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Face processing is enhanced in the left and upper visual hemi-fields

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ABSTRACT

We tested whether two known hemi-field asymmetries would affect visual search with face stimuli. Holistic processing of spatial configurations is better in the left hemi-field, reflecting a right hemisphere specialization, and object recognition is better in the upper visual field, reflecting stronger projections into the ventral stream. Faces tap into holistic processing and object recognition at the same time, which predicts better performance in the left and upper hemi-field, respectively. In the first experiment, participants had to detect a face with a gaze direction different from the remaining faces. Participants were faster to respond when targets were presented in the left and upper hemi-field. The same pattern of results was observed when only the eye region was presented. In the second experiment, we turned the faces upside-down, which eliminated the typical spatial configuration of faces. The left hemi-field advantage disappeared, showing that it is related to holistic processing of faces, whereas the upper hemi-field advantage related to object recognition persisted. Finally, we made the search task easier by asking observers to search for a face with open among closed eyes or vice versa. The easy search task eliminated the need for complex object recognition and, accordingly, the advantage of the upper visual field disappeared. Similarly, the left hemi-field advantage was attenuated. In sum, our findings show that both horizontal and vertical asymmetries affect the search for faces and can be selectively suppressed by changing characteristics of the stimuli.

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Hemi-field asymmetries; face processing; visual search; visual hemi-field; gaze direction

Unequal performance to the same stimuli presented in the left and right visual hemi-fields is believed to reflect the functional differences between the right and left hemispheres (Jordan & Patching, 2004; Martinez et al., 1997; Schiffer et al., 2004). Additionally, a number of studies have proposed that visual processing also differs between the upper and lower visual hemi-fields. In a review, Christman and Niebauer (1997) concluded that vertical asymmetries are at least as strong and prevalent as horizontal asymmetries. In the present study, we focused on face processing because face processing may be susceptible to two known search asymmetries: a left hemi-field advantage for holistic processing of spatial configurations and an upper hemi-field advantage for object recognition in general.

Enhanced holistic processing and face perception in the left visual hemi-field

Face perception relies not only on processing of features but on the spatial relations between those features, which is referred to as holistic or global processing (Richler, Cheung, & Gauthier, 2011). To induce holistic or local processing, a paradigm with large letters composed of smaller letters was introduced by Navon (1977). Because the identities of the large and small letters are independent, conditions with conflicting global and local letters can be created. Sergent (1982) asked observers to determine whether a small or large target letter was present by pressing a key. Large letters defined the target at a global level, while small letters defined it at a local level. Performance was better in the left than in the right hemi-field when global letters had to be detected, whereas the opposite was true for local letters. These behavioural results support the idea that the right hemisphere (i.e., the left hemi-field) is specialized in holistic processing of spatial configurations whereas the left hemisphere (i.e., the right hemi-field) is specialized in local processing of features.

A number of studies suggest that holistic processing and face perception are correlated and show the same

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right-hemisphere specialization. For instance, Darling, Martin, Hellmann, and Memon (2009) demonstrated that individuals with the strongest interference from conflicting global letters in the Navon paradigm were better at recognizing a culprit in a line-up after viewing a crime video. Inversely, individuals unable to recognize faces due to congenital prosopagnosia were more susceptible to interference from conflicting local letters (Avidan, Tanzer, & Behrmann, 2011; Behrmann, Avidan, Marotta, & Kimchi, 2005). Further, imaging studies support the idea that holistic processing in face processing is associated with the right hemisphere, while analytical or part-based processing is associated with the left hemisphere (Hillger & Koenig, 1991; Rossion et al., 2000; Sergent, 1984). For instance, imaging studies have established that the right fusiform region (Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997), the right occipital face area (Gauthier et al., 2000) and the right posterior superior temporal sulcus (Puce, Allison, Bentin, Gore, & McCarthy, 1998) are involved in face processing. Further, Bentin, Allison, Puce, Perez, and McCarthy (1996) found that human faces evoked a negative event-related potential at about 170 ms (the N170 component) that was larger over the right than the left hemisphere. Finally, damage to the right inferior occipito-temporal region often leads to prosopagnosia (De Renzi, 1986; De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994).

A right-hemisphere dominance has also been established for gaze processing within a network including the posterior fusiform gyrus, the parietal lobule, and the inferior and middle temporal gyrus (Wicker, Michel, Henaff, & Decety, 1998). Also, the right superior temporal sulcus was found to code for different gaze directions (Calder et al., 2007). At a behavioural level, the right hemisphere dominance leads to better gaze perception when eyes are displayed in the left hemi-field. An advantage for the left hemi-field has been demonstrated for gaze detection (Conty, Tijus, Hugueville, Coelho, & George, 2006; Palanica & Itier, 2011), gaze discrimination (Ricciardelli, Ro, & Driver, 2002) and gaze cueing (Greene & Zaidel, 2011). Face and gaze processing are mediated by the right hemisphere and a behavioural advantage occurs when stimuli are presented in the left hemi-field.

