The Effects of Hemianopia on Perception of Mutual Gaze

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SIGNIFICANCE: Individuals with left hemianopic field loss (HFL), especially with neglect history, may have greater difficulties than individuals with right HFL in judging the direction of another person's gaze.

PURPOSE: Individuals with HFL often show a spatial bias in laboratory-based perceptual tasks. We investigated whether such biases also manifest in a more real-world task, perception of mutual gaze direction, an important, nonverbal communication cue in social interactions.

METHODS: Participants adjusted the eye position of a life-size virtual head on a monitor at a 1-m distance until (1) the eyes appeared to be looking straight at them, or (2) the eyes were perceived to be no longer looking at them (to the right and left).

RESULTS: Participants with right HFL (n = 8) demonstrated a rightward error in line bisection but made gaze judgments within the range of normally sighted controls (n = 17). Participants with left HFL without neglect history (n = 6) made leftward errors in line bisection and had more variable gaze judgments; three had estimates of gaze direction outside the reference range. Four participants with left HFL and neglect history made estimates of gaze direction that were to the right of the reference range.

CONCLUSIONS: Our results suggest that individuals with left HFL, especially with neglect history, may have greater difficulties than individuals with right HFL in compensating for low-level spatial biases (as manifested in line bisection) when performing the more complex, higher-level task of judging gaze direction.

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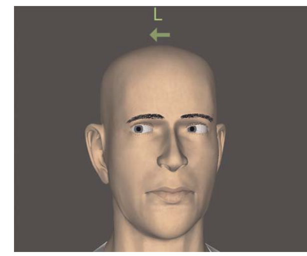

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Hemianopic field loss, the loss of half the field of vision (on the same side, left or right) in both eyes, and hemispatial neglect, impaired attention to one side of space, frequently occur as a result of stroke or traumatic brain injury.[1,2] In line bisection tasks, individuals with hemianopic field loss without neglect typically misperceive the midpoint of a horizontal line to be shifted slightly toward the affected hemifield,[3,4] whereas individuals with hemianopic field loss and neglect misperceive the midpoint to be shifted away from the affected hemifield.[5] These visuospatial misjudgments have been found for purely perceptual tasks,[6–9] as well as visuomotor tasks, such as pointing,[7] moving a hand between two closely spaced obstacles,[7] and using a joystick to keep a moving target at screen center.[10] However, a key question is whether visuospatial misjudgments found in laboratory-based tests actually manifest (or have any relevance) in more complex real-world tasks.

Determining whether someone is making eye contact with you (mutual gaze perception) is a real-world task involving complex spatial judgments. The position of the iris relative to the visible portion of the surrounding sclera provides important cues about gaze direction,[11,12] although other factors, such as head orientation, also play a role.[13] Spatial misjudgments in line bisection tasks may have little consequence, but misperception of where another person is looking may lead to incorrect inferences about the direction of their attention or misunderstanding of a nonverbal social cue.[14,15] However, with the exception of one case report,[16] we have not found any prior studies investigating gaze perception in people with hemianopic field loss. Questionnaires addressing the effects of vision impairment on everyday activities, such as the National Eye Institute Visual Function Questionnaire,[17] often include questions about general difficulties seeing faces or facial expressions but do not specifically ask about difficulties judging gaze direction. It is therefore possible that difficulties with gaze perception might not have been documented in prior studies[18,19] using questionnaires to quantify the effects of hemianopic field loss on self-reported visual function.

To address these gaps in the literature, we investigated the effects of hemianopic field loss on mutual gaze using a computer-based interactive gaze perception task developed by Gamer and Hecht[20] complemented by a short questionnaire[21] specifically addressing difficulties with mutual gaze perception. Gamer and Hecht[20] proposed that people perceive mutual gaze over a range of gaze directions, referred to as the *cone of gaze*, which is at least 10° in diameter. The gaze perception task quantifies both the direction and the width of this cone of gaze (the range of gaze directions over which a person perceives somebody to be making eye contact with him/her). In the current experiment, our aim was to evaluate the effects of hemianopic field loss on mutual gaze in conditions that simulated a real-world social situation. Thus, participants with hemianopic field loss were permitted to use any compensatory eye or head movements they might normally use. We had two main research questions: (1) Would participants with hemianopic field loss without hemispatial neglect demonstrate a contralesional shift in the perceived direction of mutual gaze (i.e., toward the side of their field loss), similar to the bias observed in line bisection,[3,4] subjective straight-ahead,[8,9] and other perceptual tasks[6]? And (2) would head orientation affect straight-ahead gaze judgments of participants with hemianopic field loss in a

