Objects Capture Perceived Gaze Direction

Janek S. Lobmaier,[1] Martin H. Fischer,[2] and Adrian Schwaninger[1,3]

[1]Department of Psychology, University of Zürich, Switzerland
[2]Psychology Department, University of Dundee, Scotland
[3]Max Planck Institute for Biological Cybernetics, Tübingen, Germany

Abstract. The interpretation of another person's eye gaze is a key element of social cognition. Previous research has established that this ability develops early in life and is influenced by the person's head orientation, as well as local features of the person's eyes. Here we show that the presence of objects in the attended space also has an impact on gaze interpretation. Eleven normal adults identified the fixation points of photographed faces with a mouse cursor. Their responses were systematically biased toward the locations of nearby objects. This capture of perceived gaze direction probably reflects the attribution of intentionality and has methodological implications for research on gaze perception.

Keywords: eye gaze, social cognition, gaze interpretation, natural cues

A person looking up into the sky may induce passersby to also look in the same direction. The direction of the person's overt attention seems to imply that something is happening there, and our own attention is shifted in the direction of the looker's gaze. Knowing where another person is looking is an important social and cognitive skill, referred to as joint attention (Argyle & Cook, 1976; Baron-Cohen, 1995a, 1995b). Joint attention is thought to be crucial whenever we want to draw another person's attention to a particular object or event (Butterworth, 1995).

A number of factors are known to influence gaze interpretation in joint attention. For example, the iris-sclera ratio is used to compute the direction of regard (Ando, 2002; Anstis, Mayhew, & Morley, 1969; Langton, Watt, & Bruce 2000). Human eyes are morphologically unique; they have a widely exposed white sclera surrounding the darker iris. Compared to other primates, humans have the largest ratio of visible sclera to iris in the eye outline (Kobayashi & Kohshima, 1997, 2001). Ando (2002) darkened one side of the sclera in photographed faces and found a substantial shift of the perceived gaze direction toward the darkened side. This finding suggests that low-level analysis of the luminance configuration within the eye region plays a role in computing gaze direction (see also Ando, 2004).

Another factor that influences gaze interpretation is the head direction of the looker (Langton, 2000; Langton et al., 2000; Wollaston, 1824). Langton (2000) used digitized photographs of faces oriented either downward, upward, to the left, or to the right. The eyes were either oriented in the same or opposite direction as the face. In a Stroop-like paradigm, participants were instructed to make speeded key-press responses to either the head or gaze direction of the stimulus. He found that participants' responses to the orientation of another person's head were strongly influenced by the direction in which the person was gazing and concluded that head and gaze direction both influence joint attention mechanisms.

Lee, Eskritt, Symons, and Muir (1998) differentiated between dyadic and triadic eye gaze. Dyadic eye gaze concerns information provided by eye contact, whereas triadic eye gaze concerns information provided by direction of regard toward objects in the environment. Studies investigating dyadic eye gaze are relatively numerous. In their classic study, Gibson and Pick (1963) found high accuracy when the task was to determine whether a looker was looking into the observer's eyes. Similarly, Cline (1967) and Anstis et al. (1969) found high accuracy when observers had to indicate whether a looker held eye contact.

Less work is done on triadic eye gaze. Leekam, Baron-Cohen, Perrett, Milders, and Brown (1997, Exp. 2) investigated the ability of healthy children and children with mental disabilities to decide which of three colored rods a looker was fixating. They found that children did not perform as accurately as adults and concluded that geometric ability must continue to develop beyond 4 years of age. Symons, Lee, Cedrone, and Nishimura (2004) investigated the ability to determine the point of focus of the looker in three-dimensional space and found that humans are highly sensitive to determine the direction of another person's gaze, regardless of whether observers had to rate the gaze from a real-life model or from digital photographs (see also Lee et al., 1998). Similarly, Schwaninger, Lobmaier, and Fischer (2005) showed that peripheral gaze targets can be determined accurately from photographed faces. In two experimental conditions they presented faces on a computer screen that were fixating one of four invisible target points. The task was to judge where the looker was gazing by placing a cursor on the perceived fixation point using the mouse. The stimuli were either whole faces or faces where only the eyes were visible. They found a general overestimation toward the outside of the actual gaze direction. Further, they found that showing the whole face (as opposed to presenting the eyes alone) does not improve perception of triadic eye gaze.