Nonetheless, face processing also takes place in the left hemisphere but in a manner that is regarded as more analytical or part-based (Bradshaw & Sherlock, 1982; Hillger & Koenig, 1991; Rossion et al., 2000). One way to prevent holistic processing while keeping the same stimuli is to present face stimuli upside-down (Freire, Lee, & Symons, 2000). With inverted faces, analytic processing is forced because featural information (i.e., the size or shape of the eyes, nose and mouth) is conveyed in relative isolation (Carey & Diamond, 1977). That is, face inversion results in a disruption of configural information that depends on face orientation (i.e., the nose is below the eyes), but the processing of featural information does not change (Farah, Tanaka, & Drain, 1995). For instance, face inversion affects the amplitude of the face-sensitive N170 component (Itier, Alain, Sedore, & McIntosh, 2007; Nemrodov, Anderson, Preston, & Itier, 2014). We will make use of the face inversion technique in Experiment 2.

Enhanced object recognition in the upper visual hemi-field

Besides a left hemi-field advantage for faces, object processing was found to be better in the upper than lower visual hemi-field. In behavioural studies, it was shown that localization of a target among distractors (Feng & Spence, 2014), discrimination between words and nonwords (Goldstein & Babkoff, 2001), identification of letters in a trigram (Hagenbeek & Van Strien, 2002) or categorical judgment of spatial relationships (i.e., above vs. below; Niebauer & Christman, 1998) are better in the upper visual field.

At a cortical level, the upper and lower visual hemi-fields are respectively represented on the lower and upper cortical sheets of the occipital lobe. The division in area V1 separates the two vertical hemi-fields within each hemisphere. The lower cortical sheets project more into the ventral stream towards temporal cortex (Fecteau, Enns, & Kingstone, 2000), which is consistent with improved object recognition abilities in the upper visual field, whereas the upper cortical sheets project more into the dorsal stream towards parietal cortex.

In line with enhanced ventral stream processing, Felisberti and McDermott (2013) observed that recognition of faces associated with cooperating behaviours was better when these faces were encoded in the upper hemi-field. In another study, Kessler and Tipper (2004) showed that long-term inhibition induced by a nogo-cue was stronger when the face was presented in the upper hemi-field, or more precisely in the upper-left quadrant. More recently, Palanica and Itier (in press) compared the limits of accurate gaze discrimination between the upper and lower visual field. They found an upper hemi-field advantage, especially with incongruent gaze-head conditions. While these studies combine perceptual and memory processes, there are also studies focusing on short-term priming.

Quek and Finkbeiner (2014a) asked participants to make left or right reaching movements to classify the gender of a target face above or below central fixation. Each target face was preceded by a masked prime face that was either congruent (i.e., same gender as target) or incongruent (i.e., opposite gender as target). The effect of congruency on reaching trajectories occurred earlier for faces presented in the upper hemi-field and the proportion of correct responses was also higher. The advantage for sex categorization of faces in the upper visual field was not caused by an attentional bias because performance to stimuli in the upper visual field was unchanged when endogenous attention was directed to the lower visual field (Quek & Finkbeiner, 2016). Furthermore, Quek and Finkbeiner (2014b) observed an upper hemi-field advantage not only for faces, but also for hands.

In sum, our literature review shows that there are two biases associated with face stimuli. First, a left hemi-field advantage related to holistic processing of spatial configurations and, second, an upper hemi-field advantage related to object recognition (see also Chambers, McBeath, Schiano, & Metz, 1999; Christman & Niebauer, 1997).

Overview of experiments

In the current study, we investigated whether the left and upper hemi-field advantages in the processing of faces also occur in a basic perceptual task. While the left hemi-field bias for faces is well established for perceptual processes (e.g., Bentin et al., 1996), there is only scarce evidence for the upper hemi-field advantage. Previous research has investigated face recognition after retention intervals of minutes (Felisberti & McDermott, 2013; Kessler & Tipper, 2004) or short-term priming by face stimuli (Quek & Finkbeiner, 2014a, 2014b, 2016). While both processes are related to basic perceptual processes (see also Palanica & Itier, 2017), none measures the efficiency of perceptual processes directly. Therefore, we chose to study face perception as a function of visual hemi-field in a visual search task.

In Experiment 1, participants searched for a face with a gaze direction that was different from the remaining faces (see Figure 1A) and signalled its presence or absence. In one block of trials, the target singleton was a straight gaze among averted gazes; in another block, it was an averted among straight gazes. Based on the literature reviewed above, faces in an upright orientation are expected to automatically trigger holistic processing and we therefore anticipate a left hemi-field advantage. Further, as faces represent complex objects, we also expect an upper hemi-field advantage.

In Experiment 2, we changed the orientation of the faces (see Figure 1B). By inverting the faces, we prevented the use of a holistic strategy while keeping the same stimuli and instructions. We expect to cancel the left hemi-field advantage for holistic processing with this manipulation. In contrast, the upper visual field advantage is not specific to faces but extends to object recognition in general, and we therefore expect the vertical asymmetry to persist.

In Experiment 3, we manipulated the saliency of the gaze singleton (see Figure 1C) by decreasing the similarity between target and non-targets. The target was a face with closed among open eyes in one block of trials and the opposite in another block of trials. We expect the advantage of the upper hemi-field to disappear because the decision about the presence or absence of the target can be based on basic visual features and object recognition is not required.

