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Gaze cues evoke both spatial and object-centered shifts of attention

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When someone observes another individual suddenly shifting gaze, the observer's attention automatically and rapidly orients to the same location. Such gaze cuing of attention has properties similar to those of exogenous cuing. We investigated whether gaze cuing is also like exogenous cuing in that it is observed for both spatial and object-/head-centered frames of reference. That is, when the face that produces the gaze cue is presented on its side, tilted 90º from upright, will attention be simultaneously directed to where the eyes would have been looking if the face had been presented upright *and* toward the actual spatial direction of gaze? It is demonstrated that gaze cues do indeed orient attention in both spatial and object-centered frames, that these effects are of similar magnitude, and that such orienting is relatively rapidly computed.

Observing averted eye gaze results in an automatic shift of attention to the direction of the observed gaze (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999; Langton & Bruce, 1999). This behavior, *joint attention*, is vital in interpersonal interactions and forms part of the basis of social development (Emery, 2000; Moore & Dunham, 1995). As such, this phenomenon is of interest not only to researchers investigating social cognition and development, but also to those investigating the mechanisms of visual attention. The mechanisms underlying the allocation of attention in space have long been the subject of intense research, and the use of gaze cues gives an opportunity to approach the question from a new direction (Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003; Langton, Watt, & Bruce, 2000).

The effects of gaze cues are rather similar to the effects of peripheral onset cues. For example, participants are quicker to respond to targets appearing at gazed-at locations even when they are told to expect targets at the opposite location (see, e.g., Driver et al., 1999) and when the target appears very quickly after cue onset (e.g., 14 msec; Hietanen & Leppanen, 2003). Furthermore, it has also recently been demonstrated that gaze cuing produces facilitatory *and* inhibitory effects of attention at the gazed-at location (Frischen & Tipper, 2004), much as do peripheral onset cues (inhibition of return, or IOR; Posner & Cohen, 1984), although the gaze-evoked IOR is much slower to emerge. Despite the similarities between gaze cuing and peripheral cuing, the two modes of orienting seem to rely on independent mechanisms (Friesen & Kingstone, 2003). In this article, we investigate whether another property of exogenous attention shifts is also possessed by the systems responsible for gaze cuing.

Previous work has investigated the frame of reference within which attention functions. A series of studies have revealed that attention can be oriented simultaneously in both space- and object-based frames (e.g., Jordan & Tipper, 1998). That is, peripheral cuing of a part of an object results in cuing at that location, but also at other parts of the same object (e.g., Egly, Driver, & Rafal, 1994). Of more relevance, exogenous cues have also been shown to activate attention states in both space- and object-centered coordinates. For example, Tipper, Jordan, and Weaver (1999; see also Tipper & Weaver, 1998, for a review) cued one of three squares. After cuing, the squares moved 120º in a circular motion. IOR was evident both for the object that had originally been cued but had moved to a new location and for the location on the screen that had been cued. Hence, the single event of a sudden onset cue inhibited attention from orienting to the location of the cue and to the object cued (see also Leek, Reppa, & Tipper, 2003). Similarly, Behrmann and Tipper (1999; see also Tipper & Behrmann, 1996) showed that hemispatial neglect, which can follow right parietal damage, can act in multiple frames of reference. That is, stimuli in the left visual field are poorly detected (space-based neglect), but in Behrmann and Tipper's study, the object was seen to rotate through space, so that the left side of the object appeared in the "good" right visual field. Detection of stimuli appearing on the left side of the object (now appearing on the right side of space) was still poor at this new location, indicating that neglect can operate in object-centered space.

A first step in the investigation of the frames of reference for shifts of attention in gaze cuing has been undertaken by Bayliss, di Pellegrino, and Tipper (2004). In their study, they presented faces oriented 90º in the picture plane.

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In this situation, the gaze cue was directed up or down. Bayliss et al. (2004) proposed that if gaze was encoded in object-centered coordinates, attention might be cued to the left or right, depending on where the eyes would have been looking had the face been presented in the normal upright orientation. For example, in Figure 1, panel A(i), one can see that with a face oriented 90º clockwise, looking down, the eyes would have been looking to the right if the face had been upright. Hence, in object-centered coordinates, this could be a rightward attentional cue. A face looking down but presented counterclockwise would be a leftward attentional cue [see Figure 1, panel A(ii)].

Previous studies have used gaze cues in faces presented upside down, leading to weaker or even abolished cuing effects, when compared with the magnitudes of cuing found with upright faces or *eye region only* displays (Kingstone, Friesen, & Gazzaniga, 2000; Langton & Bruce, 1999). These results imply that the difficulty in processing upside-down faces (see Bartlett & Searcy, 1993, for a review) leads to interference with the processing of gaze (Jenkins & Langton, 2003). Alternatively, the idea that gaze cues can activate multiple frames of reference provides a different explanation. That is, if the face is presented upside down, the two frames oppose each other. However, when a face is oriented 90º, not 180º, from the upright, the two frames will act along orthogonal axes and, hence, can be investigated separately (Bayliss et al., 2004; see also Hommel & Lippa, 1995, and Proctor & Pick, 1999, for evidence of object-centered encoding of faces).