In previous studies of gaze cueing, upright faces were presented so that any cueing effects confounded allocentric (screen- or looker-related) coordinates and egocentric (observer) coordinates. A study by Bayliss, di Pellegrino, and Tipper (2004) dissociated these two reference frames by presenting faces that were rotated 90° clockwise or counter-clockwise on the screen while the eyes were still looking to the left or right, thus cueing the upper or lower portion of the screen. Participants had to press a button when they detected the onset of a target object. The authors reported reliable cueing effects in the horizontal dimension that suggest that observers used the time between face onset and target onset to perform a mental rotation of the looker's face into the canonical upright position. Their results suggest that gaze processing is referenced to the observer's head.

However, rotating a face in the picture plane is a rather artificial stimulus manipulation that severely disrupts face processing (e.g., Thompson, 1980; Yin, 1969). This has often been explained by a disproportionate impairment of configural processing when faces are rotated (for reviews, see Schwaninger, Carbon, & Leder, 2003; Valentine, 1988). Interestingly, this does not seem to apply for gaze perception. Schwaninger et. al (2005) have shown the same inversion effects for eye gaze localization judgments when eyes were shown in isolation versus whole faces. In contrast to face recognition, the inversion effect on gaze perception must therefore be due to a disruption of processing local component information contained in the eyes alone (see also Jenkins & Langton, 2003).

In the present study, we report evidence that gaze processing is influenced by nearby objects. We manipulated the relationship between gaze position and the location of a task-irrelevant object. The question of interest was whether objects placed at or near the fixation point have an influence on the perceived gaze direction. Four conditions were tested: there was either no object, the object was on the actual fixation point, or the object was left or right from the actual fixation point. This manipulation revealed a spontaneous referencing of observed gaze to the object. Specifically, irrelevant objects attracted perceived gaze direction.

Method

Participants

Eleven participants (9 women, 2 men), ranging in age from 20 to 27 years (mean 22) took part in this experiment. All reported normal or corrected to normal vision and were naïve to the purpose of the experiment. After the experiment, participants were paid £5.

Apparatus

The experiment was run on a Pentium PIII 500E computer using custom-made software running on Windows 98. Par-

ticipants were seated on a height-adjustable chair at a distance of 50 cm from the screen and responded by using a QWERTY extended keyboard and a serial mouse. They were required to keep their head still by using a headrest. The stimulus faces were between 59 mm and 65 mm wide, thus the faces subtended between 6.75° and 7.44° horizontally.

Stimuli

Photographs of 4 faces (2 female, 2 male) gazing at two previously defined gaze locations were used. A specially designed box consisting of two horizontal, parallel boards, 400 mm apart, was used to manipulate gaze direction. Two fixation points were marked on the bottom board. These fixation points were 220 mm apart at a distance of 350 mm from a headrest that ensured that the lookers kept their heads absolutely still while fixating the two fixation points with their eyes. Eye level corresponded with the optical axis of the camera and was exactly halfway between the two boards (200 mm above the bottom board). The viewing distance between the eye and each target was, therefore, 418 mm. Three photographs were taken frontally of each looker: one with the eyes closed and one gazing at each of the two fixation points. The gaze line deviated from a straight gaze (into the camera) by 15.9° down and 17.5° left or right.

The photographs were digitally edited with Adobe Photoshop. First, the fixation points were erased from the stimuli. Neutral images were created by superimposing closed eyes on each of the directed gazes. The experimental stimuli were further treated as follows: An object (10 pence coin, silver, 14 mm diameter) was superimposed either centered on the actual fixation point, or 2.5° toward the outside or toward the inside. For the control stimuli, no object was superimposed. The object's y coordinates were kept constant across conditions, reflecting the true vertical fixation coordinate. The final pictures measured 317 mm by 269 mm, the face being between 59 mm and 65 mm wide. The resolution of the image was 28.35 pixels per cm. A sample stimulus can be seen in Figure 1.