Experiment 4 addressed a possible confounding factor in the vertical asymmetry. Faces in the upper and lower visual hemi-field were equidistant from the fixation cross. However, as can be seen in Figure 1, the eyes in the lower visual field were closer to fixation than the eyes in the upper visual field, which may have contributed to the difference in search times. To balance the distances between stimuli in the upper and lower visual field, only the eye region was displayed (see Figure 1D).

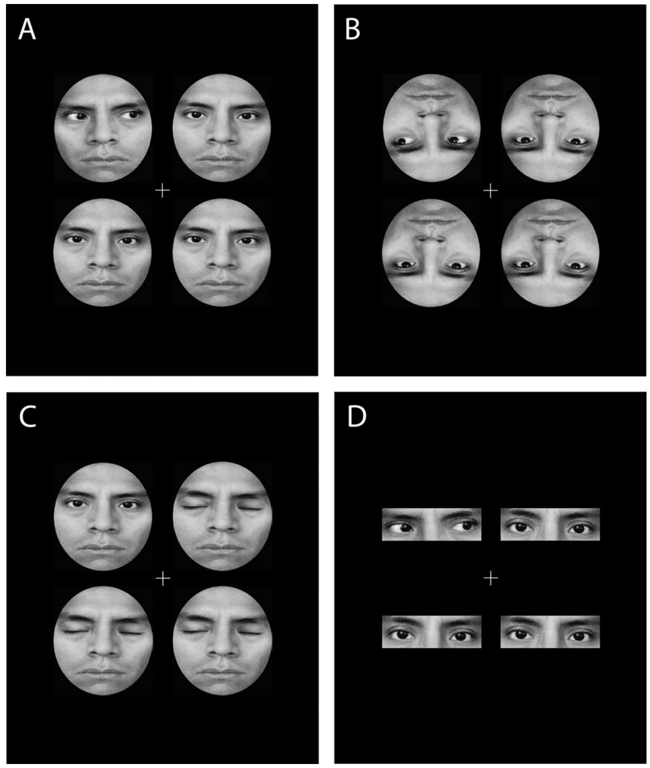

Figure 1. Illustrations of the stimuli in Experiments 1, 2, 3 and 4 are shown in panels A, B, C and D respectively. Stimuli are drawn to scale.

Experiment 1

Methods

Participants

All participants were right-handed undergraduate psychology students at the University of Geneva. Thirty-five participants took part in this experiment, but three subjects were excluded from the analyses because their percentage of correct answers was too low (< 70%). The final sample was composed of 32 subjects (18–37 years, two males). All participants reported normal or corrected-to-normal visual acuity and participated in this experiment for class credit. All procedures were approved by the ethics committee of the "Faculté de Psychologie et des Sciences de l'Education" at the University of Geneva and were in accordance with the 1964 Declaration of Helsinki. Before the experiment, participants gave their written informed consent.

Stimuli and apparatus

The experiment was conducted in a dimly-lit room, participants were seated at a distance of 45 cm from the screen. Participants' head position was stabilized with a chin rest in front of the centre of the screen. The experiment was controlled by Matlab (The MathWorks Inc., Natick, MA) using the Psychophysics Toolbox extensions. Participants' eye movements were monitored by the experimenter from outside the experimental booth with the help of the image of the eye provided by an EyeLink 1000 eye-tracker (SR-Research, Ontario, Canada). Eye movements were not recorded or analysed, but the experimenter assured that participants followed the instructions and intervened if necessary. A grey fixation cross ($0.6° \times 0.6°$) was presented in the centre of the display. Four ovals showing human faces ($4.8° \times 5°$, width × height) were displayed on the corners of a virtual square at an eccentricity of 3.8° where discrimination of gaze orientation is still very good (Palanica & Itier, 2014). The eccentricity was measured from the centre of the fixation cross to the centre of the face stimulus. The faces were drawn from the database of George, Driver, and Dolan (2001). The face items were cropped to exclude the facial contour and hairline. The pictures showed a set of six different individuals (three females and three males). Only one individual was shown on a single trial. In 50% of the trials, the gaze of one of the four faces was different (gaze singleton). That is, an averted gaze appeared among otherwise straight gazes or a straight gaze appeared among otherwise averted gazes.

Experimental task

The task of the participant was to indicate the presence or absence of a gaze singleton by pressing one of two designated keys (left or right arrow) with two fingers of the right hand. Visual error feedback was provided after choice errors, anticipations (RTs < 200 ms) and late trials (RTs > 3 s). Data were collected in two sessions of 512 trials each.

The averted gaze was directed to the right or left in separate groups of participants. That is, one group had to detect a gaze averted to the right ($n = 15$) and the other a gaze averted to the left ($n = 17$).

In one session, observers detected a straight gaze among averted gazes; in the other session, they detected an averted gaze among straight gazes. Session order was counterbalanced across participants. In half of the trials, the gaze singleton was present. On target absent trials, all faces were the same. On average, the duration of one session was 45 min. Before the experiment, participants completed 48 trials in which they were trained to perform the task while maintaining eye fixation at the centre of the screen.

Results and discussion

RTs were trimmed by removing trials with RTs exceeding the condition mean by more than 2 standard deviations, resulting in the exclusion of 2.7% of the trials in addition to the 0.2% excluded by the online criterion of 3 s for late trials. The percentage of correct responses was 87%. Because we were interested in effects of target position, we only analysed target-present trials. Mean RTs as a function of visual quadrant are shown in Figure 2A and the differences between hemi-fields are shown in Table 1.