TABLE 1. Demographics and characteristics of the participants included in analyses

	Left HFL			
	No neglect	Neglect history	Right HFL	Normal vision
n	6	4	8	17
Age (y)*	58 (52 to 67)	58 (51 to 66)	55 (44 to 62)	57 (49 to 67)
Sex, male, n (%)	4 (67)	3 (75)	6 (75)	9 (53)
Time since visual field loss* (y)	3.3 (1.5 to 15.5)	7.5 (4.0 to 11.5)	8.1 (1.7 to 13.7)	—
Binocular visual acuity (logMAR)*†	0.09 (0.04 to 0.17)	0.10 (0.02 to 0.24)	0.04 (–0.01 to 0.13)	–0.01 (–0.02 to 0.10)

*Median (interquartile range). †Freiburg Acuity Test (http://michaelbach.de/fract/).[23] logMAR = logarithm of the minimal angle of resolution (0.00 = 20/20 and 0.10 = 20/25).

similar manner to that previously reported[20–22] for observers with normal vision?

METHODS

Participants

Twenty-two participants with hemianopic field loss (13 left and 9 right) and 17 age-similar controls with normal vision were recruited. The area of hemianopic field loss was mapped under binocular viewing conditions using kinetic perimetry (Goldmann perimeter, V4e target). Four participants had incomplete hemianopic field loss and were excluded from the analyses. The remainder had complete homonymous hemianopia.[24]

The demographics and vision characteristics of the participants included in the analyses are presented in Table 1, including 10 with complete left hemianopic field loss, 8 with complete right hemianopic field loss, and 17 with normal vision. The most common cause of the hemianopic field loss was stroke (n = 12), followed by traumatic brain injury (n = 4). None of the participants with hemianopic field loss had severe cognitive impairments (all scores ≥24 on the Mini-Mental State Examination[26] or the Montreal Cognitive Assessment[27]), and none tested positive for neglect (Schenkenberg line bisection test[5] and Bells test[28]). However, four participants with left hemianopic field loss reported a history of neglect (confirmed by medical record review). In a prior study, Houston et al.[25] found that spatial biases in collision judgments differed between participants with left hemianopic field loss with and without neglect history. We therefore report the data of the four participants with neglect history separately from that for the rest of the participants with left hemianopic field loss.

Design and Procedure

For all participants, the study consisted of one session. All gaze perception tasks were undertaken binocularly with the habitual spectacle or contact lens correction used by the participant in social situations. The study adhered to the tenets of the Declaration of Helsinki and was approved by the institutional review board at Schepens Eye Research Institute. All participants received a full explanation of the experimental procedures, and written informed consent was obtained with the option to withdraw from the study at any time.

Line Bisection Task

Line bisection performance of participants with hemianopic field loss was quantified using the Schenkenberg line bisection test.[5] The average deviation of the participants' bisection from each line's true center, expressed as percent of the half-line length, was calculated.

Gaze Perception Task

Participants were seated in front of a computer monitor displaying a two-dimensional life-size virtual head (Fig. 1). The test distance was 1 m, which represents a comfortable distance for personal interactions without an intrusion into personal space.[29] A chin rest was used to align the participant to the eye level of the virtual head and maintain the 1-m test distance. A forehead rest was not used so participants could make head movements in the yaw direction if they wanted to. Participants were not given any specific instructions about how to view the virtual head and were permitted to use free eye movements. Thus, participants with field loss were able to use any compensatory eye or head movements they might normally use when viewing another person's face to make judgments about gaze direction in everyday life. Head and eye movements were not recorded.

We used the same virtual head as in the original study by Gamer and Hecht.[20] The eyes were modeled in three dimensions with

