Running Head: VERTICAL GAZE DISCRIMINATION

Asymmetry in Gaze Direction Discrimination between the Upper and Lower Visual Field

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Abstract

Previous research has shown that gaze direction can only be accurately discriminated within parafoveal limits (~5° eccentricity) along the horizontal visual field. Beyond this eccentricity, head orientation seems to influence gaze discrimination more than iris cues (Palanica & Itier, 2015). The present study examined gaze discrimination performance in the upper- (UVF) and lower visual fields (LVF), and whether head orientation affects gaze judgments beyond parafoveal vision. Direct and averted gaze faces, in frontal and deviated head orientations, were presented for 150 ms along the vertical meridian while participants maintained central fixation during gaze discrimination judgments. A striking difference was seen between gaze-head congruent and incongruent conditions. Gaze discrimination was above chance level at all but one eccentricity for the two congruent conditions. In contrast, for the incongruent conditions, gaze was discriminated above chance only from –1.5° to +3°, with an asymmetry between the UVF and LVF. Beyond foveal vision, response rates were biased toward head orientation rather than iris eccentricity, occurring in the LVF for both head orientations, and in the UVF for frontal head views. Faces in front view with a direct gaze elicited the fastest responses and above chance accuracies at all eccentricities, supporting a special status for this particular stimulus. These findings suggest that covert processing of gaze direction involves the integration of eyes and head cues, with congruency of these two social cues driving response differences between the LVF and the UVF.

Keywords: gaze discrimination, face perception, spatial attention, covert attention

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Introduction

The direction of a person's eye gaze may be used to signal focus of attention, convey information, or communicate intentions and desires (Baron-Cohen et al., 1997; Kleinke, 1986). For instance, someone's direct gaze may control social interaction through eye contact (Kleinke, 1986), while someone's averted gaze may orient the focus of attention to some other specific place or person (Driver et al., 1999; Friesen & Kingstone, 1998; see Frischen et al., 2007 for a review). Being able to accurately perceive others' gaze direction is important for proper social interactions, and plays a fundamental role in nonverbal communication and social cognition (Itier & Batty, 2009).

Numerous studies have shown that gaze perception involves the integration of iris position with head orientation cues (Anstis et al., 1969; Kluttz et al., 2009; Langton, 2000; Langton et al., 2004; Otsuka et al., 2014, 2015; Ricciardelli & Driver, 2008; Seyama & Nagayama, 2005; Shirama, 2012; Todorović, 2006, 2009; Wollaston, 1824). People are fairly accurate at discriminating whether another person is looking directly at them or away from them when the face is directly fixated (Gamer & Hecht, 2007; Loomis et al., 2008; Palanica & Itier, 2015). However, gaze discrimination accuracy drops rapidly when the stimulus is presented outside of foveal vision[1] (Burton et al. 2009; Florey et al., 2015; Loomis et al., 2008; Palanica & Itier, 2015; Yokoyama et al., 2014), and a recent study has shown that head orientation increasingly biases gaze judgments with increasing horizontal eccentricity, starting at about 3° (Palanica & Itier, 2015). In that study, individual faces were presented in frontal or deviated views with a direct- or an averted gaze at various horizontal eccentricities while participants

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[1] Vision scientists discriminate between central vision, which encompasses foveal vision (~1° eccentricity on either side of fixation) and parafoveal vision (1-5° eccentricity), and peripheral vision, which encompasses everything beyond parafoveal vision (Calvo & Lang, 2005; Larson & Loschky, 2009).

focused on a central fixation and performed a gaze discrimination judgment using a two-button press. Results revealed that by 3° of eccentricity, participants responded “direct gaze” more often when the face was in front view, and responded “averted gaze” more often when the face was in deviated view, and this effect increased as the face was presented farther away from fovea, leading to chance performance by 6° (Palanica & Itier, 2015). The study also revealed that the direct-gaze-front-head-view combination elicited the fastest and most accurate performances overall. More recently, Florey et al. (2015) presented faces centrally and peripherally (6° or 9° horizontal eccentricity), with different head orientations and iris positions, which participants categorized as either looking directly toward them, to the left, or to the right. The researchers found that forward-facing heads in the periphery were categorized as “direct-looking” over a wider range of iris positions than when viewed centrally. By contrast, for deviated heads in the periphery, the number of “direct” responses decreased significantly compared to “left” or “right” gaze judgments, supporting the view that head orientation influences gaze judgments in the horizontal periphery (Palanica & Itier, 2015).

Whether similar results could be found in the vertical periphery is currently unknown but legitimate to investigate in view of the known perceptual differences between the vertical and horizontal axes. First, the binocular visual field in adult humans is roughly elliptical in shape and measures 200° horizontally but only 130° vertically at its limits (Harrington, 1971). Moreover, it has been shown that performance in visual discrimination tasks is typically better along horizontal than vertical eccentricities (Cameron et al., 2002; Carrasco et al., 2004; Carrasco et al., 2001). The majority of such research examining visual discrimination in the periphery has used simple visual tasks with basic stimuli, such as discriminating the orientation of a Gabor patch (a sinusoidal grating embedded in a Gaussian window). However, human faces are biologically and socially significant, and the bulk of the literature supports the idea that these meaningful stimuli are processed differently than other basic stimuli or even other visual objects (e.g., Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001). Gaze perception also relies on complex and specialized brain networks (Itier & Batty, 2009), and might enjoy a special processing status given its importance in social cognition. It is thus possible that face-related perceptual judgments such as gaze direction discrimination are immune to this horizontal/vertical asymmetry. Additionally, despite the wider horizontal than vertical visual field range, the limits of central vision (< 5°) are considered similar in the horizontal and vertical axes (Larson & Loschky, 2009). Thus, gaze discrimination along vertical eccentricities might be accurate within the same central vision range as for horizontal eccentricities (Burton et al., 2009; Loomis et al., 2008; Palanica & Itier, 2015; Yokoyama et al., 2014).