Bayliss et al. (2004) did indeed observe such object-centered gaze-cuing effects. Importantly, however, in this first study they did *not* investigate whether spatial cuing was also present, since the targets were always presented only to the left and the right of the face. That is, it is unknown whether cuing toward the *actual* direction of gaze was also present or whether only object-centered cuing was evoked. In terms of the previous literature, this was an important oversight. Therefore, the present study investigated whether the object-centered cuing effect can be replicated and whether simple space-based orienting of attention is present simultaneously. Thus, in the example shown in Figure 1, panels A(iii) and A(iv), will detection of targets presented at the location to which the eyes directly gaze also be facilitated?

EXPERIMENT 1

Participants saw a face presented on its side—that is, tilted 90º clockwise or counterclockwise. Then the eyes appeared, looking up or down, followed by a target in one of four locations: top, bottom, right, or left of the screen. With four equiprobable target locations, we felt that the

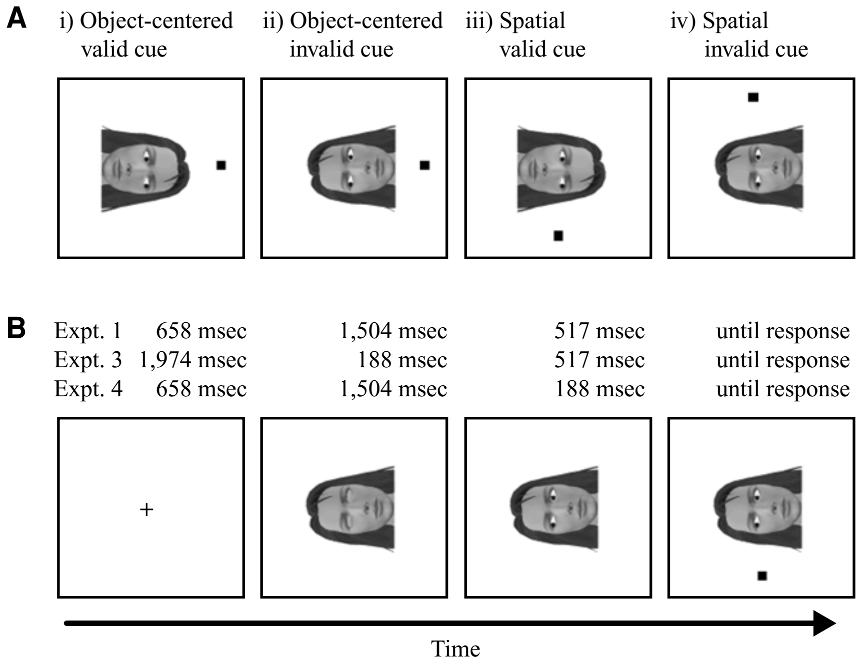

Figure 1. (A) Examples of the four experimental conditions in Experiments 1, 3, and 4. First, on the left (i), is a target that is cued in object-centered space. Because the eyes would have been looking to the right if the face had been presented upright, this is a valid cue. The second display (ii) is of an invalid object-centered cue, because the eyes would have been looking away from the target if the face had been presented upright. The third display (iii) is an example of a valid spatial cue, since the eyes look directly toward the target position. The final display (iv) on the right is an invalid spatial cue, since the eyes look in the direction opposite the target location. (B) Time course of a trial, giving stimulus durations for Experiments 1, 3, and 4 and using a valid spatial cue as an example.

participants would be even more unlikely to attempt to strategically utilize the cue in object-centered terms than were the participants in Bayliss et al.'s (2004) study, which used only two target locations (to the left and the right). Therefore, evidence of object-centered orienting in this paradigm would be stronger evidence that such effects are automatically evoked. More important, this design allowed the assessment of the hypothesis that a single gaze cue can activate dual frames of reference simultaneously, resulting in cuing along two axes. Hence, it was predicted that locations directly cued would be facilitated, as well as that there would be an overall replication of Bayliss et al.'s (2004) finding of small but reliable cuing in object-centered space.

Method

Participants. Twenty-five adults (mean age = 20.1 years, *SD* = 2.4; 3 of them male) participated in return for course credit or payment. All were naive as to the purpose of the experiment and had normal or corrected-to-normal vision. Informed consent was obtained in accordance with the guidelines of the School of Psychology, Bangor.

