualitatively different behavioral effects. Gaze cues produced a reflexive shift even when they were counter-predictive, while arrow cues did not. Neuropsychological studies also suggest that gaze cues and arrow cues have different properties in producing shifts of attention (Akiyama et al., 2006; Kingstone, Friesen, & Gazzaniga, 2000; Kingstone, Tipper, Ristic, & Ngan, 2004).

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Although both gaze cues and arrow cues contain directional properties, what makes the gaze cue unique is its social meaning. Attentional shift by gaze cues has been regarded as a precursor of gaze-following ability (Emery, 2000). Gaze following is essential to joint attention and the "theory of mind" system (Baron-Cohen, 1995). Thus, many studies have suggested that attentional shift by gaze cues relates to an understanding of another's mental state (Bonato, Priftis, Marenzi, & Zorzi, 2009; Driver et al., 1999). Nevertheless, attentional shift produced by eye gaze has been assumed to be a highly automatic process that does not require a "higher cognitive process," such as understanding the others' mental state.

In accord with this gaze as a simple process notion, some developmental studies (Moore & Corkum, 1998) have suggested that the looking behavior of an adult experimenter simply attracts the young infants' attention to the target's location, without inducing the infant to wonder precisely what the experimenter is seeing. Nevertheless, Butler, Caron, and Brooks (2000) further examined the gaze-following behavior of 14- and 18-month-olds in the joint attention paradigm under three visual obstruction conditions. In all conditions, the experimenter sat opposite the infant and either looked to the left or right towards a target on the wall. In one condition, the experimenter's line of sight was obstructed by opaque screens (screen condition), whereas in another condition the experimenter's line of sight was unimpeded (no-screen condition). In the third condition, the opaque screens contained a large window so that the experimenter could see the target on the wall. The results indicated that 18-month-olds both in the no-screen condition and in the window condition responded to the experimenters' shifts more frequently than those in the screen condition. However, 14-month-olds responded equally in all three conditions. Butler et al. (2000) concluded that 18-month-olds but not 14-month-olds comprehend the referential nature of looking and the requirements for successful looking. This study and others suggest that even young infants can take into account another's perspective when they execute gaze-following behavior.

Experiment 1

Introduction

In the present study, we examined whether a gaze-cueing effect was modulated depending on the central face's line of sight to the target. We hypothesized that a successful gaze-cueing effect is produced only when the face's line of sight is not blocked. If so, an obstruction in the line of sight of the central face will degrade the gaze-cueing effect, as was the case in the studies on the gaze-following tendencies of infants. In a pilot study, we disrupted a schematic face's line of sight to a target by simply placing vertical barriers beside the face, and observed a negligible cuing effect (i.e. similar results to the screen condition in Butler et al., 2000). Simply presenting large barriers would induce attention to them. Then, we manipulated the apparent depth of the vertical barriers, so that the face could have either a clear or an impeded line of sight to the target (Figure 1). Under the Both-Sides-Blocked Condition (Figure 1b), a vertical white barrier was located between the eyes and the target to block the face's line of sight. Under the Both-Sides-Unblocked Condition (Figure 1a), a white barrier was perceptually located behind the line of sight. A black horizontal bar was used to make the vertical barrier locations perceptually behind the line of sight. Under the Target-Side-Blocked Condition (Figure 2), only the target-side was blocked, whereas only the nontarget-side was blocked under the Target-Side-Unblocked Condition (Figure 1c). If a successful gaze-cueing effect requires a clear perspective of the other target the observer was looking at, the shift would be negligible under the two blocked conditions, in contrast to that under the two unblocked conditions.

Materials and methods

Participants. Thirteen undergraduate students (7 women and 8 men) participated in this experiment. They all had normal or corrected vision.

Stimuli. The stimuli were the same as in previous studies (Friesen & Kingstone, 1998; Okamoto & Kawai, 2006), except that the schematic face was accompanied by two vertical white barriers and a black horizontal bar. The vertical barrier width subtended 1.0 deg, and the height subtended 6.8 deg (the same as the face outline). The blank horizontal bar width subtended 11.0 deg, and the height subtended 1.0 deg (the same as the eye outlines). The vertical bars were located at 4.2 deg, as measured from the central vertical axis to the center of the target letter. The horizontal bar was located directly behind the eyes. The four stimulus conditions differed only in whether the crossing areas of the vertical and horizontal bars were white or black squares.

