# Face-sex categorization is better above fixation than below: Evidence from the reach-to-touch paradigm

Genevieve L. Quek · Matthew Finkbeiner

**Abstract** The masked congruence effect (MCE) elicited by nonconsciously presented faces in a sex-categorization task has recently been shown to be sensitive to the effects of attention. Here we investigated how spatial location along the vertical meridian modulates the MCE for face-sex categorization. Participants made left and right reaching movements to classify the sex of a target face that appeared either immediately above or below central fixation. The target was preceded by a masked prime face that was either congruent (i.e., same sex) or incongruent (i.e., opposite sex) with the target. In the reach-to-touch paradigm, participants typically classify targets more efficiently (i.e., their finger heads in the correct direction earlier and faster) on congruent than on incongruent trials. We observed an upper-hemifield advantage in the *time course* of this MCE, such that primes affected target classification sooner when they were presented in the upper visual field (UVF) rather than the lower visual field (LVF). Moreover, we observed a differential benefit of attention between the vertical hemifields, in that the MCE was dependent on the appropriate allocation of spatial attention in the LVF, but not the UVF. Taken together, these behavioral findings suggest that the processing of faces qua faces (e.g., sex-categorization) is more robust in upper-hemifield locations.

**Keywords** Face processing · Upper visual field · Location variance · Priming · Attention

In masked priming paradigms, a prime stimulus presented below the threshold of conscious awareness can influence the processing of a subsequent visible target, such that response times (RTs) are typically faster when the prime–target pair are congruent (i.e., associated with the same response). Such masked congruence effects (MCE) have been repeatedly demonstrated to be contingent upon the allocation of attention. For example, the MCE in number-comparison tasks (Naccache, Blandin, & Dehaene, 2002) and semantic categorization tasks (Fabre, Lemaire, & Grainger, 2007) has been shown to depend critically upon *temporal attention* to the prime. Focused *spatial attention* to the prime also appears to be a prerequisite for the MCE to emerge in the context of semantic categorization of words (Lien, Ruthruff, Kouchi, & Lachter, 2010) and picture stimuli (Finkbeiner & Palermo, 2009). However, whereas these congruence priming studies using word, number, and picture stimuli have suggested that nonconscious information processing *depends* on attention to proceed (Lachter, Forster, & Ruthruff, 2004), the MCE elicited by face stimuli contradicts this notion, occurring even when attention is directed away from the prime. Finkbeiner and Palermo showed that sex information carried by a nonconscious prime face is capable of modulating the subsequent sex categorization of a visible target face, regardless of whether spatial attention is captured to the prime's location or elsewhere (Finkbeiner & Palermo, 2009). That the primes in this study did not *require* attention to influence target processing would certainly suggest that the processes underlying nonconscious sex information processing are robust. It does not imply, however, that these processes are beyond the influence of top down factors such as attention. In fact, we have recently demonstrated that although masked faces do produce congruence priming effects even in the near absence of attention, the *time course* of this MCE is sensitive to manipulations of attention, in that attended primes yield earlier congruence effects than do unattended primes (Quek & Finkbeiner, 2013).

Having established that the rapid processing of face-sex information under masked conditions is sensitive to manipulations of spatial attention, we wanted to pursue the interesting