Task and Procedure

The experiment had been approved by the Ethics Review Board at the Psychology Department of the University of Dundee. A trial began with the appearance of a stimulus face with closed eyes and the object for the current condition visible. After 1,000 ms, this image was replaced by a photo of the same person looking at one of the fixation points (which were never visible). At the same time, a crosshair cursor appeared at a random location on the screen. In 25% of the trials, the object was visible 50 pixels toward the outside of the actual (veridical) fixation point (outward object condition); in 25% of the trials, the object was visible 50 pixels toward the inside of the veridical fixation point (inward object condition); in 25% of the trials, the object was visible centered on the actual fixation point (centered object condition); in the final 25%
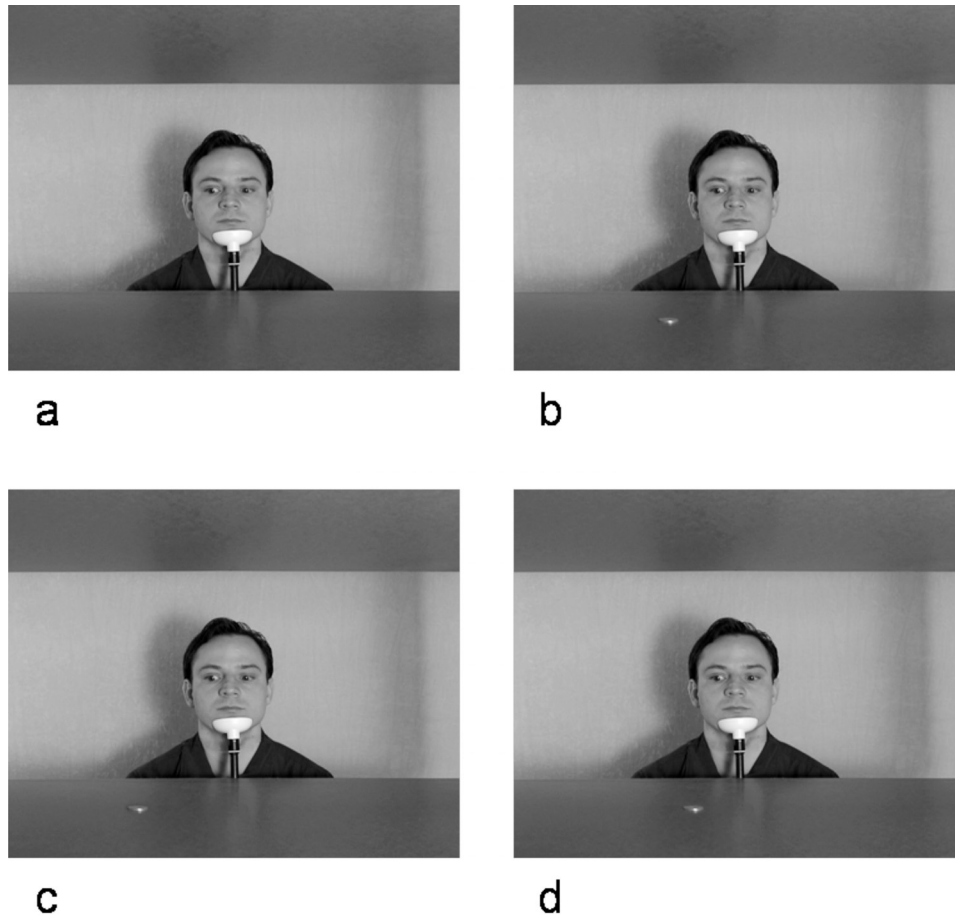
Figure 1. Examples of stimuli: (a) no object, (b) centered object, (c) outward object, (d) inward object.

of the trials, no object was visible (control condition). The task of the participants was to locate the cursor precisely at the perceived fixation location, using the computer mouse with their preferred hand, and to confirm their judgments by pressing the space bar of the keyboard with their other hand. Thirty-two different trials were possible: 2 sides (left, right) × 4 conditions (outward object, inward object, centered object, no object) × 4 different faces.

Prior to the experiment, all participants gave informed consent and information about their gender, age, and preferred hand. They then received written instructions and underwent eight practice trials encompassing all experimental conditions to ensure that they understood the task. None of the stimuli used in the experiment proper were used in the practice trials, and these data were not recorded. The participants were told that the object was randomly placed and did not predict the actual gaze target location. The experiment proper consisted of 10 blocks of 32 trials. The order of trials was randomized online for each block. After each block, participants could take a short break. The length of the break was self-paced, and participants started the next block by pressing the space bar.