Procedure. Each subject performed 16 practice trials followed by five blocks of 64 test trials, for a total of 320 test trials (80 trials for each stimulus condition: Both-Sides-Unblocked, Both-Sides-Blocked, Target-Side-Unblocked, and Target-Side-Blocked). There were three within-subject factors: the cue condition (valid or invalid), stimulus onset asynchrony (SOA) between the cue and the target (105, 300, 600, 1005 ms), and the stimulus condition. All conditions were randomly presented within the blocks.

As illustrated in Figure 2, each trial started with the presentation of a face with blank eyes and bars. After 680 ms, pupils appeared within the eyes, looking left or right. Following this cue, a target letter appeared to the left or the right of the face. The face, pupils, and target remained on the screen until a response was made or 2700 ms had elapsed, whichever came first. The subjects were instructed to indicate that they had detected the appearance of a target on the screen by pressing one (left or right) of two buttons (Cedrus, RB-420), which corresponded to the spatial location of the target. They were told that the gaze did not predict the direction of the target and were instructed to respond to the target as quickly and as accurately as possible. They were also told to fixate their gaze on a point at the

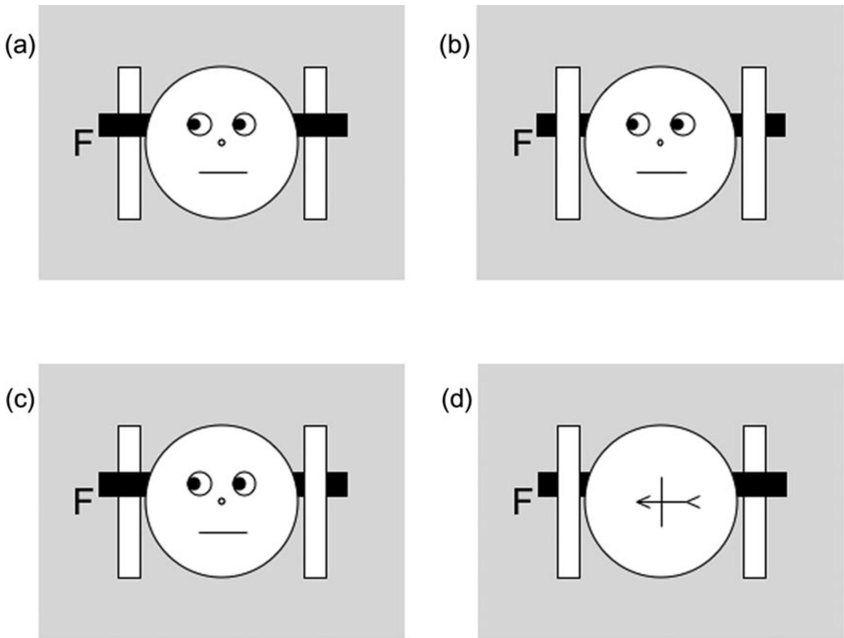

Figure 1 Example of stimuli used in experiments. (a, b, and c) Schematic faces were used in Experiment 1, and (d) an arrow with a head and a tail was used in Experiment 2.

center of the monitor (the nose of the schematic face).

Results and discussion

Incorrect responses and extreme outliers, which were response times greater or less than four standard deviations from the grand mean, were classified as errors and excluded from the analyses. Each type of error accounted for less than 1% of the trials, so they were not analyzed further.

The mean response time (RT) as a function of SOA and cue validity for each of the four stimulus conditions is presented in Figure 3. The mean RT for each condition decreased as a function of SOA, as in the previous gaze-cueing studies. There were differences in the value of valid cues among the stimulus conditions. Because our primary interest was the value of valid cues within each stimulus condition, we analyzed the RT for each condition using a 4 (SOA) × 2 (validity) analysis of variance (ANOVA). For the Both-Sides-Unblocked Condition, a main effect of SOA, $F(3, 36) = 36.15$, $p < .001$, and cue validity, $F(1, 12) = 12.97$, $p < .005$, were both significant, but interactions between them were not significant. For the Both-Sides-Blocked Condition, a main effect of SOA, $F(3, 36) = 27.42$, $p < .001$, and interaction was significant, $F(3, 36) = 4.24$, $p < .05$. However, the effect of cue validity was not significant. For the Target-Side-Unblocked Condition, the main effects of SOA, $F(3, 36) = 48.64$, $p < .001$, and cue validity,