A 2 (*elevation*: lower, upper) × 2 (*laterality*: left, right) × 2 (*gaze direction*: left, right) mixed-factors ANOVA on RTs in correct trials showed an effect of elevation, $F(1,30) = 13.47$, $p < .001$, $\eta_p^2 = .310$, with shorter RTs to faces in the upper than in the lower

Table 1. Differences between right and left, and between lower and upper hemi-field.

	Left hemi-field advantage		Upper hemi-field advantage	
Experiment	RT (ms)	PE (%)	RT (ms)	PE (%)
1 (right side up)	46*	4*	54*	3*
2 (inverted)	15	2	83*	6*
3 (closed eyes)	27*	4*	1	0.3
4 (cropped eyes)	46*	4*	50*	6*

RT = reaction time, PE = percentage errors.
*significant at 5%.
Positive numbers indicate that there was an advantage for the left or upper hemi-field.

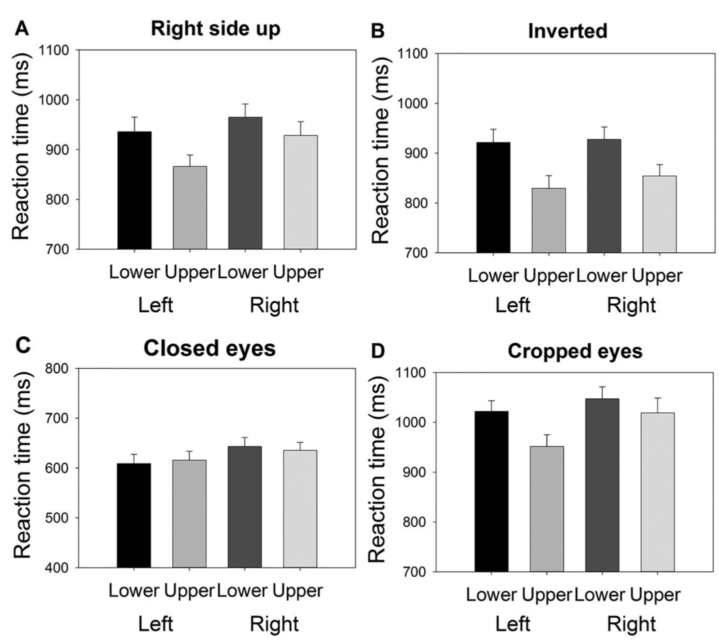

Figure 2. Results from Experiments 1–4 are shown in panels A–D, respectively. Mean reaction time and between-subjects standard error is shown as a function of visual quadrant (lower left, upper left, lower right, upper right). Note that the y-axis in Experiments 1, 2 and 4 starts at 700 ms, whereas it starts at 400 ms in Experiment 3.

visual hemi-field (897 vs. 951 ms) and an effect of laterality, $F(1,30) = 12.06$, $p = .002$, $\eta_p^2 = .287$, with shorter RTs to targets in the left than in the right visual hemi-field (901 vs. 947 ms). We also observed an interaction effect between elevation and laterality, $F(1,30) = 12.23$, $p = .001$, $\eta_p^2 = .290$. Inspection of Figure 2A shows that RTs were shorter in the left than in the right hemi-field and also in the upper than in the lower hemi-field, but that RTs were particularly short to targets in the upper left quadrant. The between-subjects factor gaze direction did not produce significant effects, $ps > .140$.

The same ANOVA as above on the percentage of correct responses showed an effect of elevation, $F(1,30) = 26.42$, $p < .001$, $\eta_p^2 = .468$, with better performance in the upper than in the lower visual hemi-field (90% vs. 87%) and an effect of laterality, $F(1,30) = 17.95$, $p < .001$, $\eta_p^2 = .374$, with better performance to targets in the left than in the right visual hemi-field (90 vs. 86%). The effect of gaze direction was not significant, $p = .195$, and the interaction between elevation and laterality did not reach significance, $p = .271$.

In accordance with our hypothesis, we found that RTs were faster in the left and upper hemi-fields. The interaction between elevation and laterality showed that search for targets in the upper left quadrant of the visual field was particularly efficient.

Experiment 2

In this experiment, we presented the faces upside-down. Inverting faces is a well-known technique to prevent holistic processing (Freire et al., 2000), which we expect to cancel the advantage of the left hemi-field. In contrast, the advantage of the upper hemi-field that we observed in Experiment 1 is not expected to change, because this advantage is not specific to faces but applies to object recognition in general (Christman & Niebauer, 1997).

Methods

Thirty-two right-handed students (one male) from the same pool as above participated in this experiment. Their ages ranged from 17 to 41 years. The methods were as in Experiment 1 except that the face stimuli were turned upside-down (see Figure 1B). Again, one group of participants had to detect a right averted gaze ($n = 16$) and the other a left averted gaze ($n = 16$).

Results and discussion

Applying the same criteria as in Experiment 1 resulted in the exclusion of 2.5% outliers and 0.2% late trials. The overall percentage of correct responses was 83%. Mean RTs as a function of visual quadrant are shown in Figure 2B and the differences between hemi-fields are shown in Table 1.