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and as yet unaddressed possibility that the visual system's ability to process nonconscious sex information could be affected by the spatial position of the face. This seems a likely possibility, given that retinal position is known to influence the processing of supraliminal faces (Afraz, Pashkam, & Cavanagh, 2010; Gainotti, 2013). Our primary goal in the present study was to determine whether masked priming effects in face-sex categorization are affected by the prime's placement along the vertical meridian. Intuitively, it seems reasonable that the visual system's capacity to discriminate human faces might vary between the vertical hemifields. Specifically, individuals might be better at discriminating faces in the upper visual field (UVF), where faces usually appear, as compared to the lower visual field (LVF), in which faces are infrequently encountered. In fact, Previc (1990) proposed that the visual processing of certain types of information in each hemifield is tuned by location-dependent statistical probabilities. According to this account, processes that support near vision and visuomotor coordination are said to be advantaged in the LVF by virtue of being in "near space," where individuals reach toward and grasp objects. These include motion processing (Amenedo, Pazo-Alvarez, & Cadaveira, 2007; Edwards & Badcock, 1993; Levine & McAnany, 2005), global processing (Christman, 1993), and the perception of coordinate spatial relationships (Niebauer & Christman, 1998). In contrast, Previc asserted that the UVF corresponds to "far space" and has become specialized for those processes that support the object recognition that is often required in this hemifield, such as during visual search (Chaiken, Corbin, & Volkmann, 1962; Fecteau, Enns, & Kingstone, 2000; Previc & Blume, 1993; Previc & Naegele, 2001; Yund, Efron, & Nichols, 1990), local processing (Christman, 1993), and perception of apparent distance (Levine & McAnany, 2005). According to this possibility, we might expect higher-level face processing[1] (e.g., sex categorization) to be supported better at above-fixation than at below-fixation locations, since from an early age we encounter human faces more frequently in extrapersonal space (i.e., the UVF) than we do in peripersonal space (i.e., the LVF). Moreover, during close-range social interaction, the UVF is typically where the eyes of other people are located, and therefore contains potent social information that informs adaptive behavior. For example, the eye gaze of another person can direct our visual attention to relevant stimuli nearby (Hood, Willen, & Driver, 1998; Langton, Watt, & Bruce, 2000), and the eye region is thought to be critical in the expression of negative emotions such as fear and anger, which may require an immediate response from an observer (Hanawalt, 1944).

[1] We note that the lower-level aspects of face recognition, such as simple detection or discrimination, could well enjoy an LVF advantage similar to that observed for other stimulus types; see work by Carrasco and colleagues regarding this possibility (Carrasco, Penpeci-Talgar, & Cameron, 2001).

Yet despite the intuition that face perception in humans might exhibit an upper-hemifield advantage, the evidence for this suggestion is equivocal at best. In fact, whereas some have argued that face perception is position-invariant (see Schwarzlose, Swisher, Dang, & Kanwisher, 2008), others have shown how face perception is position-variant with interesting individual differences (Afraz et al., 2010). In contrast, studies that have employed higher-temporal-resolution measures to examine the possibility of position variance in the *initial percept* of faces have had better success in observing vertical hemifield effects at the group level. For example, Liu and Ioannides (2010) have reported that magnetoencephalography (MEG) peak latencies in the medial prefrontal cortex (MPFC), left fusiform face area (FFA), and the left occipital face area (OFA) arise earlier within the first 100 ms following face presentation when the face appears in the UVF rather than the LVF. However, although this might seem to suggest that face information is processed more efficiently at upper-hemifield locations, this interpretation is weakened by the fact that the *reverse* patterns of results was observed for the right FFA. In this region, LVF faces elicited significantly earlier peaks than did UVF faces, with a directionally similar numerical difference observed for the right OFA (nonsignificant). In addition, the behavioral measure (accuracy rates) of Liu and Ioannides did not correlate in any clear way with the effects observed in the electrophysiological measure. Within the behavioral literature, Kessler and Tipper (2004) reported that inhibition effects elicited by previously seen face stimuli are evident only for faces presented above-fixation, suggesting indirectly that face encoding may be superior in the UVF relative to the LVF. Similarly, detection and localization of emotional schematic faces in visual search appears to be better in the upper-hemifield (Fecteau et al., 2000), and Coolican, Eskes, McMullen, and Lecky (2008) found that a chimeric mirror image face presented above-fixation is perceived as being more similar to the original face than is a mirrored face presented below-fixation. However, it is not clear to what extent the upper-hemifield advantage for faces reported in these studies could be due to the fact that participants tend to commence their visual search for targets in the UVF, regardless of stimulus type (Chedru, Leblanc, & Lhermitte, 1973; Kraft, Sommer, Schmidt, & Brandt, 2011; Previc & Blume, 1993), a possibility that seems particularly likely, given that Fecteau et al. (2000) observed a UVF advantage regardless of whether the targets were schematic faces, letters, or rectangles.