Alternatively, since perceived gaze direction usually takes place along the horizontal plane, with peoples' eyes rotating in the left and right directions compared to the direct gaze reference point, it is also possible that gaze perception is more efficient in the horizontal than in the vertical axis. Thus, the range of accurate gaze discrimination in vertical eccentricities could be smaller than in horizontal eccentricities. Moreover, it is also possible that gaze discrimination is different between the upper and lower visual fields. It has been proposed that the visual field may be divided into peripersonal (close to the body) and extrapersonal (beyond reaching distance) space (Previc, 1990, 1998), and visual scene perception is usually carried out in extrapersonal space, which may be more efficient in the upper visual field (reviewed in Danckert & Goodale, 2003). Recent studies using face stimuli also suggest that some face-related judgments, such as sex categorization, are more efficient in the upper than in the lower visual field (e.g., Quek & Finkbeiner, 2014, 2016), and the same might be true of other face-related perceptual judgments, including gaze discrimination. However, very little research has been performed in this area, and it remains unknown whether an upper/lower asymmetry exists for gaze discrimination, how strong it might be, or at what eccentricity it might occur.

To our knowledge, only two studies have investigated gaze discrimination in the vertical dimension. Burton et al. (2009) presented distractor faces between 3.6° and 4.9° of vertical eccentricity and showed that their gaze direction did not influence rapid directional (left–right) gaze judgments of a target face presented centrally, concluding that gaze direction cannot be perceived outside the focus of attention. However, the central target competed for attention, which may have impacted gaze processing outside of foveal vision[2], and the eccentricities used were limited. More recently, Yokoyama et al. (2014) used a dual-task paradigm in which participants discriminated a set of centrally-presented letters in addition to discriminating the gaze direction of a face (measuring 3° x 3°) presented parafoveally along the edge of an imaginary rectangle (measuring 8° x 10°). The researchers showed that direct gaze faces could be perceived without focused attention, while averted gaze perception required focused attention. However, Yokoyama et al. (2014) only used front-view faces, and did not measure reaction times so the speed at which gaze was processed outside of foveal vision could not be determined. Thus, it remains unknown whether covert gaze discrimination judgments can be made with faces presented in the upper and lower visual fields while no central item competes for attention. The eccentricity limits at which this discrimination can be made, and how head orientation affects these judgments, also remain unknown.

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[2] Covert attention is defined as paying attention without moving the eyes, while overt attention is defined as selectively processing one location over others by moving the eyes to focus at a desired location. Participants can thus attend covertly to an object in the periphery even while they are fixated on something else (i.e., when they have another object in fovea).

Despite the crucial role that gaze direction plays in social cognition, research in this area remains scarce. The current study thus aims at determining how well the direction of gaze could be discriminated in the vertical periphery, and what role head orientation plays in this judgment. If gaze perception is as accurate in the vertical as in the horizontal dimension, then we would expect accuracy limits to be within central vision (~5°), as shown with horizontal eccentricities (Burton et al., 2009; Loomis et al., 2008; Palanica & Itier, 2015; Yokoyama et al., 2014). Following up on our previous work, we would then expect that beyond 5° of eccentricity, a bias toward using head orientation cues for gaze judgments would be seen (Palanica & Itier, 2015). In fact, a gaze-head congruency effect should occur just beyond foveal vision, such that direct gaze faces should be discriminated faster and more accurately with a frontal head orientation, and averted gaze faces should be discriminated better with a deviated head orientation. However, within foveal vision, when target faces are directly fixated, direct gaze faces should be discriminated faster than averted gaze faces regardless of head orientation (Palanica & Itier, 2015), which would be in line with visual search studies showing faster discrimination of direct gaze over averted gaze (the so-called "stare-in-the-crowd effect"; e.g., Conty et al., 2006; Doi & Ueda, 2007; Doi et al., 2009; Senju et al., 2005; Shirama, 2012; von Grünau & Anston, 1995). Alternatively, if gaze discrimination follows the horizontal dominance and perceptual asymmetry seen with other basic stimuli and other facial judgments (e.g., Carrasco et al., 2001; Quek & Finkbeiner, 2014, 2016), we might expect reduced eccentricity limits for accurate gaze discrimination with faces presented along the vertical meridian, as well as better discrimination in the upper than in the lower visual field.