A mixed-factors 2 (*elevation*: lower, upper) × 2 (*laterality*: left, right) × 2 (*gaze direction*: left, right) ANOVA on RTs in correct trials showed an effect of elevation, $F(1,30) = 110.79$, $p < .001$, $\eta_p^2 = .787$, with shorter RTs to faces in the upper than in the lower visual hemi-field (842 vs. 925 ms), but no effect of laterality, $p = .107$. No other effects were significant, $ps > .152$.

The same ANOVA on percentage of correct responses showed a tendency for laterality, $F(1,30) = 3.20$, $p = .084$, $\eta_p^2 = .096$, with more correct responses to faces in the left than in the right hemi-field (85 vs. 83%), and an effect of elevation, $F(1,30) = 72.56$, $p < .001$, $\eta_p^2 = .707$, with more correct responses to faces in the upper than in the lower visual hemi-field (87 vs. 81%).

To evaluate differences between Experiments 1 and 2, we conducted a 2 (*elevation*: upper, lower) × 2 (*laterality*: left, right) × 2 (*experiment*: 1, 2) mixed-factors ANOVA on RTs. The difficulty of the task was the same with upright and inverted faces, as shown by the non-significant main effect of experiment, $p = .238$. Further, the advantage of the upper hemi-field tended to be larger in the present than in the previous experiment (83 vs. 54 ms) $F(1,62) = 3.39$, $p = .070$, $\eta_p^2 = .052$, which we had not predicted. Finally, the effect of laterality tended to be smaller in the present than in the previous experiment (15 vs. 46 ms), $F(1,62) = 3.14$, $p = .081$, $\eta_p^2 = .048$, which is consistent with our predictions.

The results of Experiment 2 are in line with our hypotheses. By inverting the faces we were able to prevent subjects from using holistic processing, which cancelled the left hemi-field (right hemisphere) advantage. Further, we observed that the advantage of the upper hemi-field tended to be larger with inverted than with upright faces, which we had not predicted. With inverted faces, the eyes were closer to fixation when they were above than below fixation. Potentially, the smaller eccentricity facilitated search in the upper hemi-field in addition to the already existing advantage of the upper hemi-field.

Experiment 3

In this experiment, we manipulated the saliency of the gaze singleton by decreasing the similarity between target and nontargets. The goal of this experiment was to test if vertical asymmetries persist with a much easier task. Blockwise, participants searched for closed among open eyes or for open among closed eyes. Visual inspection of the stimuli suggested that open among closed eyes were more salient than closed among open eyes (compare panels 3A and 3B), which we confirmed by computing saliency maps using standard algorithms (Walther & Koch, 2006). The reason was that the white of the eyes was very salient among closed eyes, but the dark region in closed eyes was less salient among open eyes. For ease of exposition, we refer to "open among closed eyes" as salient target and "closed among open eyes" as non-salient target. Because both targets were easier to detect than the targets in Experiments 1 and 2, we think that object recognition was involved to a lesser degree. In particular, detection of the highly salient target was unlikely to involve object recognition, but could be entirely based on low-level saliency detection. Because the advantage of the upper visual hemi-field concerned object recognition, we expect the vertical asymmetry to disappear, particularly for the highly salient target (for a similar argument, see Quek & Finkbeiner, 2014a). Further, the faces were shown in an upright position, which automatically resulted in holistic processing. Therefore, the enhanced processing of faces in the left hemi-field should prevail, but it may be that holistic processing is also bypassed when low-level features are sufficient to perform the task.

Methods

Fourteen students ranging in age from 18 to 23 years participated. Methods were as in Experiment 1 with the exception that the eyes were open or closed (see Figure 1C). When the eyes were open, the gaze was directed straight ahead. Participants were asked to detect the presence of a face with open eyes among faces with closed eyes (high target saliency) in one session, and the presence of a face with closed eyes among faces with open eyes (low target saliency) in another session.

Results and discussion

Applying the same criteria as in the previous experiments, 1.4% outliers and 0.1% late trials were excluded. The percentage of correct responses was 96%. Mean RTs as a function of visual quadrant are shown in Figures 2C and 3C, and the differences between hemi-fields are shown in Table 1.

A 2 (*target saliency*: low, high) × 2 (*elevation*: lower, upper) × 2 (*laterality*: left, right) repeated-measures ANOVA on RTs in correct trials showed an effect of target saliency, $F(1,13) = 13.78$, $p = .003$, $\eta_p^2 = .515$, with shorter RTs with high than low target saliency (593 vs. 658 ms), an effect of laterality, $F(1,13) = 14.45$, $p = .002$, $\eta_p^2 = .526$, with shorter RTs in the left than right hemi-field (612 vs. 639 ms), but no effect of elevation, $p = .902$. However, elevation interacted with target saliency, $F(1,13) = 11.38$, $p = .005$, $\eta_p^2 = .467$. Instead of the upper hemi-field advantage associated with object recognition, follow-up *t*-tests showed an advantage for the lower hemi-field with high (587 vs. 599 ms), $t(13) = 4.30$, $p < .001$, but not with low target saliency (665 vs. 652 ms), $p = .120$. Further, laterality interacted with target saliency, $F(1,13) = 8.12$, $p = .014$, $\eta_p^2 = .385$, showing that the left hemi-field advantage was significant with low (638 vs. 678 ms), $t(13) = 5.05$, $p < .001$, but not with high target saliency (586 vs. 600 ms), $p = .158$.