Thus, to date, the evidence that the processing of faces qua faces is sensitive to spatial position is equivocal at best. We suspect that one reason for this is that face discrimination is resolved so quickly in the visual system that only those measures with very high temporal resolution will be able to consistently observe effects of spatial position. With this in mind, we chose to employ a behavioral measure capable of revealing experimental effects within the same timeframe that Liu and

Ioannides (2010) observed the MEG response to face stimuli to be sensitive to manipulations of vertical hemifield (i.e., first ~250 ms from target onset). In the standard version of the reach-to-touch paradigm (see Freeman, Dale, & Farmer, 2011; Song & Nakayama, 2009; Spivey, Grosjean, Knoblich, & McClelland, 2005), participants categorize a target by reaching to the left or right while the position of their hand is sampled at a high frequency (e.g., 200 Hz). A range of kinematic properties of the reaching response can be used to document experimental effects of interest, including response time from target onset (RT), overall travel time, time to peak velocity, acceleration, curvature, and path offset. Comparing conditional mean values of any of these indices would enable one to observe experimental effects of interest during *response execution time*, or the time period during which the participant actually performs the reaching movement—typically well after stimulus processing has taken place. In the version of the reach-to-touch paradigm that we employed here (see Finkbeiner, Coltheart, & Coltheart, 2014; Quek & Finkbeiner, 2013), we took initial velocity in the correct direction as our index, and examined how it varied as a function of how long the participant viewed the target before commencing their response. In this way, our dependent measure could reveal how much the participant knew about the target at the time of movement initiation, enabling us to map out the onset and growth of an experimental effect in *stimulus-processing time*, rather than response execution time. Being able to observe the unfolding of an effect may be especially important in the present case, since the highly efficient nature of sex-categorization (Bruce & Young, 1998) means that any effect of vertical hemifield on this process might well be very short-lived. Using this newly developed version of the reach-to-touch paradigm, we show that the extent to which the sex of a nonconscious prime face is able to influence the sex-categorization of a subsequent conscious target depends on vertical hemifield. Masked face primes presented above-fixation enjoy a *temporal* processing advantage, in that the MCE reflected in participants' reaching responses emerges *earlier* for faces presented in the UVF than in the LVF.

## Method for Experiments 1a and 1b

Our study consisted of two near-identical experiments that both used a 2 × 2 × 2 fully crossed factorial design. The factors were Cue Validity (valid vs. invalid), Visual Field (upper vs. lower), and Prime Type (congruent vs. incongruent). In the interest of exposition, we have combined these two experiments and report them as one below.

### Participants

A group of 51 individuals between 18 and 28 years of age were recruited from the student population at Macquarie University. Of these, 32 participated in Experiment 1a and 19 participated in Experiment 1b. All were strongly right-handed and received either financial compensation or undergraduate course credit in return for their participation.

### Stimuli

In total, we used 24 grayscale stimuli matched on luminance and contrast. The stimuli consisted of 12 critical face items (ten target items and two prime items) drawn from the Psychological Image Collection at Stirling database (PICS; available at http://pics.psych.stir.ac.uk/) and cropped to exclude the facial contour and hairline. We also used 12 noncritical animal stimuli (ten distractor items and two foil items) taken from the Hemera Photo Objects Collections (Hemera Photo Objects, Gatineau, Quebec, Canada). Each finished stimulus subtended 4.2º × 3.37º of visual angle from a viewing distance of 68 cm.