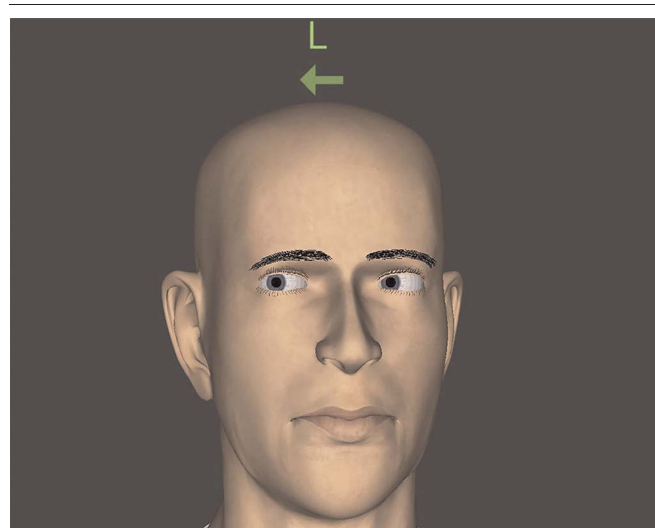

FIGURE 1. The virtual head used in the experiment. In this example, the head is rotated 8° to its left (i.e., to the right of the participant), and the eyes are turned to the left, as seen from the viewpoint of the participant. The green letter and arrow were used to indicate the task for each trial. Here, the participant had to decenter the gaze to the left toward the leftmost edge of the cone of gaze.

appropriate convergence settings such that they moved in synchrony and remained converged at the participant's eye plane at all times (this did result in slightly different angular rotations of the two eyes). Shadows were not cast, simulating the situation of frontal and ambient illumination. The orientation of the virtual head could either be directed straight toward the participant or be turned away by 8° horizontally (left or right; Fig. 1), thus simulating social situations in which the direction of gaze has to be judged when the other person's head orientation is not directly aligned with the gaze. Participants could rotate the eyes of the virtual head in the yaw plane without constraint using a mouse.

In the centering task, participants moved the eyes to the right or to the left from an initial random leftward or rightward gaze offset, respectively, until the virtual head seemed to be gazing straight toward them. For each trial, the angular deviation of the final position of the virtual eyes from the true straight-ahead gaze position was computed. The mean and standard deviation of the final eye positions for the trials in each of the three head orientations (–8° [left], 0° [center], and 8° [right]) were calculated for each participant, providing an assessment of his/her ability to judge straight-ahead gaze.

In the decentering task, the initial direction of the virtual eyes was always centered. Participants then moved the eyes in the specified direction, left or right, until the point where they felt that the eyes were just about to stop looking at them (i.e., stop making eye contact). The width of the range of mutual gaze, the gaze cone, was then computed as the difference between the decentering values to the left and to the right. The means of these gaze cone widths were calculated for each of the three head orientations.

There were 16 trials for each of the three head orientations for both the centering and decentering tasks, giving a total of 96 trials. The trials were randomly interleaved and took approximately 30 to 40 minutes to complete. Participants were given as much time as needed to practice the tasks and become familiar with operating the mouse before experimental data collection commenced.

Questionnaire

To gain insights into whether the participants encountered difficulties with gaze perception in everyday situations, two questions[21] were administered before completing the gaze perception task: "Because of your eyesight, how much difficulty do you have in knowing whether a person is looking at you during social interactions (e.g., conversations)?" "Because of your eyesight, how much difficulty do you have in knowing whether a person is looking at somebody else during social interactions?" In each case, difficulty was rated on a five-point scale (from 1 "no difficulty" to 5 "extreme difficulty"). Participants who reported any difficulty were asked to describe their difficulties.

RESULTS

Line Bisection

As expected,[4] participants with left hemianopic field loss (without neglect history) showed a leftward bias, whereas participants with right hemianopic field loss showed a rightward bias on the line bisection task (medians, –4.9% [interquartile range, –7.2 to –3.8%] and +5.2% [interquartile range, 0.3 to 7.0%], respectively). Participants with left hemianopic field loss and neglect history had a median line bisection error of 4.6% (interquartile range, –3.3 to 10.0%). Participants with normal vision did not complete the line bisection task; however, line bisection errors of normally sighted observers are typically around 1 to 2%.[4,30]

Gaze Perception Task

Straight-ahead Gaze Direction

Our primary research question was whether participants with hemianopic field loss would make lateralized errors in judging straight-ahead gaze direction. To address this, we first examined the distributions of the means of the straight-ahead gaze judgments when the virtual head was centered (Fig. 2). Straight-ahead gaze for participants with normal vision was a median of –0.1°, which did not differ significantly from true straight-ahead, 0.0° (Wilcoxon signed rank test: $z = 0.829$, $P = .41$). The judgments of participants with right hemianopic field loss were all within the range of the participants with normal vision, and the median –0.7° was also not significantly different from 0.0° (Wilcoxon signed rank test: $z = 1.54$, $P = .12$). For the left hemianopic field loss group without neglect, the median straight-ahead gaze direction of –1.0° was also not significantly different from 0.0° (Wilcoxon signed rank test: $z = 0.734$, $P = .46$). However, there was wide between-subject variability, much wider than that for participants with right hemianopic field loss (Fig. 2). There were three participants with left hemianopic field loss without neglect whose mean direction of straight-ahead gaze fell outside the 5th to 95th percentile range of the participants with normal vision; one of these participants judged straight-ahead gaze to be further to the right, and two judged it to be further to the left (Fig. 2). All four participants with left hemianopic field loss and neglect history made straight-ahead gaze judgments that were outside the range of the participants with normal vision, and all were to the right of true straight-ahead, with a median of 3.9° (Wilcoxon signed rank test: $z = 1.83$, $P = .07$).