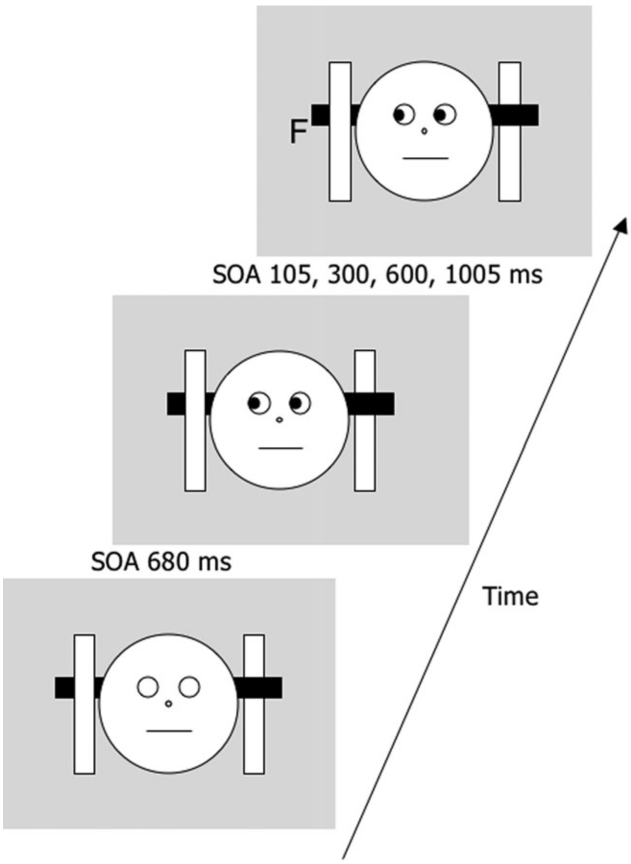

Figure 2 Illustration of a trial sequence in Experiment 1. SOA = stimulus onset asynchrony.