### Apparatus and procedure

The participants in Experiments 1a and 1b completed 400 and 480 experimental trials, respectively; in both cases, the experiment proper was preceded by a practice block of 80 trials (not analyzed). Participants in Experiment 1a sat at a rigid table before a 70 × 39-cm touchscreen monitor fixed 50 cm from the table edge, with peripheral response panels marked "M" and "F" on either side of the screen. Participants in Experiment 1b sat before a 75-cm-wide rigid table with a CRT monitor fixed 75 cm from the front edge and two lateral response panels, 50 cm from the front edge, positioned at the left and right desk edges. Figure 1 depicts the testing setup for participants in Experiment 1a.

In both experiments, the participant's task was to classify the sex of a target face by reaching out to touch the appropriate response panel. The correct touch position for each sex was counterbalanced across participants. We recorded reaching trajectories using motion capture devices to track the position of the finger in Euclidean space—in Experiment 1a, we used an OptotrakCertus, NDI (200 Hz) to sample the position of a small light-emitting diode fixed to their index finger. We employed the same approach in Experiment 1b with a Polhemus Liberty electromagnetic tracking system (240 Hz) and a small sensor.

Figure 2 shows the visual trial structure for both experiments. Each trial frame consisted of two display panels (75 × 100 pixels) positioned immediately above and below a central fixation point. The trial commenced when the participant moved their right index finger into the "start position"—a region of space on the body midline at the front edge of the table. Participants first saw two checkerboard forward masks whose duration varied from trial to trial to increase uncertainty. This fixation frame was followed by the sudden onset and offset of an exogenous spatial cue (a schematic face) presented
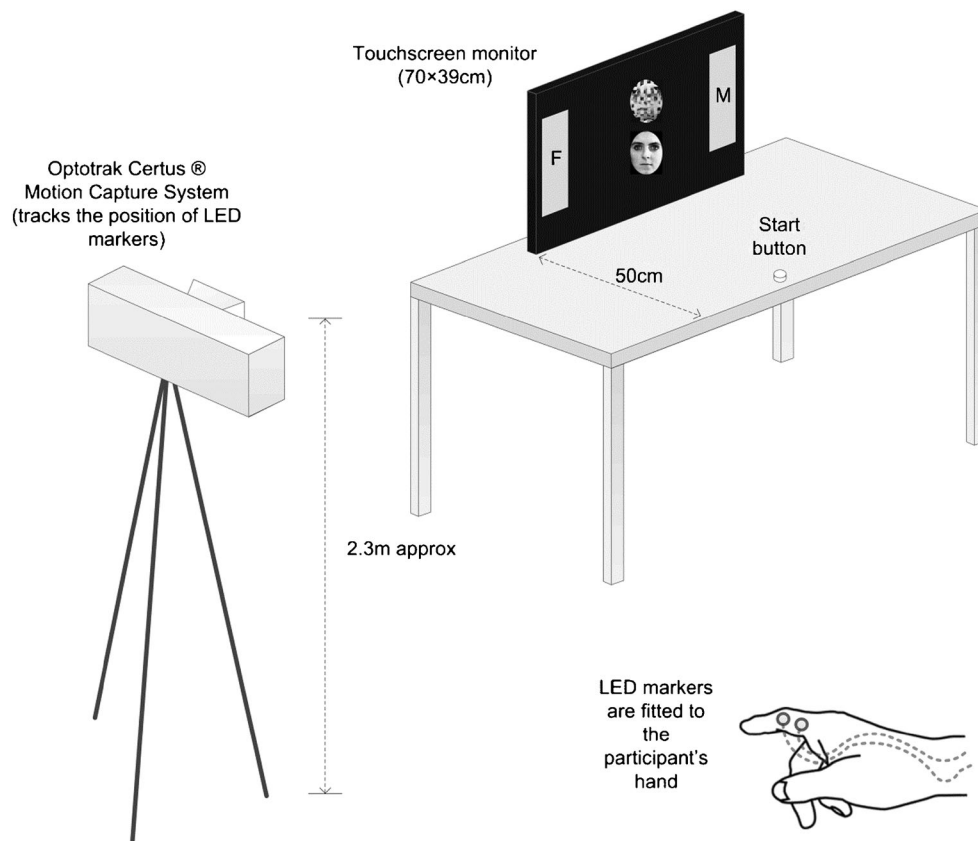
Fig. 1 Testing setup for Experiment 1a. Participants sat before an LCD touchscreen monitor fixed 50 cm from the table edge. Throughout the experiment, response boxes marked "M" and "F" appeared at the left and right edges of the screen (order counterbalanced across participants). To initiate each trial, participants depressed a start button, aligned with the body midline, that was fixed 3.5 cm from the table edge. When the target appeared, participants had 400 ms to release the button and begin reaching toward the monitor. Throughout the experiment, the position of the participant's finger was recorded by an Optotrak Certus motion capture system (200-Hz sample rate). For Experiment 1b, we used a very similar testing setup, in which the finger's position was recorded using a Polhemus Liberty electromagnetic tracking system (240-Hz sample rate)