Analyses

For each trial, the localization errors in the horizontal (x) and vertical (y) dimensions were calculated by subtracting the veridical fixation coordinates and the judged fixation coordinates from each other, so that positive error values indicated overestimation of gaze direction away from the screen center, and negative error values indicated underestimations toward the screen center. These error values were averaged across faces. Less than 1% of the trials had to be discarded prior to analysis, due to trial lapses. Using a within-subjects design, a multivariate analysis of variance (MANOVA) was carried out, with the factors presentation side (left, right) and object (no object, centered object, outward object, inward object). Separate two-way repeated measures analyses of variance (ANOVAs) were run for errors on the x and y axes with the factors presentation side (left, right) and object (no object, centered object, outward object, inward object).

Results

The MANOVA revealed a main effect of object, $F(3, 30)$ = 8.864, p < .001. There was no effect of presentation

side, $F(1, 10) = 3.232$, $p = .088$. Neither did the interaction of presentation side*object reach statistical significance, $F(3, 30) = 1.040$, $p = .409$. The results are depicted in Figure 2 for errors in the x dimension and in Figure 3 for errors in the y dimension. On the x axis, the mean gaze localization errors were 3.13° (82 pixels) when no object was visible, 2.86° (75 pixels) when the object was placed on the actual gaze location, 3.16° (83 pixels) when the object was toward the outside of the actual gaze location, and 2.78° (73 pixels) when the object was toward the inside of the actual gaze location. On the y axis, the mean localization errors were 0.77° (19.5 pixels) when no object was visible, 0.59° (15 pixels) when the object was placed on the actual gaze location, 0.49° (12 pixels) when the object was toward the outside of the actual gaze location, and 0.62° (16 pixels) when the object was toward the inside of the actual gaze location. Separate two-tailed t tests revealed that all error scores were significantly different from zero, all $t(21) > 3.6$, $p < .01$.

Separate ANOVAs on the errors on the x and y axes revealed significant object effects for the x axis, $F(3, 30) = 5.975$, $MSE = 91.917$, $p < .01$, and for the y axis, $F(3, 30) = 11.894$, $MSE = 16.259$, $p < .001$. On the x axis, follow-up pairwise comparisons revealed the following significant differences: between centered object and outward object, $SE = 1.412$, $p < .001$, between inward object and outward object, $SE = 3.193$, $p < 0.01$, and between no object and inward object, $SE = 3.18$, $p < .05$. On the y axis, the following comparisons reached significance: between no object and centered object, $SE = 1.041$, $p < .01$,

between no object and outward object, $SE = 1.514$, $p < .01$, between no object and inward object, $SE = 1.277$, $p < .05$, between centered object and outward object, $SE = 0.819$, $p < .05$, and between outward object and inward object, $SE = 1.442$, $p < .05$. The effect of presentation side and the interaction of presentation side*object did not reach statistical significance for errors on either axis.

Discussion

The most important finding of the present study is that an object placed near the actual fixation point of another person's gaze influences the perception of the person's gaze. Our result shows that not only the iris-sclera ratio (Ando, 2002; Anstis et al., 1969; Langton, Watt, & Bruce 2000) or other cues from the looker's head (Langton, 2000) are important to determine where a person is looking, but that objects located near the possible gaze target influence the perceived gaze direction.