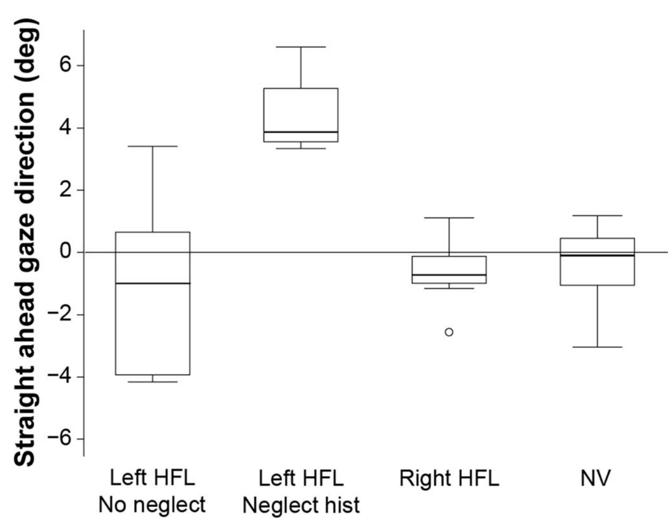

FIGURE 2. Boxplots of the direction of the eyes of the virtual head corresponding to perceived straight-ahead gaze for each of the vision groups when the virtual head was centered. 0° represents true straight-ahead. Negative directions signify gaze to the participant's left and positive to the participant's right. The horizontal line within each box is the median, box length is the interquartile range (IQR), whiskers represent the range of the data within 1.5 × IQR, and open circle indicates outlier within 1.5× to 3 × IQR. HFL = hemianopic field loss; NV = normal vision.

Our second research question was whether the orientation of the virtual head would affect straight-ahead gaze judgments of participants with hemianopic field loss in a manner similar to that previously reported[20–22] for observers with normal vision. To address this, the group medians were plotted for the three virtual head directions (Fig. 3). Qualitatively, it can be seen that head orientation affected all vision groups in a similar manner, with judgments of perceived straight-ahead gaze shifted toward the direction of the virtual head rotation. This effect is expected because the eccentricity of the iris and pupil within the eye socket increased as the head was turned (for details, see the Discussion section). The effect of head orientation was significant, or marginally significant, in each group (Kruskal-Wallis test: $\chi^2 = 5.80$ [$P = .05$] for left hemianopic field loss without neglect, $\chi^2 = 4.89$ [$P = .08$] for left hemianopic field loss with neglect history, $\chi^2 = 15.41$ [$P < .001$] for right hemianopic field loss, $\chi^2 = 31.17$ [$P < .001$] for normal vision). It is also noticeable that the participants with left hemianopic field loss and neglect history consistently perceived straight-ahead gaze to be further to the right compared with the other groups, when the virtual head was orientated to the left and right, as well as straight-ahead (Fig. 3).

Finally, we examined the variability (standard deviation) of the straight-ahead gaze judgments (Fig. 4). There was a significant effect of vision group (Kruskal-Wallis test: $\chi^2 = 12.29$, $P = .007$). Participants with left hemianopic field loss without neglect and participants with left hemianopic field loss with neglect had more variability in their judgments than did the normal vision group (Mann-Whitney test: $z = 2.80$ [$P = .005$] and $z = 2.60$ [$P = .01$], respectively). However, the right hemianopic field loss group did not differ significantly from the normal vision group (Mann-Whitney test: $z = 1.57$, $P = .12$).