either above the top panel or below the lower panel (50 ms on, 50 ms off). The subsequent prime frame (50 ms) contained the critical prime face (either male or female) in one panel and a noncritical animal stimulus in the opposite position. The target face then appeared for 100 ms in the same position as the prime, with an animal distractor presented in the other panel.[2] Identical scrambled faces appeared as backward masks in both panels until the participant completed the classification response by reaching out to touch the appropriate response panel. We told participants to fixate on the central dot at the start of each trial and highlighted that the target could appear with equal probability either above or below fixation. Our spatial-cueing procedure was a variant of the classic Posner cueing paradigm (Posner, 1980), in which covert attention is "captured" at a location by the sudden appearance of a brief peripheral cue. In these paradigms, in which the cue is always nonpredictive of target location (i.e., 50 valid : 50 invalid), the

cue is thought to capture attention in a bottom-up, automatic way (Yantis & Jonides, 1990). Thus, we expected the schematic face cue to be effective in capturing spatial attention to the vertical hemifield in which it appeared, despite being uninformative of the upcoming target's location.

It is important to highlight that the total time between cue onset and prime offset was 150 ms in our trial structure. This is important to note, because reflexive saccade latencies take 200–250 ms (Walker, Walker, Husain, & Kennard, 2000). Thus, any cue-induced eye movements in our paradigm would have taken place *after* the prime stimulus had been extinguished. Hence, we are reasonably confident that our dependent measure, the prime-induced MCE, was not modulated in any systematic way by overt eye movements. We were also careful to minimize the contribution of the hemispheric processing differences for faces between the right and left visual fields (Gilbert & Bakan, 1973; McCarthy, Puce, Gore, & Allison, 1997; Rossion et al., 2000). Whereas many previous studies have presented target faces at diagonal locations (upper left, upper right, lower left, or lower right), effectively confounding vertical asymmetry effects with the known

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[2] The animal foil and distractor appeared inverted on approximately 50% of trials; the orientations of the foils and distractors had no reliable effect, so we have not included this variable in the present analysis.

laterality effects for faces, we chose to present our prime–target face pairs immediately above and below fixation (i.e., along the vertical meridian).

On each trial, we defined the start of a participant's reaching movement as the point at which the finger's tangential velocity reached 10 cm/s. The time in milliseconds from target onset until this point was noted as that trial's movement initiation time (MIT). How participants initiated their reaching movements differed slightly between Experiments 1a and 1b. In Experiment 1a, participants began their reaching movement as soon as they saw the target face appear in either panel. To prevent participants from delaying their movement until they were certain of the target's sex, we gave negative feedback (a loud buzz and visual feedback: e.g., "Too late!") and aborted the trial if they failed to initiate their movement within 400 ms of target onset. Thus, the MIT latencies in Experiment 1a could range from 0 to 400 ms. Aborted trials were cached and re-presented at the end of the block. To prevent anticipatory movements (i.e., moving *before* target onset), 10% of trials did not include a target, and on these "no-go" trials, participants were required to keep their finger in the start position. In Experiment 1b, we wanted to ensure a greater spread of MIT latencies relative to target onset, especially within the earliest stages of stimulus processing. To this end, we trained participants to initiate their reaching movements in