Apparatus. The digitized face (subtending 12.4º × 12.8º of visual angle) was presented in the center of the computer screen (measuring 37 × 27 cm, with a refresh rate of 11.75 msec) and could appear oriented clockwise or counterclockwise 90º (see Figure 1). The pupils (0.76º × 0.76º) could appear in the left or right of the eye regions (1.9º × 1.1º). The target was a small black square (1.4º × 1.4º). Target locations were 11.9º above, below, to the left, and to the right of the center of the screen. The participants sat approximately 60 cm from the screen, with a chinrest. The stimuli were presented using E-Prime software.

Design. There were two within-subjects factors. The first one, *frame of reference*, referred to whether the target appeared on the vertical axis—in line with or opposing eye gaze (*spatial*)—or on the horizontal axis (*object-centered*), and the second factor, *validity*, referred to whether the target appeared in a cued or an uncued location.

Procedure. The participants were told that neither the direction of gaze nor the angle of head orientation predicted target location. They were asked to maintain fixation throughout each trial and to respond to the target as quickly as possible with a press on the space bar. On each trial, the fixation cross appeared at the center of the screen for 658 msec, followed by the face, oriented 90º either clockwise or counterclockwise, for 1,504 msec, before the onset of the gaze cue (see Figure 1, panel B). The face was positioned so that the central point between the eyes was the position of the fixation cross presented on the previous display. Hence, the eyes were at the center of the screen and were equidistant from fixation. The pupils appeared 517 msec before target onset, and the target remained on the screen until a response had been given or 1,974 msec had elapsed. A blank screen preceded each trial for 1,269 msec. The validity and frame-of-reference factors produced four trial types, each repeated 80 times over the course of the experiment. After a practice block of 12 trials, four experimental blocks of trials were completed. In each block, 80 experimental and 12 catch trials (no target, no response required) were presented. All manipulations, the orientation of the face, the direction of gaze, and the position of the target were randomized. We avoided blocking any factors, in order to reduce the possibility of any strategic orienting behavior.

Results

There were few misses (0.10%) and false alarms (1.6%). Trials with reaction times (RTs) greater than 1,000 msec or smaller than 150 msec were removed, followed by trials with RTs more than 2 *SD*s above or below the participant's mean. Altogether, 4.8% of the experimental trials were removed. The remaining RTs contributed to mean scores (see Figure 2) and were submitted to an ANOVA, with frame of reference (spatial or object-centered) and validity (valid or invalid) as within-subjects factors. An alpha value of .05 was used to test for the significance of the tests employed in these experiments. The main effect of validity was significant [$F(1,24) = 30.9, p < .001$], showing that overall cuing effects were found, with shorter RTs to cued than to uncued targets (330 vs. 342 msec). The main effect of frame of reference was significant [$F(1,24) = 28.9, p < .001$], due to shorter RTs to targets appearing on the vertical axis (spatial; 332 msec) than to targets on the horizontal (object centered; 340 msec) axis. The interaction of validity and frame of reference was also significant [$F(1,24) = 10.4, p = .004$], due to a greater effect of validity in the spatial frame of reference (RT of invalid trials minus RT of valid trials shows a cuing effect of 18 msec) than in the object-centered frame of reference (7-msec cuing). Planned contrasts revealed that cuing to the actual direction of gaze was significant [$F(1,24) = 26.7, p < .001$], as was cuing to the direction of gaze in object-centered coordinates [$F(1,24) = 10.5, p = .003$; see Figure 2].

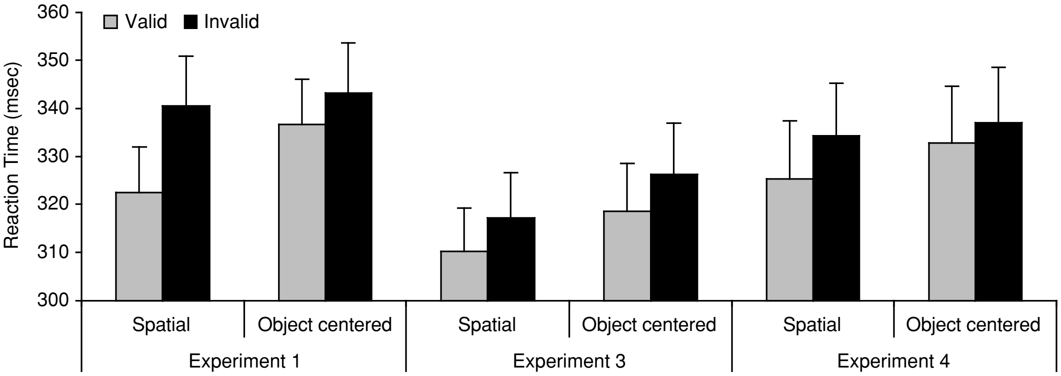

Figure 2. Graph of the reaction times for each condition in Experiments 1, 3, and 4, with standard error bars.