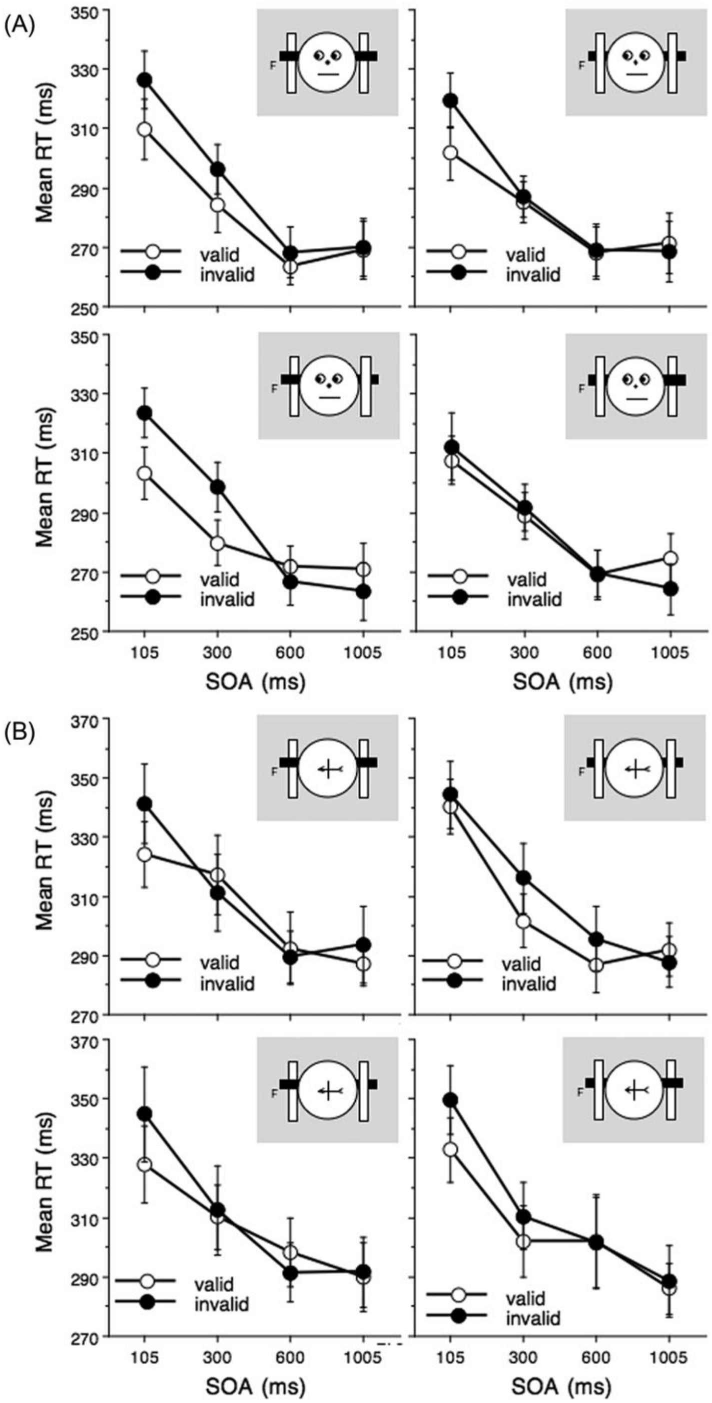

Figure 3 Mean response time (RT) as a function of cue-target stimulus onset asynchrony (SOA) for each stimulus condition in (a) Experiment 1 and (b) Experiment 2. The horizontal bars represent the standard error of the mean.

$F(1, 12) = 5.33$, $p < .05$, and interaction, $F(3, 36) = 8.24$, $p < .001$, were significant. For the Target-Side-Blocked Condition, a main effect of SOA, $F(3, 36) = 26.59$, $p < .001$, was significant. The main effects of cue validity and interaction were not significant.

The results clearly show a gaze-cueing effect in the Both-Sides-Unblocked and Target-Side-Unblocked conditions, as in previous gaze-cueing studies (Friesen & Kingstone, 1998; Okamoto & Kawai, 2006), but not in the Both-Sides-Blocked and Target-Side-Blocked conditions. These findings indicate that attention shift occurred only when the face's line of sight was not blocked. In other words, the gaze-cueing effect was modulated depending on the other's perspective the observer was looking at. These results provided further evidence that the gaze-cueing effect is not purely reflexive (Ristic & Kingstone, 2005; Vecera & Rizzo, 2006), and suggest that the gaze-cueing effect may involve higher cognitive processes.

Experiment 2

Introduction

There could be another simple explanation for the results of Experiment 1. Stimulus situations common to the two unblocked conditions might produce reflexive attentional shifts (i.e. the white squares near the target drew the observer's attention there). If this was the case, the same pattern in the results should be observed by other nonsocial cues (an arrow). Alternatively, if a clear line of sight of the face the observer was looking at (i.e. joint attention) was crucial to the results of Experiment 1, then the orienting effect will not be observed in any of the four conditions.

Materials and methods

Participants. Fourteen undergraduate and graduate students (2 women and 12 men) participated in this experiment. They all had normal or corrected vision.

Stimuli and procedure. We used the same set of face contour and bars as in Experiment 1, but replaced the facial components (i.e. eyes, nose, and mouth) with an arrow (Figure 1d). The fixation display consisted of a black-line drawing of a cross at the center of the face contour. The cross was composed of a horizontal line and a vertical line, each of which was 2.2 deg long. The intersection of the two lines served as the fixation point. The directional cue was provided by an arrowhead and a tail appearing at the opposite end of the horizontal line. They were composed of two lines that measured 0.6 deg high × 0.6 deg wide (Friesen et al., 2004). The experimental design and procedure were identical to those of Experiment 1.

Results and discussion

Errors were dealt with as in Experiment 1 (less than 3% of the trials). As in Experiment 1, the RT decreased as a function of SOA for all of the stimulus conditions. There were no differences in cue validities in any of the four stimulus conditions. Again, our primary interest was the value of the valid arrow cues. A 4 (SOA) × 2 (validity) ANOVA was conducted for each stimulus condition. In all conditions, only the main effects of SOA, $Fs(3, 39) > 27.39$, $ps < .001$, were significant. The main effects of cue validity, $Fs(1, 13) < 2.88$, $ps > .11$, and interaction, $Fs(3, 39) < 2.25$, $ps > .10$, were not significant in any of the conditions.

These results indicate the results of Experiment 1 cannot be attributed to an artifact specific to the unblocked conditions (the white square existing near the target). These results also show that the nonsocial directional cue (the arrow) did not produce reflexive orienting, as opposed to previous studies with arrow cues (Ristic et al., 2002; Tipples, 2002). We will discuss a possible account for these null effects later. Here, it is obvious that the eye gaze cue and the arrow cue have a different sensitivity to the obstruction of the line of "sight".