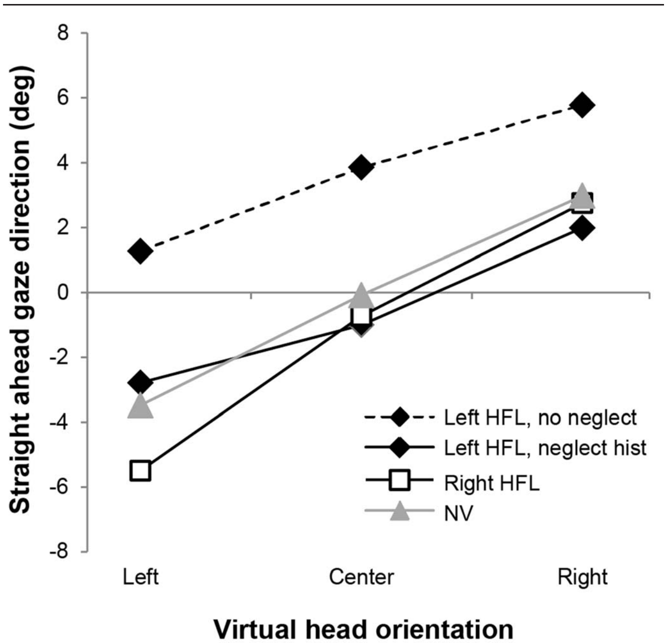

FIGURE 3. Median direction of the eyes of the virtual head corresponding to perceived straight-ahead gaze for each of the vision groups when the virtual head was oriented to the left, center, and right. 0° represents true straight-ahead. Negative directions signify gaze to the participant's left and positive to the participant's right. HFL = hemianopic field loss; NV = normal vision.

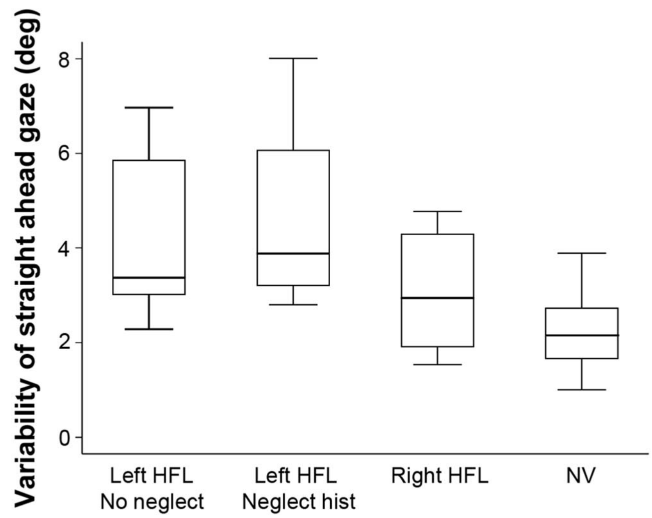

FIGURE 4. Boxplots of variability (SD) in the judgments of the direction of straight-ahead gaze (data pooled across the three head orientations). The horizontal line within each box is the median, box length is the interquartile range, and whiskers represent the range of the data within 1.5 × interquartile range. HFL = hemianopic field loss; NV = normal vision.

Gaze Cone Width

There were no significant group differences in the gaze cone widths (medians, 16.7° for normal vision, 21.9° for left hemianopic field loss without neglect, 24.2° for left hemianopic field loss with neglect, and 27.8° for right hemianopic field loss; Kruskal-Wallis test: $\chi^2 = 4.06$, $P = .25$).

Self-reported Difficulties

Participants with hemianopic field loss reported little to moderate difficulty (median rating, 2.5) in knowing whether a person was looking at them or someone else; by comparison, participants with normal vision reported no difficulty (median rating, 1). For participants with hemianopic field loss, the main difficulties occurred in social or work settings where they were interacting with a group of people (such as at the dinner table or in a work meeting) or were in a crowd (such as in stores, bars, and the subway). The reported difficulties were always related to interacting with people who were out of view, approaching from or sitting on the side of their field loss rather than people within their field of vision. In fact, one participant specifically commented "if they are in my vision I do not have a problem."

DISCUSSION

Our primary research question was whether participants with hemianopic field loss would make lateralized errors in judging straight-ahead gaze direction. Despite exhibiting a rightward bias on line bisection, gaze judgments of participants with right hemianopic field loss did not differ from those made by controls with normal vision. By comparison, participants with left hemianopic field loss exhibited a leftward bias on line bisection and were much more variable in their gaze judgments. However, as a group, they also showed no overall bias, on average, when judging straight-ahead gaze. The only exception was the small group of four participants with left hemianopic field loss and a history of neglect who exhibited a trend for a rightward bias in their judgments.