Methods

Participants. Twenty one undergraduate students from the University of Waterloo (UW) (13 females, 8 males; 19 right-handed; age range 18-25 years, $M = 20.6$) participated in the study for course credit. All participants had normal or corrected-to-normal vision, and signed informed written consent. This study was approved by the UW Research Ethics Board, and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Stimuli. Greyscale facial photographs of four male and four female identities with neutral expression were used from George et al. (2001). Each individual was photographed with a frontal head orientation (head pointed straight towards the camera), and with the head oriented 30° to the right side (deviated heads). Their eyes were looking straight ahead (direct gaze) or 30° to the right side (averted gaze), creating four original pictures that were then mirror-reversed to yield 8 pictures of the same identity as follows: 2 frontal direct gaze, 1 frontal left-averted gaze, 1 frontal right-averted gaze, 2 deviated direct gaze, 1 deviated left-averted gaze, and 1 deviated right-averted gaze. Thus, in each head condition, faces had a direct gaze (i.e., eyes looking straight ahead) and an averted gaze (i.e., eyes looking 30° to the left and right sides). Each face photograph (4.4° × 6.6°) contained an eye region that subtended 2.5° horizontally by 0.5° vertically for frontal heads, and 2.2° horizontally by 0.5° vertically for deviated heads. The iris diameter of all face stimuli subtended 20 minutes of arc. The eye region of all face stimuli was in the centre, along the horizontal midline of the photographs, so that each face stimulus presentation displayed the eye region with equal visual angle increments in the upper and lower visual fields across eccentricities. Examples of the face stimuli used in the current study are shown in Figure 1 (however, see George et al., 2001 for examples of the actual face stimuli[3]).

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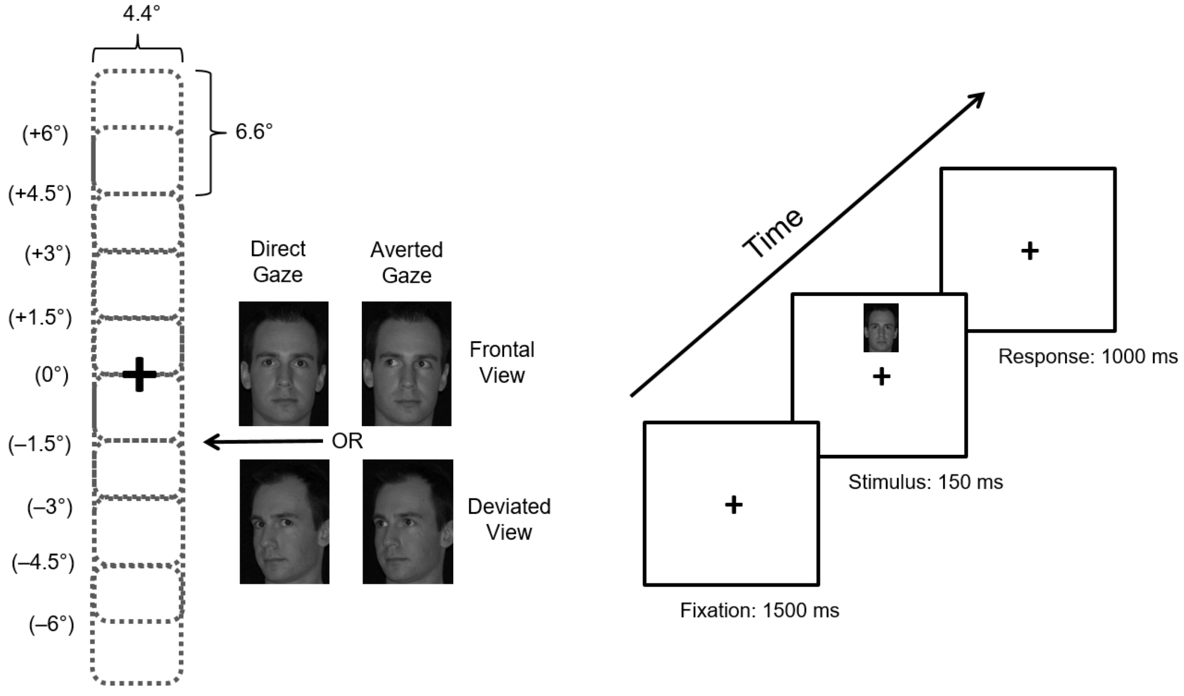
[3] We did not have authorization to publish the actual face photographs.



A. Stimulus Presentation.

B. Example Trial Sequence.

Figure 1. Schematic representation of stimulus presentation (A), and example trial sequence (B). The dotted rectangles are shown to represent all of the 9 possible locations of stimuli presentation, but were invisible during trials. Negative (–) eccentricities represent target positions below fixation, while positive (+) eccentricities represent those above fixation. The fixation cross was shown during the entire duration of each trial to keep participants' fixation focused. Please also note that for averted gaze faces, both left- and right-looking faces were used, and for deviated head views, both left- and right-facing head orientations were used.

Apparatus. Stimuli were presented on a Viewsonic PS790 CRT 19-inch colour monitor with an Intel Corel 2 Quad CPU Q6700; the screen resolution was 1024 x 768 pixels, with a refresh rate of 60 Hz. Participants' initial fixation and possible eye movements were monitored with a remote EyeLink 1000 (SR Research) eye-tracker at a sampling rate of 1000 Hz. Participants viewed stimuli at a distance of 70 cm, which was maintained by a chin and forehead rest.