General discussion

In the present study, we examined whether attentional shift by eye gaze could be modulated by blocking the line of sight of the face the observer was looking at. The observer's attention was shifted when the line of sight was clear, but not when it was blocked. Arrow cues failed to produce an attentional shift regardless of the line of "sight" being blocked or not. The present study indicates that a social orienting effect was produced depending on the other's perspective the observer was looking at.

Why did the unblocked conditions in Experiment 2 fail to produce shifts of attention (i.e. a null effect)? Although both gaze cues and arrow cues can trigger reflexive shifts of attention (Ristic et al., 2002; Tipples, 2002), there seem to be some differences in their potential. It is evident that arrow cues did not produce attentional shift when they were counter-predictive, while the gaze cues did (Friesen et al., 2004; Senju, Tojo, Dairoku, & Hasegawa, 2004). The cueing effect by the arrows may be susceptible to other factors that conflict with the direction the arrow cues indicate. In the present study, large barriers appeared both outside of the "face-contour" preceding the presentation of the small central cues. These large stimuli would draw strong attention, and prevent the potential for the central cues to shift attention "beyond" the barriers. In fact, we could not obtain a gaze-cueing effect in our unpublished study, in which the vertical barriers were merely presented beside the face. Utsuki and Hashimoto (2004) replicated this result. These studies suggest that the large peripheral barriers took attention away from the central cue. Therefore, the arrow cues did not produce reflective shifts of attention. In contrast, the situation in which the central face can "see" the target might be the one that is capable of causing an attentional shift from gaze cues that occur beyond the barriers (Nuku & Bekkering, 2008). These results suggest that the gaze-cueing effect takes into account another's perspective status.

Although many studies (Driver et al., 1999; Friesen et al., 2004) have emphasized that attentional shift by gaze cues is purely automatic, there are some reasons to think that the gaze-cueing effect is affected at least in part by top-down processes. Ristic and Kingstone (2005) used an ambiguous stimulus that could be perceived as representing a "face" or a "car." An attentional shift occurred when the stimulus was perceived as a "face" stimulus, but not when it was perceived as a "car" stimulus. This is consistent in part with the present finding that the social attention effect is modulated by top-down processes responsible for stimulus interpretation.

Vecera and Rizzo (2006) examined attentional shift by eye gaze in a patient with frontal-lobe damage, and found that the gaze-cueing effect is not purely reflexive and at least in part includes a voluntary process in the frontal lobe. Friesen et al. (2004) showed that healthy adults have more difficulty overcoming cue-target conflicts for a counter-predictive gaze than for a counter-predictive arrow, whereas autistic spectrum patients, who often lack reciprocal gaze interaction, showed the opposite pattern in the results (Senju et al., 2004).

Among other factors, what makes a gaze cue unique is its relevance to the "theory of mind" system (Baron-Cohen, 1995; Calder, Lawrence, Keane, Scott, Owen, Christoffels, & Young, 2002). Calder et al. (2002) showed that eye-gaze processing shares brain areas with the theory of mind system: Both processes activate not only the posterior superior temporal sulcus (the gaze-processing region), but also the medial frontal area. Williams, Waiter, Perra, Perrett, and Whiten (2005) demonstrated that the ventromedial prefrontal cortex was activated only when both the observer and a man on a monitor looked at the same target (i.e. joint attention situation), but not when joint attention was not accomplished.