The fact that objects in the visual field bias the perception of gaze has methodological implications for research on joint attention. For example, in a frequently cited paper, Leekam et al. (1997) presented photographs of a looker behind three rods and asked children to determine which of the objects the looker fixated. By manipulating the separation between objects, they determined the children's ability to resolve another person's gaze direction. However, in the light of the present findings, it appears that the
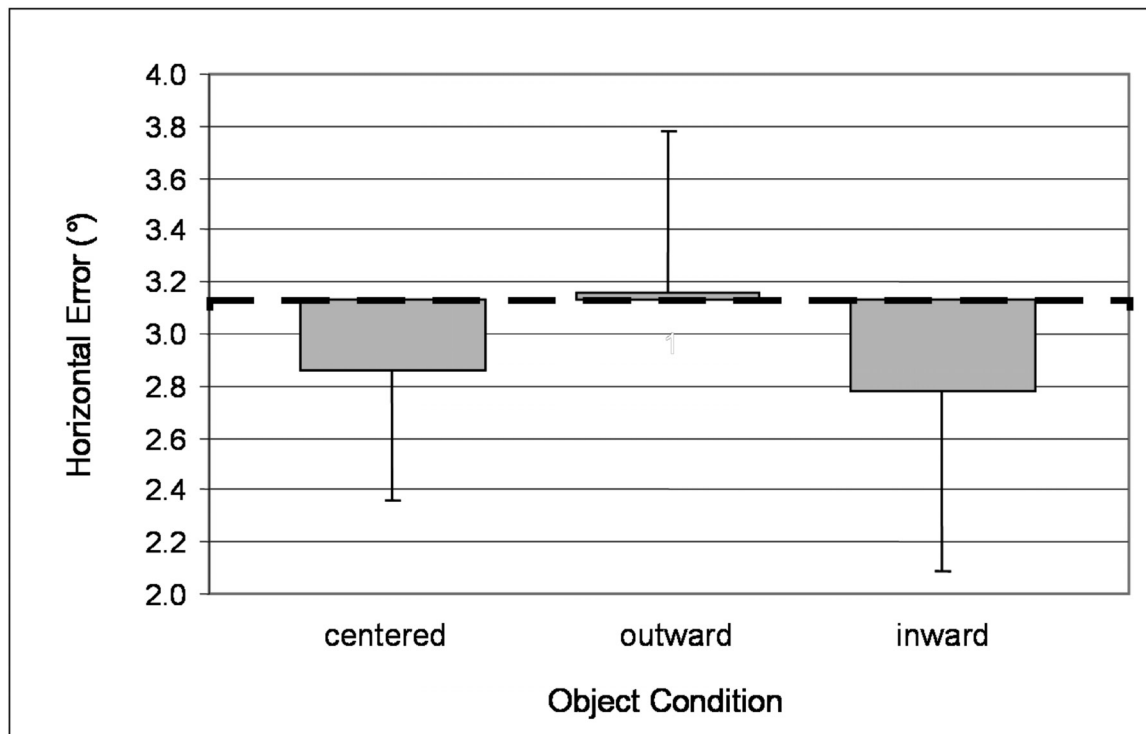

Figure 2. Mean gaze localization errors in the x dimension for centered object, outward object, and inward object. Larger values reflect bias away from screen center. Error bars depict standard errors of the means. Dashed line reflects baseline localization without object.
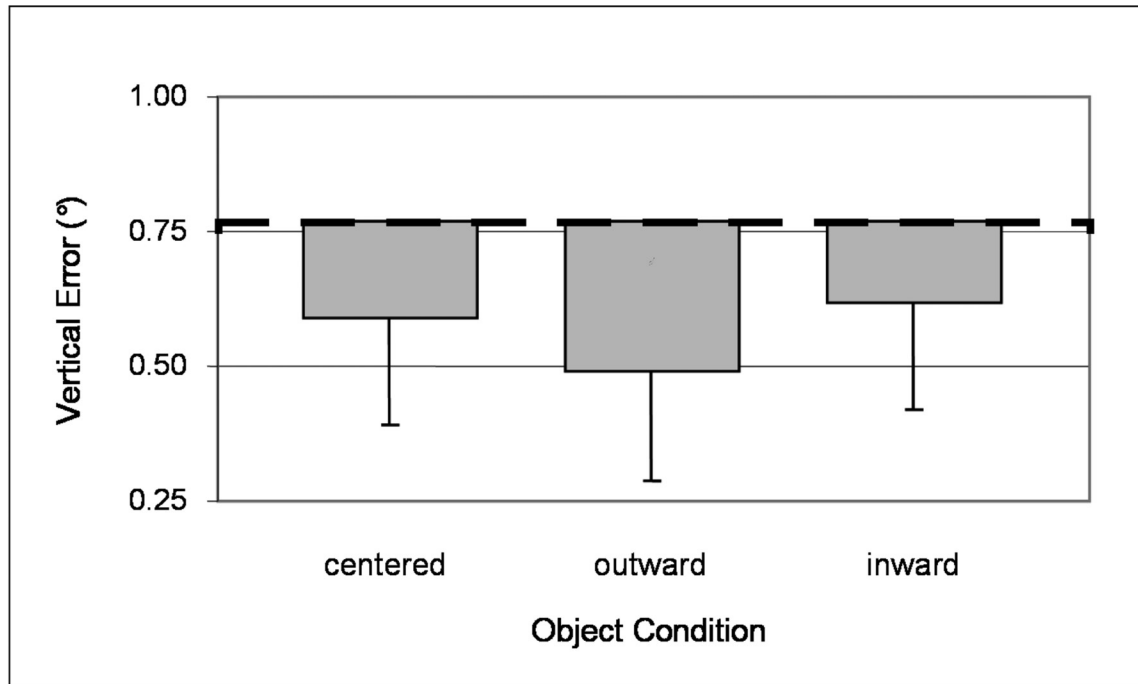
Figure 3. Mean gaze localization errors in the y dimension for centered object, outward object, and inward object. Larger values reflect bias away from screen center. Error bars depict standard errors of the means. Dashed line reflects baseline localization without object.