Procedure. Each trial began with the presentation of a fixation cross (1° x 1°) for 1200 ms. The face was presented for 150ms only after participants fixated on the cross for 300 ms ("fixation trigger", see Figure 1). Regardless of whether a response was made or not, the next trial began 1000 ms after stimulus presentation. Participants were instructed to remain fixated on the cross and to not move their eyes during the entire experiment. Faces were randomly presented in one of 9 possible locations along the vertical axis, with their centre positioned from –6° (below fixation) to +6° (above fixation) visual angle vertically, in 1.5° increments. Using their index and middle fingers of their dominant hand, participants discriminated between direct and averted gaze faces as quickly and as accurately as possible, by pressing the *b* or *m* keys of a standard keyboard. Gaze discrimination responses (i.e., *direct* or *averted*) for each keyboard button (i.e., *b* or *m*) were counterbalanced across participants. Before the experimental session, participants familiarized themselves with the stimuli and task by performing 9 practice trials (one for each possible stimulus location).

Trials were evenly divided into the four possible gaze-head combinations: frontal head with direct gaze (DG), frontal head with averted gaze (AG), deviated head with DG and deviated heads with AG. For each of the 9 eccentricities, there were a total of 128 trials (32 trials x 4 gaze/head combinations), for a total of 1152 trials divided into 8 blocks of 144 trials each. Head orientation, gaze direction, and eccentricity presentation were randomized within each block. Rests were given between blocks and the experiment lasted about 70 minutes. After the practice trials, all participants verbally confirmed that they could differentiate between DG and AG for each head orientation. This was to ensure that participants were aware that gaze direction *and* head orientation were both changing independently, and at random, for each face stimulus in each potential target position.

Data Analysis

For each eccentricity, left- and right-averted gaze directions were combined (preliminary analyses revealed no significant differences between left- and right-averted gaze targets across eccentricities). Only correct responses were used for RT analysis. Trials in which participants moved their eyes away from fixation were discarded (i.e., when more than one fixation was recorded, 2.9% of the total data). RTs below 150 ms (0.1% of the total data) or above 2.5 standard deviations (9.3% of the total data) from the mean of each gaze-head condition per eccentricity were eliminated. RTs exceeding 1000 ms were recorded as a miss (7.2%).

Because there were four stimulus categories (DG frontal head, AG frontal head, DG deviated head, AG deviated head), we could calculate accuracy for each of these four conditions, despite the fact that the same two response buttons were used. For a given head orientation, when a DG stimulus was presented at a given eccentricity, participants could respond DG (hit), AG (error), or simply not respond at all (miss). When an AG stimulus was presented, participants could respond AG (hit), DG (error), or not respond (miss). For each individual eccentricity, accuracy was calculated separately for each gaze direction and head orientation as the number of correct responses made minus the number of errors, out of the total number of trials for that gaze-head condition at that eccentricity (i.e., (hits – errors) / (hits + errors + misses)). A 0% accuracy rate to a particular condition indicated chance level performance.

To examine the hypothesis that participants were relying more on head orientation for gaze judgments beyond fovea, as we previously found with presentations along the horizontal axis (Palanica & Itier, 2015), we also calculated the overall percentage of DG button presses made for each head orientation, regardless of whether participants were correct or not, out of the total number of button presses for that head orientation (i.e., DG responses / (DG responses + AG responses)). In this two-button press discrimination task, a 50% DG response rate (in a particular head orientation) indicated an equal amount of DG button presses and AG button presses. Thus, a percentage of DG responses that is significantly higher than 50% indicates that the DG button was pressed more often than the AG button, while a percentage of DG responses that is significantly lower than 50% indicates that the AG button was pressed more often than the DG button (e.g., a 70% DG response rate automatically means a 30% AG button press response rate). This measure was used as a proxy for a bias toward responding "direct gaze" whenever the face was in front view, and a bias to respond "averted gaze" whenever the face was in a deviated head view.

RTs and accuracy were analyzed using a 2 (head orientations: front-view, deviated view) by 2 (gaze directions: DG, AG) by 9 (eccentricities: –6°, –4.5°, –3°, –1.5°, 0°, +1.5°, +3°, +4.5°, +6°) repeated measures ANOVA. Proportions of DG button presses were analyzed using a 2 (head orientations) by 9 (eccentricities) repeated measures ANOVA. The Greenhouse-Geisser degrees of freedom correction was used wherever the Mauchly's test of sphericity was significant (i.e., sphericity assumption violated)[4].

For RTs and accuracy, planned paired sample (two-tailed) *t*-tests were performed comparing DG versus AG within each head orientation at each eccentricity. Paired sample *t*-tests were also used to compare frontal versus deviated head orientations within each gaze direction at each eccentricity. The Bonferroni correction was used for these planned *t*-tests comparing the two gaze directions and two head orientations across the 9 eccentricities (i.e., 36 comparisons), making *p* value significance thresholds at .0013. The eccentricities at which gaze was

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[4] For clarity, only the adjusted *p*-values were reported and the original degrees of freedom kept.

discriminated above chance level was computed by comparing the accuracy for each gaze direction in each head orientation to chance level at each eccentricity using one-sample *t*-tests (two-tailed, with a test value of 0), with the same adjusted *p* values (.0013).