response to an imperative auditory go-signal, rather than at target onset (Finkbeiner et al., 2014). On each trial, participants heard a sequence of three beeps of increasing pitch and had to coincide their movement onset with the arrival of the third beep. We allowed participants to begin moving up to 100 ms before and 200 ms after the onset of the third beep—MIT latencies outside this response window were aborted using the procedure described for Experiment 1a. We varied the temporal proximity of the target to the go-signal using three different stimulus onset asynchronies (SOAs), such that the target could appear either simultaneously with the third beep (40% chance), 150 ms before the third beep (40% chance), or 250 ms before the third beep (20% chance). Thus, the MIT latencies in Experiment 1b could range from –100 ms to 450 ms.[3] This procedure enabled us to examine reaching trajectories initiated across a wide range of target-viewing times, so as to better observe the emergence of the experimental effects as a function of stimulus processing time. To do so, we used MIT latency as a proxy for target-viewing time on each trial, since the longer the MIT latency was, the more time the participant had to process the target before commencing the reaching movement. Importantly, although both experiments required participants to *initiate* their reaching movement within a narrow time window, the classification reaching response itself was not speeded. Participants had over 3 s to reach out and touch a response panel—ample time for the finger to change direction or correct its course.

At the conclusions of both experiments, we assessed participants' awareness of the prime stimuli by informing them of the prime's presence and asking them to complete additional prime detection trials (80 trials for Exp. 1a, 160 trials for Exp. 1b). The task during these trials was identical to that in the experiment proper (i.e., reaching out to classify the target), except that after completing the reaching response, participants were presented with two faces (the real prime and a lure) and were asked to indicate which one of the two had been the prime on that trial. We counterbalanced the positions of the real prime and lure across trials, and instructed participants to maintain the same strategy for the prime-detection trials as they had for the trials in the experiment proper.

Data preparation and analyses

*Response bias identification* Prior to analyzing the participants' trajectory data, we inspected their prime-detection data for evidence of response bias. An $A'$ value (Zhang & Mueller, 2005) for either the congruent or the incongruent condition
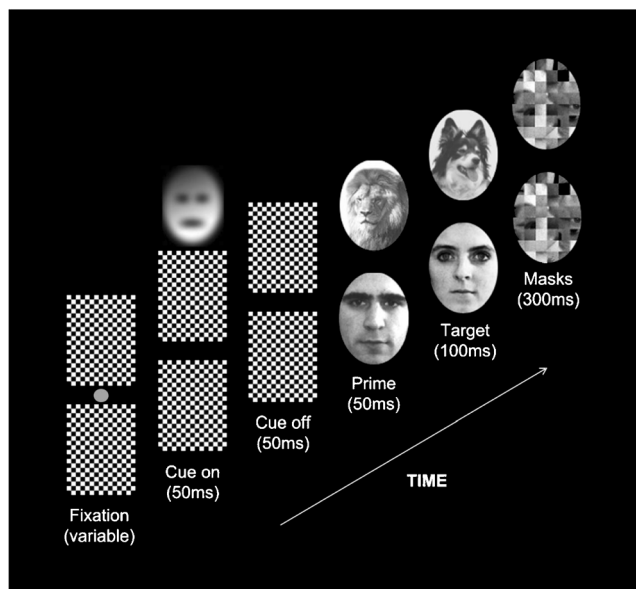


**Fig. 2** Trial structure for Experiments 1a and 1b. Participants saw two identical checkerboard panels displaced around a central fixation dot. The task was to classify the sex of a target face that could appear with equal probability in either the upper or lower panel (i.e., in the upper or lower visual field). Targets were preceded by a prime face of the same or the opposite sex (i.e., congruent or incongruent). We used an exogenous spatial-cueing procedure, whereby the sudden onset/offset of a schematic face was used to cue the participant toward the target location (valid cue) or the opposite location (invalid cue). The ratio of valid to invalid cues was 50:50, such that the spatial cue was nonpredictive of target location