Discussion

This experiment clearly demonstrated that like exogenous cuing, gaze-evoked shifts of attention can take place in two frames simultaneously.[1] Thus, target detection at both the actual location toward which the eyes are gazing (top or bottom) and the location the eyes would be gazing if the head were in its normal orientation (right or left) was facilitated. In this experiment, the spatial-cuing effect in the vertical axis was larger than the object-centered effect in the horizontal axis. A further issue that we engaged in subsequent experiments (3 and 4) concerns the time course of these cuing effects. However, before we continued to address these issues, it would be fruitful to establish baseline gaze cuing effect magnitudes along the horizontal and vertical axes. Therefore, the next experiment provided two important pieces of information that were necessary for interpreting the spatial and object-centered cuing effects observed in Experiment 1: first, whether pure gaze-evoked cuing effects are equivalent in both the vertical and the horizontal axes, and second, the size of the cuing effect produced by gaze when head information is not present.

EXPERIMENT 2

In order to establish a baseline cuing effect that could be evoked in the circumstances we introduced in Experiment 1 yet would be devoid of contextual (i.e., face orientation) information, we adopted the following procedure. Since the face is critical to the central effects we present here (i.e., object-centered gaze cuing), in this experiment we removed the surrounding face from the display, leaving only the eyes visible to the participants. Furthermore, since the shading around the eyes could potentially give the participants information about the orientation of the (deleted) face, we took the lower half of the eye region, inverted it, and pasted it onto the top half of the eye region, to produce a gaze cue that was geometrically identical to the cue used in Experiment 1 but that provided no contextual information about head orientation (see Figure 3, boxes A and B). Hence, cuing in the direction of gaze could now be examined in both the vertical and the horizontal axes. This provided a basic measure of gaze-cuing effects in both axes and, also, a measure of the effects when head context was removed.

It was predicted that these simple, purely spatial gaze-cuing effects, with no contextual information whatsoever, would not differ along the horizontal and vertical axes. If this result were confirmed, this would suggest that the magnitude differences between the spatial (18 msec) and the object-centered (7 msec) cuing effects in Experiment 1 were due to differences in the relative strength of each frame of reference, rather than to a basic difference in standard cuing along the vertical and horizontal axes. Furthermore, whether the 18-msec spatial-cuing effect in Experiment 1 was determined solely by the direction of gaze would be tested, because if this was indeed the case, the cuing effect in the vertical axis should be similar when only the eyes were present (Experiment 2). In contrast, if the vertical gaze-cuing effect in Experiment 1 was influenced by the head context, the effects might be smaller in Experiment 2 when no head was visible.

Method

Participants. Twenty-five adults volunteered for this study (mean age = 21.7 years, *SD* = 2.5; 4 of them male). All were naive as to the purpose of the experiment and had normal or corrected-to-normal vision. Informed consent was obtained in accordance with the guidelines of the School of Psychology, Bangor.

Apparatus, Design, and Procedure. All aspects of this experiment were the same as those in Experiment 1, except that only the eye regions were presented. The lower half of the eye region was flipped and pasted over the upper region in order to achieve a stimulus that was devoid of any cues as to the isometric orientation of the face from which it was taken. A further difference was that instead of the cue being presented rotated either clockwise or counterclockwise, in Experiment 2, the cue appeared oriented either vertically or horizontally. Targets were defined as *valid* (i.e., looked at), *invalid* (i.e., looked away from), or *neutral* (i.e., presented along the axis orthogonal to the cue direction; see Figure 3).

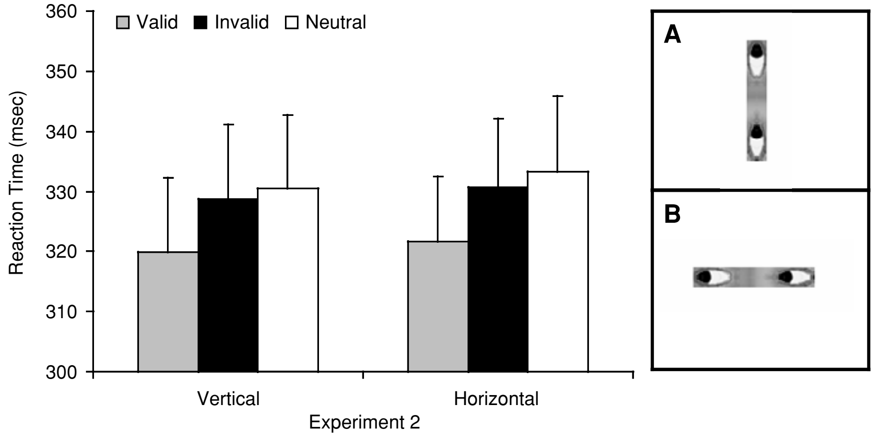

Figure 3. Graph of the reaction times for each condition in Experiment 2, with standard error bars. Also, examples of (A) the vertical gaze cue stimuli and (B) the horizontal gaze cue stimuli are shown to the right of the graph.