The same ANOVA on percentage of correct responses showed an effect of target saliency, $F(1,13) = 14.76$, $p = .002$, $\eta_p^2 = .532$, with better performance with high than low target saliency (95% vs. 93%), an effect of laterality, $F(1,13) = 12.52$, $p = .004$, $\eta_p^2 = .491$, with better performance in the left than in the right hemi-field (96 vs. 92%) and no effect of elevation, $p = .592$. However, elevation interacted with saliency, $F(1,13) = 5.04$, $p = .043$, $\eta_p^2 = .279$, showing a tendency for better performance in the upper hemi-field with low target saliency (94 vs. 92%), $t(13) = 1.98$, $p = .070$, but no effect with high target saliency (95 vs. 96%), $p = .38$. Further, laterality interacted with target saliency, $F(1,13) = 11.31$, $p = .005$, $\eta_p^2 = .465$, showing that the left hemi-field advantage was significant with low (95 vs. 90%), $t(13) = 5.84$, $p < .001$, but not with high target saliency (96 vs. 95%), $p = .330$.

To evaluate RT-differences between Experiments 1 and 3, we conducted a 2 (*elevation*: upper, lower) × 2 (*laterality*: left, right) × 2 (*experiment*: 1, 3) mixed-factors ANOVA. The significant interaction of elevation and experiment, $F(1,44) = 5.16$, $p = .028$, $\eta_p^2 = .105$, showed that the advantage of the upper hemi-field disappeared in Experiment 3. In contrast, the interaction of laterality and experiment did not reach significance, $p = .403$, showing that the advantage of the left hemi-field persisted, although it was numerically smaller (27 vs. 46 ms). Also, RTs were overall shorter in Experiment 3 than in Experiment 1 (626 vs. 924 ms), $F(1,44) = 59.35$, $p < .001$, $\eta_p^2 = .574$, showing that the task was easier. The remaining effects were not significant, *p*s > .259.

Reducing task demands cancelled the advantage of the upper visual field, and created asymmetries that depended on target saliency. For high target saliency, the upper hemi-field advantage turned into the opposite, a lower hemi-field advantage, suggesting that detection of a basic visual feature is different from more complex object recognition involved in gaze perception. Further, the horizontal asymmetry was attenuated with targets of high saliency. Thus, visual field asymmetries depend on whether target detection involves object recognition or low-level saliency processing. Discussion of the lower hemi-field advantage is deferred to the General discussion.

Experiment 4

The goal of this experiment was to replicate the upper visual field advantage while eliminating differences in the vertical eccentricity of the stimuli. In Experiments 1 and 3, the eye region was farther from fixation in the upper than in the lower hemi-field because the eye region is located in the upper part of a face (see Figure 1). By presenting only the eye region, we were able to equalize the vertical eccentricity.

Methods

Thirty female students ranging in age from 17 to 24 years participated. We used rectangular cuts from the face stimuli used previously (see Figure 1D). The eye regions had a size of 4.8° × 1.5° (width x height) and were shown 3.2° to the left or right and 3.2° above or below central fixation (centre-to-centre). As in Experiments 1 and 2, one group of participants had to detect a right averted gaze ($n = 15$) and the other a left averted gaze ($n = 15$).

Results and discussion

Applying the same criteria as in the previous experiments, 2.6% outliers and 0.6% late trials were

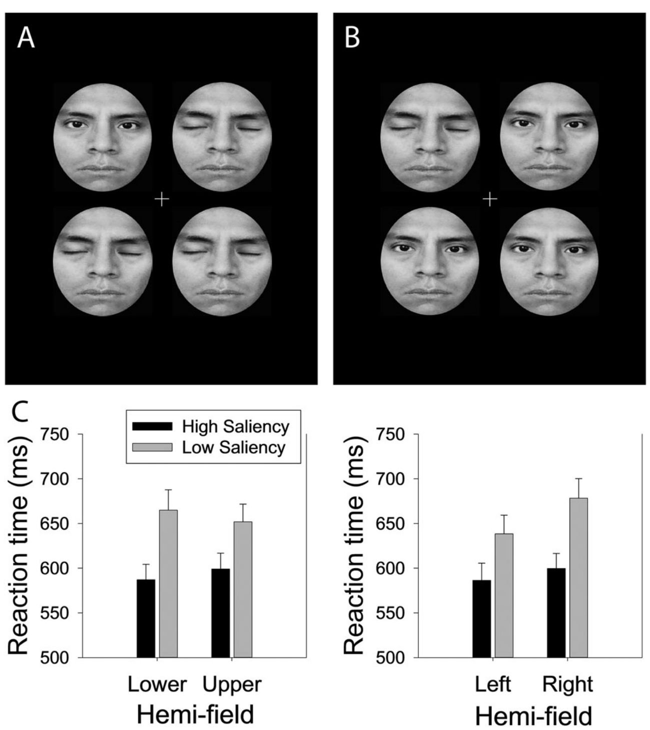

Figure 3. Additional results from Experiment 3. C: Mean reaction time is shown as a function of target saliency (A: high saliency = open among closed eyes, B: low saliency = closed among open eyes) and visual hemi-field (vertical, horizontal).

excluded. The percentage of correct responses was 78.9%. Mean RTs as a function of visual quadrant are shown in Figure 2D and the differences between hemi-fields are shown in Table 1.