For DG button presses, paired sample (two-tailed) *t*-tests were performed comparing frontal versus deviated head orientations at each eccentricity. One-sample *t*-tests (test value of 50) were also performed for each head orientation at each eccentricity to examine the bias of responding with one or the other button). The Bonferroni correction was used for all these planned *t*-tests comparing the two head orientations across the 9 eccentricities (i.e., 18 comparisons), making *p* value significance thresholds at .0028.

Results

Reaction Times. For RTs (Figure 2A), the main effects of eccentricity ($F(8, 160) = 32.37$, $MSE = 4782.45$, $p < .001$, $\eta_p^2 = .62$), gaze direction ($F(1, 20) = 8.75$, $MSE = 8227.99$, $p < .01$, $\eta_p^2 = .30$), and head orientation ($F(1, 20) = 67.06$, $MSE = 3350.62$, $p < .001$, $\eta_p^2 = .77$) were strongly modulated by interactions between eccentricity and gaze direction ($F(8, 160) = 6.17$, $MSE = 1609.39$, $p < .001$, $\eta_p^2 = .24$), eccentricity and head orientation ($F(8, 160) = 3.21$, $MSE = 927.47$, $p < .01$, $\eta_p^2 = .14$), gaze direction and head orientation ($F(1, 20) = 54.35$, $MSE = 5023.39$, $p < .001$, $\eta_p^2 = .73$), and eccentricity by gaze direction by head orientation ($F(8, 160) = 3.03$, $MSE = 1419.26$, $p < .05$, $\eta_p^2 = .13$). This complex pattern reflected the fact that RTs increased steadily overall with eccentricity for all conditions except for the AG deviated head condition, which remained at a constant level for positive eccentricities (i.e., in the upper visual field). While DG elicited shorter RTs than AG, this effect was seen only in the front head condition, with the DG-front-view condition eliciting the shortest RTs overall. Planned comparisons performed at each eccentricity confirmed that RTs were faster for DG than AG for frontal heads from –6° to +3° (planned *t*-tests, all *p* < .001), while no gaze differences were found for deviated heads at any eccentricity. RTs were also faster for DG frontal than DG deviated heads across all eccentricities (all *p* < .001), while no differences were found between AG frontal and AG deviated heads.

These results support a gaze-head congruency effect, but only for frontal heads; DG faces were discriminated faster than AG faces for frontal heads. In contrast, no congruency effect in favour of AG for deviated heads was found (no significant gaze differences). These results also do not support our hypothesis that, at 0° eccentricity, DG should be discriminated faster than AG regardless of head orientation (Palanica & Itier, 2015). DG was discriminated faster than AG at 0°, but only for frontal heads.

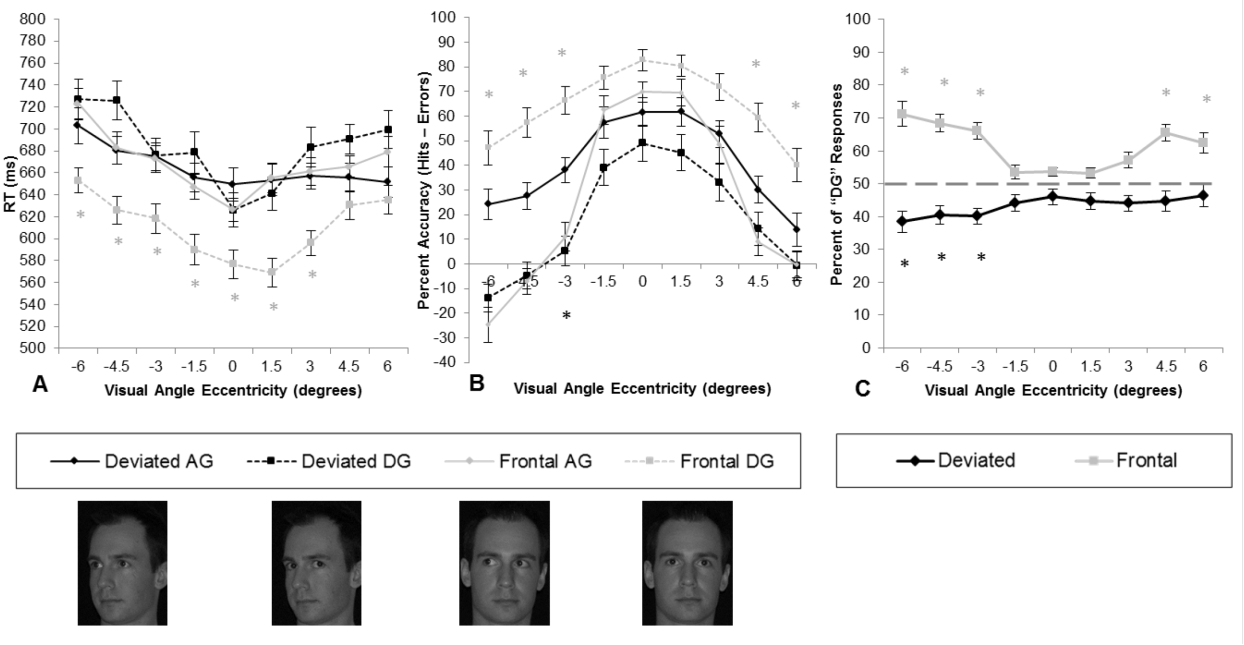

Figure 2. (A) Mean RT responses, and (B) mean percent accuracy (hits – errors), as a function of gaze direction (Direct Gaze (DG), Averted Gaze (AG)), head orientation (deviated, frontal), and eccentricity (from –6° to +6°), with standard errors shown with each mean. Grey stars represent significant DG versus AG comparisons for frontal heads; black stars represent significant DG versus AG comparisons for deviated heads (**p* < .001). Note that 0% accuracy means chance level performance. (C) Percent of "DG" responses for each head orientation (deviated or frontal