Results

There were few misses (0.20%) and false alarms (2.7%), and 7.3% of the trials were excluded as outliers, as in Experiment 1. Means for each condition were submitted to a 2 (orientation: horizontal or vertical) × 3 (validity: valid, invalid, or neutral) ANOVA. There was a cuing effect, since the main effect of validity was significant [$F(1,24) = 13.4, p < .001$], with RTs in valid trials being shorter than those in invalid or neutral trials (321 vs. 330 vs. 332 msec, respectively). Neither the main effect of orientation [$F(1,24) = 1.79, p = .193$] nor the critical interaction [$F(2,48) < 1$] approached significance, suggesting that cuing was not different along the two axes (see Figure 3). Planned contrasts confirmed that cuing was present from both vertical [$F(1,24) = 11.6, p = .002$] and horizontal [$F(1,24) = 7.29, p = .013$] cues (both benefits for valid targets over invalid targets were 9 msec). Valid targets were also detected more quickly than neutral targets appearing on the axis orthogonal to the cue, for both vertical [$F(1,24) = 19.7, p < .001$] and horizontal [$F(1,24) = 11.0, p = .003$] cues, whereas RTs did not differ between the invalid and the neutral targets on either axis [$F\text{s}(1,24) < 1, p\text{s} > .37$].

Discussion

This experiment demonstrated that the cuing evoked by the eyes used in these experiments was equivalent along the horizontal and the vertical axes. Furthermore, the targets appearing in neutral positions were responded to as quickly as the invalid targets, suggesting that where there is only spatial information available (i.e., no face providing contextual information about head orientation), attention is equally distributed between the invalid location and locations along the axis that is orthogonal to the cue direction. Hence, the subsequent experiments, performed to investigate the time course of cuing in spatial (vertical) and object-centered (horizontal) coordinates, utilizing the presence of an isometrically rotated face, can be interpreted in terms of the fact that cuing in simple spatial terms is equal along the vertical and the horizontal axes.

Interestingly, when compared with the cuing effects found in Experiment 1, the vertical-spatial cuing effect found in Experiment 2 (9 msec) was significantly weaker than the spatial cuing effect in Experiment 1 (18 msec), as was shown by a planned contrast [$F(1,47) = 5.05, p = .029$]. However, the horizontal-spatial effect in Experiment 2 (9 msec) was not different from the object-centered cuing effect in Experiment 1 (7 msec) [$F(1,47) < 1, p = .49$]. This suggests that the spatial-cuing effect along the vertical axis in Experiment 1 when the face was visible might itself have depended on a strong representation of the face that produced the cue. That is, stronger effects were observed for the vertical axis in Experiment 1 than in Experiment 2 because, in the former case, both the eye and the head were combined. In contrast, the spatial cuing effects on the horizontal axis produced by eye gaze (Experiment 2) were equivalent to the head-centered effects observed in Experiment 1.

EXPERIMENT 3

In Experiment 3, we altered the amount of time available for viewing the face prior to the gaze cue. In Experiment 1, the face was presented for the relatively long time of 1,504 msec, prior to the gaze onset. We reasoned that a process of mental rotation, where the head is normalized to the upright orientation, is necessary for these object-centered cuing effects (Lawson, 1999; Shepard & Metzler, 1971). If the cue appeared quickly after the onset of the face, we might see a very different cuing pattern emerge. In Experiment 3, we reduced the presentation of the head prior to cue onset from 1,504 to 188 msec (see Figure 1, panel B).

Reducing the exposure time of the face prior to the gaze cue could have a number of effects. First, it was possible that mental rotation of the face to the upright would not be completed, and hence, this would reduce the head-centered cuing effects. Second, it was possible that these mental rotation processes would be relatively rapid and would be completed sufficiently to produce head-centered gaze-cuing effects. And third, it was possible that the ongoing mental rotation processes acting on the head to produce object-centered cuing would interfere with the spatial orienting determined by actual gaze direction. Thus, as has been discussed, it might have been the congruency of gaze and head that produced the relatively large spatial cuing for the vertical orientation in Experiment 1. Therefore the spatial effects might be smaller when the head was only briefly seen in Experiment 3, because ongoing mental rotation processes would impair *visible* head-based effects.

Method

Participants. Twenty-five adults volunteered for this study (mean age = 19.9 years, *SD* = 1.7; 2 of them male). All were naive as to the purpose of the experiment and had normal or corrected-to-normal vision. Informed consent was obtained in accordance with the guidelines of the School of Psychology, Bangor.