Although studies on the gaze-cueing effect have assumed that attentional shifts underlying gaze following are triggered highly reflexively by the presence of a gaze stimulus, recent studies suggest that attentional shifts are modulated, at least in part, by mental-state attribution. Nuku and Bekkering (2008) compared the gaze-cueing effects in response to a static virtual human head with open versus closed eyes (Experiment 1) or of a face wearing sunglasses versus a face whose eye region was blocked out by a broad, dark square (Experiment 2). Larger gaze-cueing effects were found with the former rather than the latter conditions in both experiments. This result partly parallels the findings in infants (Butler et al., 2000) mentioned above, suggesting that the gaze-cueing effect is modulated by mental-state attribution. However, there are some problems with this study. One major problem is that stimulus properties are confounded, making it hard to determine which of these two factors is responsible for the differential findings, as pointed out by Teufel, Alexis, Clayton, and Davis (2010). The heads presented in Nuku and Bekkering (2008) were slightly oriented toward the left or right side of the screen. Thus, when the head was oriented leftward, both left and right eyes (including those blocked by sunglasses and occluders) were located in the left part of the screen, which would draw participants' attention to the left side of the screen. In the previous studies, such asymmetry has been avoided. In addition, both the open eyes and the sunglasses seem to have a higher contrast than the closed eyes and the dark square occluders. Therefore, it was not clear whether weaker gaze-cueing effects were elicited by a face with closed eyes than by a face with open eyes (or a face whose eye region was blocked out by a dark square than by a face wearing sunglasses) because observers attributed different mental states to those faces, or whether differences in the visual properties of the stimuli were responsible for the smaller gaze-cueing effects (e.g. were mediated by differential allocation of attention to the different types of stimuli; Teufel et al., 2010). In the present study, however, the stimulus properties among conditions were minimized by making a horizontal symmetry, and the gaze-cueing effects were obtained only when the directional cues were the faces, but not when the cues were arrows, indicating that others' perspectives can modulate the gaze-cueing effect even in the absence of the confounding visual properties of the stimuli.

Recently, Teufel et al. (2010) set up a unique paradigm to address any contribution of mental attribution in gaze-following behavior by avoiding the methodological problem in Nuku and Bekkering (2008). In their deception procedure, participants met an experimenter before initiating the task and were convinced that they were interacting with the experimenter in the adjoining room by a "live" video link. Two types of prerecorded video clips were used to prime the participants' attention. In the video clips, the model (i.e. the person previously met) wore one of two pairs of goggles. The lenses of both pairs were highly mirrored and thus looked identical from the perspective of the participant. The participants believed, however, that one pair was transparent from the perspective of the model and that the model therefore could see, whereas the other pair was opaque and the model could not see, because the participants wore those pairs of goggles beforehand. The two goggles had different frame colors but were counter-balanced for the conditions. Thus, their physical characteristics were identical. Teufel et al. (2010) showed that reflexive gaze following was found when observers believed that the model was wearing transparent goggles and could see, but it was reduced when they believed that the model was wearing opaque goggles and could not see. They suggested that the attribution of a "seeing" mental state to a face plays an important role in reflexive gaze following.

The present study is obviously in line with Teufel et al. (2010). Nevertheless, there are several advantages to the present study. First, we obtained the gaze-cueing effect with a simple 2-D schematic face. Teufel et al. (2010) suggested that a "live" setting was crucial for participants to recruit the mental attribution to modulate. They set up a detailed deception design to achieve this. They emphasized to the participants to keep in mind whether or not the model on the screen was able to see, depending on which pair of goggles he was wearing. The present study indicates that this complicated setting was not necessary to address the role of the mental state in the gaze-cueing effect. Second, a static face picture, in contrast to recorded movie clips, is sufficient to modulate the gaze-cueing effect in the blocking paradigm. Third, the gaze-cueing effect was sufficiently modulated by blocking the line of sight, not necessarily preventing the actual sight of the model. This procedure allows the face stimulus to be the same among the experimental conditions. Fourth, they employed a somewhat unfamiliar index for the effect, not the conventional RT, because of their deception paradigm. The results of the present study are based on RT, the conventional index of the effect. Among others, the present study compared gaze cues and arrow cues. Neither Teufel et al. (2010) nor Nuku and Bekkering (2008) employed the arrow cues as stimuli. Therefore, it is not clear whether their results were limited to the face (and eye) cues or even nonsocial directional cues. The present study also provides detailed time courses of the cueing effect with various SOAs, including some that were not addressed in the previous studies. Note that both Teufel et al. (2010) and Nuku and Bekkering (2008) obtained smaller but still significant gaze-cueing effects in their "blocked" conditions, while the present study did not find significant cueing effects in the blocked conditions or for any of the arrow cues.

The present study clearly demonstrated that the orienting effect by gaze cues is not merely an automatic process. Rather, it seems to involve interpretation of the gaze (Baron-Cohen, 1995). The gaze cues and the arrow cues turned out to have different properties to shift attention, at least in the present experimental setting. Our results suggest that attentional shift by gaze cues involves a higher social cognitive process, such as taking another's perspective or joint attention.

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