view) and eccentricity (with standard errors shown with each mean), regardless of whether the response was correct or incorrect. Grey stars represent response rates for frontal heads that are significantly greater than 50% ($p < .0028$), indexing a bias to respond “DG” whenever the face was in frontal view; black stars represent response rates for deviated heads that are significantly lower than 50% ($p < .0028$), indexing a bias to respond “AG” whenever the face was in deviated view. For all graphs, negative visual angles indicate target positions in the lower visual field, while positive visual angles indicate target positions in the upper visual field.

Accuracy. For accuracy rates (Figure 2B), main effects of eccentricity ($F(8, 160) = 101.18$, $MSE = 427.62$, $p < .001$, $\eta_p^2 = .84$) and head orientation ($F(1, 20) = 77.03$, $MSE = 615.91$, $p < .001$, $\eta_p^2 = .79$) were modulated by interactions between eccentricity and head orientation ($F(8, 160) = 2.88$, $MSE = 193.30$, $p < .05$, $\eta_p^2 = .13$), eccentricity and gaze direction ($F(8, 160) = 3.75$, $MSE = 417.50$, $p < .05$, $\eta_p^2 = .16$), head orientation and gaze direction ($F(1, 20) = 38.88$, $MSE = 4456.84$, $p < .001$, $\eta_p^2 = .66$), and eccentricity by head orientation by gaze direction ($F(8, 160) = 15.37$, $MSE = 342.67$, $p < .001$, $\eta_p^2 = .44$). In general, higher accuracy was found for DG frontal heads followed by AG deviated heads (the two congruent conditions), and then by AG frontal heads followed by DG deviated heads (the two incongruent conditions). Accuracy decreased steadily with eccentricity, but there was a sharper decrease for the incongruent than the congruent conditions, especially in the lower visual field. For the two congruent conditions, performances were above chance level (i.e., > 0%) at every eccentricity for DG frontal heads (one-sample t-test, $p < .0013$), and at every eccentricity, except at +6°, for AG deviated heads ($p < .0013$). In contrast, for the two incongruent conditions, performances were not significantly different from chance level from –6° to –3°, and from +4.5° to +6°, (all $p > .0013$). In other words, accurate discrimination of gaze only occurred between –1.5° and +3° for the incongruent gaze-head conditions. For frontal heads, higher accuracy was found for DG than for AG faces from –6° to –3°, and from +4.5° to +6° (planned t-tests, all $p < .001$, grey stars in

Figure 2B). For deviated heads, higher accuracy was found for AG than for DG faces only at –3° ($p < .001$, black star in Figure 2B). Additionally, higher accuracy was found for DG frontal than DG deviated heads at all eccentricities (all $p < .001$), while higher accuracy was found for AG deviated than AG frontal heads from –6° to –3° (all $p < .001$).

Overall, these results do not support our hypothesis that discrimination accuracy would only occur within the limits of central vision (~5°), as gaze discrimination was above chance up from –6° to +4.5° or even +6° for congruent conditions. However, these findings support a strong congruency effect with lower accuracy for the incongruent gaze-head conditions (i.e., AG frontal and DG deviated faces) than for the congruent conditions (i.e., DG frontal and AG deviated faces), especially beyond foveal vision. In fact, when head and gaze were incongruent, discrimination occurred at an even smaller set of eccentricities than the central vision limits, between –1.5° and +3°. Additionally, these findings support a perceptual asymmetry along the vertical meridian, with accurate gaze discrimination seen at farther eccentricities in the upper than in the lower visual field, as seen with other basic stimuli and facial judgments (e.g., Carrasco et al., 2001; Quek & Finkbeiner, 2014, 2016).

Proportion of DG responses (proxy for response bias). For DG response rates (Figure 2C), main effects of head orientation ($F(1, 20) = 38.39$, $MSE = 802.38$, $p < .001$, $\eta_p^2 = .66$) and eccentricity ($F(8, 160) = 3.93$, $MSE = 75.33$, $p < .05$, $\eta_p^2 = .16$) were found, which were modulated by an interaction between head orientation and eccentricity ($F(8, 160) = 15.07$, $MSE = 59.89$, $p < .001$, $\eta_p^2 = .43$). Beyond fovea, the percent of DG responses increased for frontal head stimuli, while the number of AG responses increased for the deviated head stimuli, although this effect was more pronounced in the lower visual field. More specifically, for frontal heads, DG button presses were significantly *above* 50% from –6° to –3°, and from +4.5° to +6°

(all $p < .0028$), indicating a bias to press "DG" (grey stars in Figure 2C). For deviated heads, DG button presses were significantly *below* 50% from –6° to –3° (all $p < .0028$, black stars in Figure 2C), indicating a bias to press "AG". DG button responses were also higher for frontal than for deviated heads from –6° to –3°, at 0°, and from +3° to +6° (all $p < .0028$).