Apparatus, Design, and Procedure. All aspects of this study were the same as those in Experiment 1, except that the fixation cross appeared for 1,974 msec, followed by the face for 188 msec before the onset of the gaze cue, followed by the target after 517 msec. The longer fixation duration was used so that the total trial duration matched that in Experiment 1.

Results

There were few misses (0.15%) and false alarms (1.3%), and 5.3% of the trials were excluded as outliers, as in Experiment 1. Means for each condition (see Figure 2) were submitted to an ANOVA. The main effect of validity was significant [$F(1,24) = 26.5, p < .001$], with shorter RTs on valid than on invalid trials (314 vs. 322 msec). As in Experiment 1, RTs were also shorter to targets on the vertical axis (314 vs. 322 msec), resulting in a significant main effect of frame of reference [$F(1,24) = 22.8, p < .001$]. However, unlike in Experiment 1, the frame-of-reference × validity interaction did not approach significance [$F(1,24) < 1$]. That is, the spatial and the object-centered cuing effects were of equivalent magnitude.

Planned contrasts revealed that cuing in the direction of gaze was again significant [$F(1,24) = 7.5$, $p = .011$], but with quite a small magnitude (7 msec, in comparison with the 18-msec effect in Experiment 1). The object-centered cuing effect was also significant [$F(1,24) = 34.3$, $p < .001$], with cuing of 8 msec (in comparison with the 7-msec effect in Experiment 1).

A mixed-factor ANOVA was also conducted to compare the cuing effects in Experiment 3 with those in Experiment 1. The experiment × frame-of-reference × validity ANOVA revealed significant effects of validity [$F(1,48) = 55.7$, $p < .001$] and frame of reference [$F(1,48) = 50.8$, $p < .001$]. However, there were two interactions involving experiment that were of interest. First, the validity × experiment interaction approached significance [$F(1,48) = 3.60$, $p = .064$], with Experiment 3 showing weaker overall cuing. More important, however, the experiment × validity × frame-of-reference interaction was significant [$F(1,48) = 7.19$, $p = .010$]. A further ANOVA compared spatial effects in the vertical axis between Experiments 1 and 3 and showed there was a weaker spatial-cuing effect in Experiment 3 than in Experiment 1 [$F(1,48) = 6.67$, $p = .013$], whereas another ANOVA showed that the object-centered cuing effect was equivalent between the two experiments [$F(1,48) < 1$].

Discussion

Reducing the exposure of the face prior to the gaze cue had a clear effect on the orienting of attention. Somewhat to our surprise, the data supported the third hypothesis proposed in the introduction to this experiment. That is, brief presentation of the face did *not* reduce the object-centered cuing effects on the horizontal axis. In sharp contrast, reducing viewing time of the face *did* reduce the spatial cuing in the vertical axis (in comparison with Experiment 1). We tentatively propose that the ongoing mental rotation of the face to the upright, although facilitating object-centered cuing, interfered with the integration of information about actual gaze direction and head orientation assumed to mediate the strong spatial/vertical cuing effects in Experiment 1.

EXPERIMENT 4

The final experiment also investigated the time course of the spatial and object-centered gaze-cuing effects. Experiment 1 was replicated, except that the cue–target stimulus onset asynchrony (SOA) was reduced from 517 to 188 msec in Experiment 4. This SOA was certainly sufficient to observe standard cuing from eye gaze. However, whether a face on its side can produce cuing with a relatively short SOA was unknown. It was anticipated that at this shorter SOA, the simple spatial-cuing effect would have already emerged, but the object-centered frame of reference, which relies on more complex representations, might not have yet had time to exert influence on performance, and hence, no object-centered cuing would be observed. If, however, the two cuing effects were affected uniformly—that is, were reduced by the same order of magnitude—we might infer that these cuing effects emerged with a similar initial time course.

Method

Participants. Twenty-six participants completed this experiment, but 1 participant was excluded due to a high false alarm rate on catch trials. All were naive as to the purpose of the experiment and had normal or corrected-to-normal vision. Informed consent was gained in accordance with the guidelines of the School of Psychology, Bangor. The remaining 25 participants (8 of them male) had a mean age of 24.4 years (*SD* = 4.3).

Apparatus, Design, and Procedure. The apparatus, design, and procedure were the same as those in Experiment 1, except for the cue–target SOA, which was reduced from 517 to 188 msec (see Figure 1, panel B).