presence of multiple objects leads to an underestimation of this ability.

Gaze lines were generally overestimated toward the outside, as is evident from the positive sign of all error values, including the baseline results without object. An object placed on the actual gaze target or toward the inside of the actual fixation point reduced this overestimation. Thus, the object captured the perceived gaze line, but cues from the eye itself were also taken into account. Participants seem to compromise between information from cues in the gaze target area and cues from the eyes. It could be argued that our measure of perceived gaze direction may be contaminated by the observers' monitoring of their own hand movements (cf. Castiello, 2003). However, we allowed ample time for correction of the adjustments, so this argument is not an issue. Our finding is consistent with the view that the presence of the object may capture the attention of the observer, and thus influence the judgments. What was clearly shown in this study is that the presence of an object influences the perceived gaze direction of another person. It will have to be the issue of future research to understand the exact reason for this effect.

To know where another person is looking helps us to determine the other person's intention (Baron-Cohen, 1995a, 1995b; Emery, 2000). Our tendency to orient to the direction of another person's attention seems to be crucial for the development of effective social interactions and theory of mind (Baron-Cohen, 1995a). Our results are compatible with the view that gaze processing is biased toward the assumption that a person is looking at an object rather than at an empty space. This object-based capture of per-

ceived gaze direction could reflect the attribution of intentionality to the observed person. A visible object is likely to be relevant for the observer; thus it is sensible to assume that an observed person will probably attend to an object in his or her visual field that is relevant at that moment in time. Therefore, at least two signals have to be integrated: (1) the information contained in the eyes of the looker and (2) the location of a nearby object that might be related to the intention of the looker. Our study included only one distracting object; it will have to be the issue of future research to investigate the role of several visible objects.

This novel finding reveals a limitation of previous work. Specifically, much of the previous research on gaze perception adopted paradigms that were unlike real-life situations, by using empty spaces as gaze targets (e.g., Anstis et al., 1969; Cline, 1967) or tilted faces (Bayliss et al., 2004). Kingstone, Smilek, Ristic, Friesen, & Eastwood (2003) pointed out the importance for researchers to take a look at the real world in order to understand the role of attentional processes for human performance. We used an object as a possible gaze target because in real life people rarely stare at empty space. Mostly they focus on an object that might be of interest to them and others. Our results emphasize the importance of naturally available objects as reference frames for spatial processing. Further experiments should determine whether the object bias in gaze processing is a low-level mechanism that reflects stimulus encoding or a higher-level process based on the need to assign an action intention to the observed person. Furthermore, in future studies on joint attention, an eye-tracking system may be used to ascertain what information was used to make the responses.

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Janek S. Lobmaier

Psychologisches Institut der Universität Zürich
Kognitive Neurowissenschaft
Treichlerstrasse 10
CH-8032 Zürich
Switzerland
Fax +41 1 634 1589
E-mail j.lobmaier@psychologie.unizh.ch