Thus, beyond central vision, predominantly in the lower visual field, participants pressed the DG button significantly more than the AG button for frontal heads, while they pressed the AG button significantly more than the DG button for deviated heads. This pattern of responses suggests a bias to respond "DG" whenever a face was in front view, and a bias to respond "AG" whenever a face was in deviated view, regardless of the actual gaze direction of the stimulus. This bias was seen in the lower visual field for both head orientations, but only for frontal faces in the upper visual field. It appears that, as gaze direction became more difficult to decipher, participants relied more on head orientation to make gaze judgments (Palanica & Itier, 2015). As they did so, they also increased their errors and thus decreased their accuracy to the incongruent gaze-head conditions, to the point of reaching chance level for those conditions in the lower visual periphery. As this effect was more pronounced in the lower visual field, these results support an asymmetry along the vertical meridian in how much participants rely on head orientation to make their gaze judgement.

Discussion

The present study intended to extend our previous research design (Palanica & Itier, 2015) by investigating: i) whether and to what extent gaze discrimination was possible in the upper and lower visual fields, ii) whether direct gaze was discriminated better than averted gaze in this vertical dimension, and iii) to what extent head orientation affected this gaze discrimination. Faces in frontal or deviated head orientation and with direct or averted eye gaze direction, were presented randomly across nine eccentricities. Fixation was kept centred on a central fixation cross by means of an eye-tracker and participants categorized gaze direction as "direct" (i.e., looking at the participant) or "averted" (i.e., looking away), as fast and as accurately as possible. The design was identical to that used in Palanica and Itier (2015), except that faces were presented across vertical, rather than horizontal, eccentricities, extending just beyond parafoveal vision in the upper and lower visual fields.

In the horizontal dimension, gaze discrimination was within the limits of central vision, that is, ±5° (Burton et al., 2009; Loomis et al., 2008; Palanica & Itier, 2015; Yokoyama et al., 2014). In contrast, in the vertical dimension, the limits of gaze discrimination were at or even beyond those of central vision for congruent conditions but well below central vision limits for the incongruent gaze-head conditions. In addition, in contrast to horizontal eccentricities, results revealed an asymmetry in gaze discrimination between the upper and lower visual fields for incongruent gaze-head conditions. In the upper visual field, the limits of accurate gaze discrimination ranged from +3° for incongruent gaze-head conditions, to +4.5°, and even +6° for congruent conditions (i.e., slightly above central vision). In the lower visual field, accurate gaze discrimination was achieved up to –6° for congruent gaze-head conditions, but only to –1.5° for incongruent conditions. This asymmetry could not be due to an initial fixation bias since participants had to focus on a centred fixation to trigger each trial (gaze-contingent procedure), and all trials where more than one fixation was made were eliminated. Additionally, the eye region of the face stimuli was in the centre of the photographs, so each gaze judgment was made with equal visual angle increments in the upper and lower visual fields.

Studies support a general vertical hemi-field asymmetry in visual perception. One theory proposes that the visual field may be divided into peripersonal (close to the body) and extrapersonal (beyond reaching distance) space (Previc, 1990, 1998). Because extrapersonal space is largely represented in the upper visual field (reviewed in Danckert & Goodale, 2003), processes such as visual search or scene perception, which are generally carried out in extrapersonal space, may be more efficient in the upper visual field. We may attend more to the upper than to the lower visual field to remain vigilant to stimuli in extrapersonal space, as supported by clinical investigations. For example, in patients with unilateral neglect—a disorder typically arising from right parietal lesions in which patients behave as if the left half of their world has ceased to exist—a vertical bias has been described in various visual attention tasks, with behavioural performance being least accurate when targets are located in the lower left visual quadrant compared to the upper quadrants (Cappelletti et al., 2007; Cazzoli et al., 2011; Halligan & Marshall, 1989; Làdavas et al., 1994; Müri et al., 2009; Pitzalis et al., 1997). Some patients with bilateral cortical lesions have also shown neglect to stimuli in the lower visual field in peripersonal space (Butter et al., 1989; Mennemeier et al., 1992; Pitzalis et al., 2001; Rapcsak et al., 1988).