A mixed-factors 2 (*elevation*: lower, upper) × 2 (*laterality*: left, right) × 2 (*gaze direction*: left, right) ANOVA on RTs in correct trials showed an effect of elevation, $F(1,28) = 10.39$, $p = .003$, $\eta_p^2 = .271$, with shorter RTs to faces in the upper than in the lower visual hemi-field (985 vs. 1034 ms) and an effect of laterality, $F(1,28) = 11.23$, $p = .002$, $\eta_p^2 = .286$, with shorter RTs to targets in the left than in the right visual hemi-field (987 vs. 1033 ms). The interaction effect between elevation and laterality was also significant, $F(1,28) = 5.08$, $p = .032$, $\eta_p^2 = .154$, showing that the difference between upper and lower hemi-field was stronger on the left than on the right, resulting in particularly short RTs in the upper left quadrant. None of the remaining effects in the ANOVA reached significance, $ps > .369$.

The same ANOVA as above on percentage of correct responses showed an effect of elevation, $F(1,28) = 31.49$, $p < .001$, $\eta_p^2 = .529$, with higher percentage correct to targets in the upper than in the lower visual hemi-field (83 vs. 77%) and an effect of laterality, $F(1,28) = 10.21$, $p = .003$, $\eta_p^2 = .267$, with higher percentage correct to targets in the left than in the right visual hemi-field (82 vs. 78%). None of the other effects reached significance, $ps > .127$.

To evaluate RT-differences between Experiments 1 and 4, we conducted a 2 (*elevation*: upper, lower) × 2 (*laterality*: left, right) × 2 (*experiment*: 1, 4) mixed-factors ANOVA. RTs were slower in the present experiment than in Experiment 1 (924 vs. 1010 ms), $F(1,60) = 6.83$, $p = .011$, $\eta_p^2 = .102$. We confirmed the effect of elevation, $F(1,60) = 22.81$, $p < .001$, $\eta_p^2 = .275$, and laterality, $F(1,60) = 22.34$, $p < .001$, $\eta_p^2 = .271$, as well as the interaction between elevation and laterality, $F(1,60) = 13.10$, $p = .001$, $\eta_p^2 = .179$. None of the other effects reached significance, $p = .627$.

We successfully replicated the advantages of the left and upper hemi-fields with stimuli that showed only the eye region instead of the entire face, thereby balancing the eccentricity of the stimuli in the upper and lower hemi-field. Because the results were unaffected by the type of stimuli (entire face vs. eye region), we conclude that differences in eccentricity cannot account for the asymmetries between hemi-fields.

General discussion

We investigated vertical and horizontal asymmetries in visual search with complete or cropped face stimuli. Experiment 1 showed that both laterality and elevation affected RTs and percentage of correct responses in search for a gaze singleton. We found better performance in the left and upper visual hemi-field. Inverting the orientation of the faces in Experiment 2 reduced the advantage of the left hemi-field, showing that holistic face processing contributed to the horizontal asymmetry. Decreasing the task difficulty by enhancing the saliency of the target cancelled the upper hemi-field advantage in Experiment 3, showing that complex object recognition contributed to the vertical and also to the horizontal asymmetry. Experiment 4 showed that the eye region is sufficient to produce effects of both laterality and elevation.

Asymmetries in the vertical and horizontal hemi-fields

Faster RTs when face targets were presented in the left compared to the right hemi-field were expected as holistic processing is better in the left hemi-field (Bentin et al., 1996; Bradshaw & Sherlock, 1982; Hillger & Koenig, 1991; Rossion et al., 2000; Sergent, 1984). Faster RTs when face targets were presented in the upper compared to the lower hemi-field were expected because object recognition is better in the upper visual field (Chambers et al., 1999; Christman & Niebauer, 1997; Felisberti & McDermott, 2013; Kessler & Tipper, 2004; Palanica & Itier, 2017; Quek & Finkbeiner, 2014a, 2014b). The contribution of our study was to investigate the efficiency of a basic perceptual process, visual search, as a function of visual hemi-field. Similar to the inhibition of face recognition performance in Kessler and Tipper (2004), search was particularly efficient when targets were presented in the upper left quadrant of the visual field, as evidenced by the interaction of horizontal and vertical hemi-field. The advantage of the upper left quadrant over the others is consistent with a recent MEG study. Lee, Kaneoke, Kakigi, and Sakai (2009) compared extrastriate brain activity of subjects engaged in a contrast-based visual search task. Square areas were randomly displayed in quadrants of the visual field. They found different response properties in the upper compared to the lower hemi-field, but only in the left hemi-field. However, we note that the previous study focused on low-level contrast perception and more research is needed to better understand the neural basis of the upper-left bias in visual search with complex stimuli.