It is interesting to compare our results with those of a recent investigation[25] of the effects of hemianopic field loss and neglect on spatial judgments in a simulation of another real-world task. Participants judged whether they would have collided with a human figure that appeared at various lateral offsets from the travel path in a simulation of walking along a shopping mall corridor. Consistent with the findings of the current study, participants with right hemianopic field loss and left hemianopic field loss without neglect did not show any spatial bias in collision judgments (despite a bias on line bisection), but participants with left hemianopic field loss with neglect or neglect history demonstrated a rightward bias. Thus, residual neglect, not detected on traditional pencil-and-paper tests, seems to manifest in simulations of more ecological tasks.

So, why might individuals with hemianopic field loss exhibit lateralized biases in some but not all laboratory tasks? One possibility is that paradigms in which people with hemianopic field loss commonly exhibit spatial biases, such as line bisection tasks[3,4] and judgments of visual straight-ahead in a dark room,[8,9] lack relevance to everyday tasks. By comparison, the assessment of mutual gaze or judging potential collisions when walking is highly representative of tasks performed in everyday life and critically dependent on world-referenced coordinates. Thus, it is possible that some individuals with hemianopic field loss may be able to compensate for low-level spatial biases when performing more complex, higher-level tasks with greater relevance to activities of daily living.

There may, however, be other explanations for the lack of lateralized errors in the higher-level gaze judgment task in the current study. First, data from line bisection studies suggest that the linear error in bisection decreases as line length decreases,[31,32] such that at some point the linear error might not be measurable. Thus, visuospatial misjudgments might not be detected when the size of the object is relatively small. This is a relevant consideration given that the width of a typical head (approximately 16 cm) subtends only approximately 9° when viewed from 1 m. Second, presence of macular sparing might be helpful when making gaze judgments, especially in fixed-gaze conditions (e.g., if participants were required to maintain fixation on a specific location on the virtual head). However, to simulate everyday viewing conditions, we used free-gaze conditions to enable participants to use habitual viewing strategies (compensatory eye movements) when performing the gaze perception task. Thus, any effects of macular sparing might be less than would have been the case if fixed-gaze conditions had been used.

Our second research question addressed the effect of head orientation on gaze judgments. The orientation of the head or prominent facial features such as the nose can serve as a potent cue to gaze direction.[13,33–35] Prior studies have reported both repulsive and attractive effects of head orientation on perceived gaze direction. In the current study, head rotation was substantial enough that the eccentricity of the iris was the dominant cue and perceived gaze shifted away from the head direction (a repulsive effect).[35] Thus, when asked to adjust the eyes such that gaze appeared straight-ahead, gaze was shifted in the same direction as the head. In other words, when the virtual head was turned to the left, a slightly leftward gaze direction of the virtual eyes was perceived by the participants as being straight-ahead. Both participants with hemianopic field loss and those with normal vision demonstrated this effect, consistent with prior studies[21,22] which have used the Gamer and Hecht[20] gaze perception task.

In contrast to the results from the gaze perception task, the responses to the brief questionnaire suggested that the participants with hemianopic field loss did have difficulties in social situations when interacting with groups of people rather than a single person. However, the reported difficulties were always related to interacting with people who were out of view, approaching from, or sitting on the side of their field loss rather than judging gaze direction of people within their field of vision.

Brain lesion location may be an important factor in gaze perception. However, in the current study, we did not have access to neuroimaging data to confirm brain lesion locations of the participants. Akiyama et al.[16] reported a patient with left hemianopic field loss with a rare lesion confined almost exclusively to the right superior temporal gyrus who had difficulty maintaining eye contact. In laboratory testing, this patient consistently made errors in discriminating contralesional gaze direction, judging straight-ahead gaze to be to the left of the true position. By comparison, three hemianopic field loss participants without superior temporal gyrus lesions did not show any consistent bias.

In summary, our results suggest that small lateralized errors consistently made by individuals with hemianopic field loss in line bisection tasks do not necessarily translate in a straight-forward manner to the more complex task of judging eye gaze direction. Gaze judgments of participants with right hemianopic field loss were indistinguishable from those of normal vision controls, whereas participants with left hemianopic field loss exhibited much greater variability in their gaze judgments. These findings suggest that individuals with left hemianopic field loss, especially with neglect history, may have greater difficulties than individuals with right hemianopic field loss in compensating for low-level spatial biases (as manifested in line bisection) when performing the more complex, higher-level task of judging gaze direction.

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