Results

Misses (0.03%), false alarms (5.4%), and RT outliers (5.7%) were removed from analysis, as in the previous experiments. Means for each condition (see Figure 2) were submitted to an ANOVA. The main effect of validity was significant [$F(1,24) = 15.4$, $p = .001$], with RTs shorter on valid (329 msec) than on invalid (336 msec) trials, replicating the overall gaze-cuing effect. Again, the frame-of-reference main effect was significant, with quicker responses to targets appearing on the vertical axis [$F(1,24) = 15.6$, $p = .001$] (i.e., spatially cued or uncued; 330 msec) than to those on the horizontal axis (i.e., object-centered cued or uncued; 335 msec). The frame-of-reference × validity interaction approached significance [$F(1,24) = 3.92$, $p = .059$]. This was due to more cuing in the spatial frame of reference (9 msec) than in the object-centered frame of reference (4 msec). Planned contrasts showed that, again, both the spatial [$F(1,24) = 14.1$, $p = .001$] and the object-centered [$F(1,24) = 6.61$, $p = .017$] cuing effects were significant.

Comparing this experiment with Experiment 1 was important to the evaluation of the importance of the cue–target SOA. Hence, a mixed-factor ANOVA included experiment as a between-subjects factor. Both frame-of-reference and validity main effects were significant [$F(1,48) = 44.3$, $p < .001$, and $F(1,48) = 46.2$, $p < .001$, respectively], and these factors significantly interacted [$F(1,48) = 14.3$, $p < .001$]. More important, there was more cuing in Experiment 1 than in Experiment 4, since the validity × experiment interaction reached significance [$F(1,48) = 4.26$, $p = .044$]. However, this effect was consistent across object-centered and spatial-cuing effects, since the frame-of-reference × validity × experiment interaction was nonsignificant [$F(1,48) = 2.64$, $p = .11$]. This shows that the change in cue–target SOA from Experiment 1 (517 msec) to Experiment 4 (188 msec) modulated the overall cuing effect uniformly, weakening both spatial and object-centered effects equivalently. A similar analysis compared Experiments 3 and 4, but no interactions involving experiment approached significance [$F(1,48) < 2.8$, ps $> .1$].

Discussion

Again, the results were clear. Both spatial and object-centered gaze-cuing effects were replicated. Although the object-centered cuing effect was slightly smaller than that in the baseline Experiment 1, the effect was still significant. Similarly, significant spatial gaze-cuing effects were also observed, although, again, smaller than those in Experiment 1. Therefore, both spatial and object-centered effects can be evoked relatively rapidly, although both of them seem to require more time following cue onset to evolve to their full magnitude (Experiment 1). Since these effects were uniformly weaker in this experiment, as compared with Experiment 1, we may conclude that the two cuing effects are indeed evoked following a similar post-cue time course, since both cuing effects were numerically reduced, but neither was abolished, by the reduction in cue–target SOA.

GENERAL DISCUSSION

The observation of a shift in gaze direction when we interact with other individuals evokes rapid and automatic shifts of attention to the same location in space. These gaze-evoked shifts of attention are similar to those controlled by other attention systems, such as those evoked by sudden onset peripheral (exogenous) cues. Thus, like exogenous cues, gaze cues rapidly and automatically shift attention (Driver et al., 1999; Friesen & Kingstone, 1998), and they also show the facilitation and subsequent IOR cuing effects over extended SOAs (Frischen & Tipper, 2004). The present work extends our knowledge further by showing that like exogenous cues, gaze cues can also simultaneously evoke shifts of attention in both space-based and object-/head-centered frames of reference.

Our experiments have revealed the following properties of spatial and object-centered gaze cue orienting: First, the object-centered gaze-cuing effect, although small, is relatively stable. It seems to be rapidly computed when the face is seen only for a brief time prior to gaze cuing (Experiment 3) and even when the cue–target interval is short (Experiment 4). Second, the object-centered and spatial gaze-cuing effects are of equivalent magnitude. This was revealed via Experiment 2, where gaze cues were presented oriented vertically or horizontally, but with the face absent. These "pure" spatial gaze effects were equivalent in the vertical and the horizontal axes and were 9 msec, which was not different from the 7-msec object-/head-centered cuing effect in Experiment 1. Third, the 18-msec spatial gaze-cuing effect in Experiment 1 was significantly larger than the other effects obtained in these experiments. In particular, it was significantly larger than the basic gaze-cuing effects (vertical axis) in Experiment 2 (9 msec). Interestingly, this cuing effect was reduced either by presenting the face briefly prior to the gaze cue (Experiment 3) or by presenting a brief cue–target interval (Experiment 4). Although weaker cuing at a short SOA (Experiment 4) may be simply due to the fact that it takes time for gaze cues to exert their full influence on attention (Driver et al., 1999), the weak vertical/spatial cuing in Experiments 2 and 3 may show that cuing along this axis relies on a strong representation of the actual orientation of the face. So, when the face was not present (Experiment 2) or had been presented for a short time prior to cue onset (Experiment 3), weak vertical spatial cuing was found. In Experiment 3, ongoing mental rotation of the face might have interfered with the literal representation of the visible face, impairing integration of head and gaze information.