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[3] In Experiment 1b, we allowed participants to begin their movement up to 100 ms before the auditory go-signal. Thus, on those trials in which the go-signal and the target were presented simultaneously (0-ms SOA), participants could initiate their movement prior to target onset, yielding a negative MIT. Having a small percentage of trials with negative MITs was intended, since these trials provided a baseline condition.

that fell outside the range of .20 to .80 would indicate a disproportionately high hit rate for congruent trials and a conversely low hit rate for incongruent trials. Such a pattern would indicate a response bias in which a participant tended to identify the prime face on the basis of the target's sex (i.e., if the target on that trial was female, participants would tend to select the female prime). Because prime-detection data obtained in such a context cannot give a reliable indication of the participant's ability to identify the prime under masked conditions, we removed any participants who did not meet the criteria above from all subsequent analyses (seven from Exp. 1a and four from Exp. 1b). The remaining 40 participants' data were included in all subsequent analyses.

*Trajectory data preparation* To prepare each trajectory for analysis, we firstly selected the raw samples beginning 50 ms before and concluding 300 ms after the point of movement onset (i.e., MIT latency). For each individual sample, we then calculated x-velocity, a signed value that reflects the velocity of the finger along the left–right axis (i.e., the target classification dimension, "left for male" and "right for female"). The more positive the x-velocity is at any given sample, the faster the finger is headed toward the correct response panel at that moment in time. In contrast, a negative x-velocity value indicates that the finger is moving *away* from the correct response panel (i.e., in the wrong direction). The measure can be used as a momentary index of the participant's response certainty, in that the more positive x-velocity is, the faster the finger is moving in the correct direction at that particular moment—so the more certain the participant must be regarding their classification. For the present face-sex categorization task, the MCE is reflected in higher (more positive) x-velocities on congruent than on incongruent trials. That is, the finger heads in the correct response direction faster when the prime and target are associated with the same classification response (i.e., congruent) rather than difference responses (i.e., incongruent). This is akin to the shorter RT latencies for congruent than for incongruent trials that are typically observed in masked priming buttonpress experiments (Finkbeiner & Palermo, 2009; Naccache et al., 2002).

*Orthogonal polynomial trend analysis (OPTA)* Before submitting the raw x-velocity profiles to statistical analyses, we used a modified version of orthogonal polynomial trend analysis (OPTA; see Karayanidis, Provost, Brown, Paton, & Heathcote, 2011; Woestenburg, Verbaten, & Slangen, 1983). In our version of this procedure, we used MIT latency as the sole covariate in a high-degree polynomial regression model of participants' x-velocity profiles. The advantage of this approach was twofold. First, it enabled us to examine how x-velocity profiles varied as a function of MIT—that is, target-viewing time. Because MIT was the duration for which the participant processed the prime–target information prior to