In Experiment 2, we were able to strongly reduce the left hemi-field advantage by presenting faces upside-down, a well-known method to prevent holistic processing of faces (Freire et al., 2000). Instead, featural information is not affected by orientation, which allows the processing of upside-down faces to proceed analytically (Farah et al., 1995). Conty et al. (2006) investigated the stare in the crowd effect (i.e., better processing of straight than averted gazes) and found that the left hemi-field advantage was also present when just the eye region was displayed, which may at first sight seem to contradict the role of holistic processing. Similar to our task, their participants had to detect whether a gaze singleton was present or not. However, the laterality effect disappeared when the nose and eyebrows were concealed from the eye region, reinforcing the idea that the left hemi-field advantage is specific to holistic processing that occurs even when only a part of the face is presented. Further, we observed that the upper hemi-field advantage remained with upside-down faces, suggesting that the advantage of object recognition in the upper hemi-field was based on analytic rather than holistic processing.

In Experiment 3, we manipulated the saliency of the gaze target. With high target saliency, the effect of vertical hemi-field was inverted and the effect of horizontal hemi-field was attenuated. This result supports the idea that the upper hemi-field advantage appears only for difficult searches involving object recognition. With an easy task that can be solved on the basis of low-level saliency information, the advantage of the upper hemi-field disappears and may even turn into the opposite. This result is consistent with previous research on basic sensory processing, where an advantage for the lower visual field was reported. Perceptual thresholds for orientation (Carrasco, Talgar, & Cameron, 2001; Previc, 1990; Rezec & Dobkins, 2004), direction of motion (Rezec & Dobkins, 2004) and colour (Gordon, Shapley, Patel, Pastagia, & Truong, 1997; Levine & McAnany, 2005) were found to be better in the lower visual field (see also Previc, 1990). Further, the horizontal advantage was attenuated with high target saliency, suggesting that holistic processing is not involved when detection can be based on a low-level visual feature. Thus, the present data are consistent with the assumption that detection of highly salient targets circumvents both holistic processing and object recognition. Possibly, saliency differences can be detected before these processes are completed.

Our results are in line with previous studies investigating vertical asymmetries in the processing of letters or spatial relations (reviewed in Christman & Niebauer, 1997). As mentioned previously, performance in the upper visual field was found to be superior for word–nonword discrimination (Goldstein & Babkoff, 2001), letter naming in a trigram (Hagenbeek & Van Strien, 2002) or categorical judgments of spatial relationships (i.e., above vs. below; Niebauer & Christman, 1998). Therefore, we conclude that the upper hemi-field advantage is not specific to face stimuli as the left hemi-field advantage is. Instead, the upper hemi-field advantage depends on task complexity. When participants could rely on basic visual features (i.e., a saliency difference between open and closed eyes) to solve the task, requirements on object recognition were low and the superiority of the upper hemi-field did not play out. At the cerebral level, our results are in line with Previc's (1990) interpretation that vertical asymmetries can be related to the ventral and dorsal processing pathways. As mentioned before, the lower cortical sheets (upper visual field) project more into the ventral stream stretching from V1 downwards into the temporal lobes, whereas the upper cortical sheets (lower visual field) project more into the dorsal stream stretching from V1 forward into parietal cortex (Fecteau et al., 2000). While high-level processing such as object recognition takes place in the ventral stream, the dorsal stream is specialized in motion perception and visuo-motor coordination (Milner & Goodale, 1995).

Attentional asymmetries

While we have not directly addressed the issue of eventual asymmetries in the distribution of attention, we think an attentional account is unlikely. First, the evaluation of Previc's hypothesis with respect to attentional asymmetries is mixed. For instance, He, Cavanagh, and Intriligator (1996) claimed that attentional resolution was better in the lower visual field by showing lower visual field advantages in difficult search tasks, but no differences in basic search tasks. In contrast, Carrasco et al. (2001) showed that attention, as measured by the effects of exogenous cueing, was similar in the upper and lower visual fields, whereas perceptual performance was better in the lower visual field. Meanwhile, Rezec and Dobkins (2004) showed that discrimination of basic visual features was better in the lower visual field when search involved the complete visual field, suggesting an attentional bias to the lower visual field, whereas discrimination at cued locations in the upper or lower visual field were equal. Thus, evidence for attentional asymmetries is not conclusive.

Second, our series of experiments provides evidence against an attentional account. If attention had been preferentially directed to the left or upper hemi-field, we would have expected the same differences between horizontal and vertical hemi-fields with inverted faces or in an easy, saliency-based search task. However, the differences disappeared, suggesting that the nature of stimuli and task, and not an attentional preference, determined hemi-field asymmetries. A similar conclusion was reached by Quek and Finkbeiner (2014a) who demonstrated that the greater susceptibility for priming in the upper hemi-field persisted even when participants directed their attention to the lower hemi-field because the target was more likely to appear below than above fixation.

Conclusion

The purpose of this series of experiments was to investigate horizontal and vertical hemi-field asymmetries using a visual search paradigm with face stimuli. In Experiments 1 and 4, we found faster RTs when gaze singletons were presented in the left and upper hemi-field. In Experiments 2 and 3, we selectively eliminated the horizontal and vertical asymmetry. The left hemi-field advantage for holistic processing of faces was cancelled by using inverted faces in Experiment 2 and the upper hemi-field advantage for object recognition was cancelled by using a highly salient pop-out target in Experiment 3. Overall, our findings suggest that characteristics of the stimulus are crucial when investigating hemi-field asymmetries in face processing using gaze discrimination but, for typical face stimuli, search performance is best in the left and upper hemi-field. More research in facial processing is needed to test whether this effect generalizes to other tasks such as sex categorization or facial expression evaluation.

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