We should note, however, that findings from behavioral studies using a wide variety of experimental paradigms are not always consistent on upper versus lower visual field processing efficiency. For example, for letter or word recognition, and visual search, superior performances have been shown for the upper visual field in some studies (e.g., Fecteau et al., 2000; Heron, 1957; Previc & Blume, 1993; Previc & Naegele, 2001; Shelliga et al., 1997), and for the lower visual field in others (e.g., Carrasco et al., 1998; He et al., 1996; Mishkin & Forgays, 1952; Talgar & Carrasco, 2002). The present study used face stimuli, which are known to be processed and attract attention differently from other visual stimuli (e.g., Bindemann et al., 2005; Langton et al., 2008; Palermo & Rhodes, 2007; Ro et al., 2001). Indeed, it has been shown that during free-viewing of visual scenes, attention is strongly drawn toward faces, even when presented with entire bodies (Fletcher-Watson et al., 2008; Hewig et al., 2008; Palanica & Itier, 2012). Since faces are usually located in the upper visual field (i.e., atop one's body), humans might have learned to be more vigilant toward the upper visual field in order to react to the social cues provided by faces, such as gaze direction or facial expression. Recent event-related potential (ERP) studies support the possible attention bias toward the upper visual field during face perception, with a larger neural response recorded to faces situated mostly in the upper visual field (fixation on the mouth) compared to faces situated more in the lower visual field (fixation on the eyes or nose), as early as 100 ms after face onset (Neath & Itier, 2015; Neath-Tavares & Itier, 2016). Other recent behavioural studies also suggest better processing of faces in the upper visual field as revealed by sex-categorization tasks (Quek & Finkbeiner, 2014, 2016). The present results suggest that a small advantage is seen for gaze discrimination in the upper compared to the lower visual field, but only when gaze direction is incongruent with head orientation. Future research should investigate this possible upper visual field bias for other face judgments.

Similar to our previous study examining gaze discrimination along the horizontal periphery (Palanica & Itier, 2015), in the current study, head orientation influenced gaze judgments beyond foveal vision, especially in the lower visual field. Accuracy decreased with vertical eccentricity, with a steeper decrease for the incongruent gaze-head conditions (i.e., AG frontal and DG deviated faces) than for the congruent conditions (i.e., DG frontal and AG deviated faces). The congruent versus incongruent difference in accuracy was largest in the lower visual field. One explanation for these findings may be a stronger response bias toward head orientation seen mainly in the lower visual field. Indeed, for front view faces, participants pressed the DG button significantly more than the AG button from –3° to –6°, which helps explain the chance level performance seen for the AG frontal head condition (i.e., gaze-head incongruent) by –4.5° and onward. Similarly, for deviated head views, participants pressed the "AG" button significantly more than the "DG" button from –3° to –6°, which helps explain the chance level performance seen for the DG deviated head condition at these same eccentricities. That is, in the lower visual field, significantly more DG button presses were made for frontal heads, and significantly more AG button presses were made for deviated heads. Thus, as gaze became less easily processed in the lower visual field, participants seem to have relied more on head orientation to respond, increasing errors and thus decreasing accuracy for the incongruent gaze-head conditions.

In the upper visual field, performances reached chance level for both front-view and deviated-view incongruent conditions by +4.5°. However, the tendency to respond according to head orientation was seen only for frontal heads, with significantly more DG than AG button presses made from +4.5° to +6°, which helps explain the chance level performance for the AG frontal head condition at these same eccentricities. Although chance level was also reached for the DG deviated head condition by +4.5°, this was not associated with a bias toward responding "AG" more often for the deviated faces.

In terms of gaze discrimination speed, RTs were faster for DG-frontal than for AG-frontal faces across nearly all eccentricities, including the foveal position (0°). In fact, the combination of a frontal head with direct gaze elicited the fastest RTs compared to the other three conditions, similar to our previous study (Palanica & Itier, 2015), and supporting a special status for this particular stimulus in gaze discrimination (see Shirama, 2012, for the suggestion that frontal faces with direct gaze attract attention in visual search studies and drive the "stare-in-the-crowd effect"). For deviated heads, there was no congruency effect in favour of any gaze direction for RTs. Unlike our previous study using horizontal eccentricities (Palanica & Itier, 2015), RTs were not significantly faster for DG than for AG faces in the foveal position for deviated heads. Considering that foveal presentation (i.e., 0°) was the exact same in both vertical and horizontal eccentricity designs, this effect is puzzling and might reflect an influence of presenting stimuli in different visual fields (i.e., a form of experimental context). That is, the simple fact of expecting faces only along the vertical axis might abolish the DG advantage in fovea, and influence participants' vigilance toward extrapersonal space. In turn, this finding suggests that the attention grabbing effect of direct gaze over averted gaze might not be a general rule as initially suggested by the stare-in-the-crowd literature, but rather emerge under specific conditions and contexts.

In conclusion, the current study showed that it is possible to process gaze direction in the upper and lower visual fields, and that the eccentricity limits for gaze judgement depend on the gaze-head congruency. Gaze discrimination could be achieved up to ±6° for DG frontal head stimuli and from –6° to +4.5° for AG deviated heads. For the incongruent conditions, however, discrimination could only be achieved from –1.5° to +3°, a very limited range with a smaller limit in the lower than in the upper visual fields. Responses were also biased toward head orientation rather than iris position beyond foveal vision, and especially in the farthest eccentricities. This bias was seen for both head orientations in the lower visual field, but only for frontal heads in the upper visual field. Thus, across both visual fields, the bias to respond "DG" when the face was in front view was stronger than the bias to respond "AG" when the face was in deviated view. These findings support the notion that processing of gaze direction involves the integration of social cues from the eyes (iris position) and head shape, with a greater weight given to head orientation in the lower than in the upper visual field. Results also support a special status for faces in frontal view with a direct gaze which elicited the fastest response times and the highest accuracies overall, above chance level at all eccentricities. Future research could examine whether the impact of head orientation on gaze perception in the vertical visual field is seen to the same extent in clinical populations known to display deficits in social interactions and in eye contact, such as autism spectrum disorder, social anxiety disorder, and schizophrenia.

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