Also of note in the data were the main effects of target axis in Experiments 1, 3, and 4. That is, target detection was faster when they were presented in the vertical axis then when they were presented in the horizontal axis. We suspect that the facilitated processing of targets presented above and below fixation was due to the gaze-cuing procedure. That is, in these three experiments, the participants saw the eyes consistently look up or down. These were the only two possible precuing conditions, since the gaze cue was never oriented to the left or right. It is very likely that this knowledge resulted in the prioritization of the spatial code corresponding to the vertical axis, even though targets were just as likely to appear along the horizontal axis. This prioritization might have facilitated RTs to targets along the vertical axis per se, independently of which direction the eyes actually looked. Support for this idea was provided by the data in Experiment 2. Here, gaze cues were oriented both vertically and horizontally, and there was no hint of a main effect of target axis (vertical vs. horizontal; see Figure 3). Importantly, the bias to orient to the vertical axis in Experiments 1, 3, and 4 confirms the notion that the object-/head-centered cuing effect along the horizontal axis is not under strategic control.

One of the more striking aspects of the object-/head-centered gaze-cuing effect is that the result is rather surprising, since it appears to be a maladaptive shift of attention. That is, it is surprising that the inhibitory neural mechanism, described by Perrett and colleagues (Perrett, Hietanen, Oram, & Benson, 1992; Perrett et al., 1985) seemingly fails to prevent orienting of attention to anywhere other than to the actual direction of gaze. Perrett et al. (1992) showed that the cells in the superior temporal sulcus that code for the orientation of the head are actively inhibited when the eyes are visible. That is, since eyes are a more reliable cue to the actual direction of attention, the representation of the orientation of the head is suppressed, to avoid an incorrect inference regarding the direction of social attention. Although the head orientations studied by Perrett and colleagues were those indicating a direction of attention, the present procedure is also an example of a situation in which such an inhibitory mechanism acting on object-/head-centered coding would be valuable.

Nevertheless, the object-centered effects were present, and in one case (Experiment 3), the "maladaptive," object-centered effect was numerically larger than the intuitive, simple, and (in terms of social interactions) appropriate shift of attention to the actual direction of gaze. Although both effects were small in Experiment 3, this observation demonstrates that object-centered representations can have a significant impact on spatial attention, even in a situation in which it would seem not to serve one well to shift attention in such a manner. Furthermore, this experiment provides further tentative evidence that a mental rotation process does indeed underlie the object-centered cuing effect. The uniform reduction in the two cuing effects in Experiment 4, due to the reduction in cue–target SOA, again lends provisional support to the hypothesis not only that these two effects are simultaneously present, but also that they may be evoked following a similar time course.

The present results certainly support the findings of Langton (2000; Langton & Bruce, 1999, 2000) and of Hietanen (1999, 2002), who have shown that head orientation (looking up or down, or left or right) and gaze-cuing effects are encoded in parallel and can compete for the control of attention. However, in the present procedure, the head orientation itself is not a cue to social attention, since the head is rotated isometrically. To resolve the paradox of orienting attention to locations that are not directly looked at, we might speculate that during social interactions, it would be useful to predict where a person might look in the near future. Therefore, in the present experiments, what may be computed is where the person will be looking when the head orientation returns to the normal upright position that dominates virtually all social interactions.

In conclusion, these findings have implications for how social gaze is encoded by the attention system. It seems an important feature of a joint attention system that under certain circumstances, attention can orient to places other than the looked-at location, despite the existence of neural mechanisms that should prevent such orienting. In addition to the implications for the direction of social attention through gaze cues, this finding will have implications for the study of attention in general. That is, the effects will surely generalize to other directional stimuli that produce effects similar to gaze cues, such as arrows (e.g., Bayliss, di Pellegrino, & Tipper, 2005; Bayliss & Tipper, 2005; Hommel, Pratt, Colzato, & Godijn, 2001; Tipples, 2002) or directional word stimuli (Hommel et al., 2001), as long as they are presented in a context that affords mental rotation. Although the temporal dynamics of the object-centered and spatial-cuing effects of these gaze-cuing effects require further investigation, the observation of simultaneous cuing in two frames of reference demonstrates two things. First, it confirms that gaze-evoked shifts of attention have properties that are similar to those of other types of attention shifts (e.g., Egly et al., 1994; Tipper et al., 1999). Second, these cuing effects might reflect actual (space-based) and potential (object-/head-centered) attention states of an observed person.

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NOTE

1. Here, we mean that the two effects, spatial and object-centered cuing, were observed following perceptually identical cues. Whether these attention shifts have the same time course is a matter for further study, but this experiment conclusively demonstrates that in this procedure, attention is operating in dual frames of reference. That is, at the moment of target presentation, both spatial and object-centered attentional orienting is observed. Experiments 3 and 4 engaged these issues further.

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