initiating the reaching response, yoking any given trial's x-velocity data to its MIT latency enabled us to observe the masked congruence effect while stimulus processing was still ongoing. Second, because each individual trial contributed to the regression model, this procedure yielded a much better signal-to-noise ratio than would simple averaging. For example, the signal-to-noise ratio given by OPTA has been reported by Karayanidis et al. to be 2.5 times that of simple averaging. Similarly, Woestenburg et al. have reported that OPTA increases the signal-to-noise ratio over simple averaging and Wiener filtering by up to a factor of 10. In our OPTA procedure, trials within each individual design cell (e.g., participant, level of cue validity, level of visual field, and level of prime type) were ordered by MIT latency from 1 to *n*, such that the trial with the shortest MIT was ranked 1st, and the trial with the longest MIT was ranked *n*th (where *n* was the number of trials in that design cell). We then fitted a polynomial regression model to the x-velocity profiles that included MIT rank as the only covariate and polynomial terms up to the 15th order. Terms that did not explain significant variance were dropped from the model, so that only significant coefficients were used to generate predicted x-velocity profiles (one for each trial).
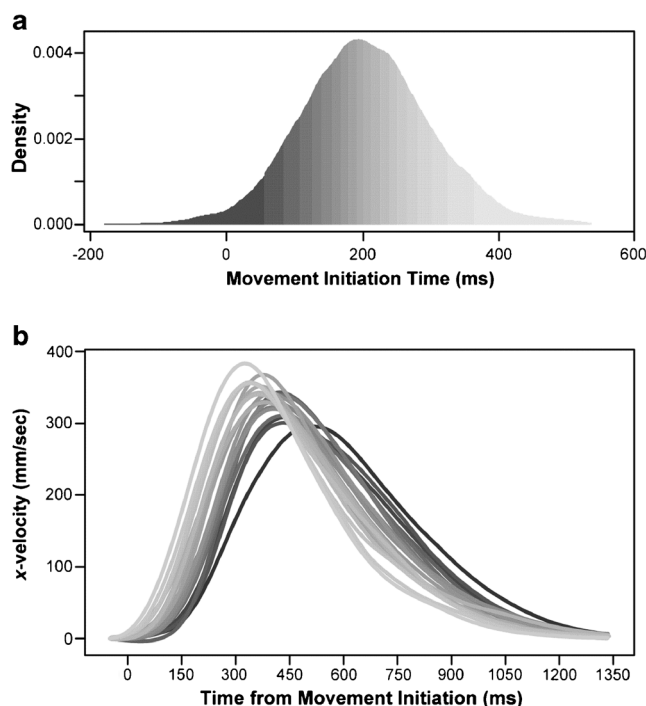


**Fig. 3** Grouping trajectories by target-viewing time. (**a**) The analysis began with the distribution of movement initiation time (MIT) latencies from target onset (i.e., a distribution of target-viewing times). We then fitted a polynomial regression model to the x-velocity profiles, incorporating MIT rank as a covariate (see the text). (**b**) Mean predicted x-velocity profiles by MIT quantiles. Darker colors indicate trials with short MIT latencies (beginning at the 1st quantile); lighter colors correspond to longer MIT latencies (up to the 20th quantile). Note the clear effect of MIT latency: The longer that participants waited to begin moving, the faster the finger moved in the correct direction during the reaching response itself

Finally, we averaged the fitted *x*-velocity values from the first 300 ms of the reaching movement and submitted this mean value, which we will refer to as the *initial x-velocity*, to statistical analysis. To visualize the effect of target-viewing time (i.e., MIT latency) on the complete reaching response, we used the corresponding MIT rank values to group the *x*-velocity profiles into 20 bins of equal proportion (i.e., semidecile; see Fig. 3b). The mean *x*-velocity profiles (averaged across participants) from the different MIT quantiles are presented in the bottom panel of Fig. 3. As is clear in this figure, the longer that participants waited to *begin* their reaching movements, the more quickly they reached peak *x*-velocity (i.e., the faster they moved in the correct direction).

*Statistical analyses* All analyses were carried out using custom software written in R (www.r-project.org). We used the lmer4 package (http://lme4.r-forge.r-project.org; see Bates, Maechler, & Bolker, 2011) to implement linear mixed-effects modeling (LMM; see Baayen, Davidson, & Bates, 2008; Bates, 2005), which enables the experimenter to consider fixed and random effects simultaneously. We used an incremental nested model comparison procedure in which we evaluated the relative contribution of each effect and interaction term by comparing a model that included the effect of interest to one that did not include this effect. For each comparison, we determined which of the two models fit the data better by inspecting the Akaike information criterion (AIC), Bayesian information criterion (BIC), and log likelihood values for each model (Akaike, 1974; Schwarz, 1978). These values reflect a model's goodness of fit, and in the case of AIC and BIC, impose a penalty that increases with the number of estimated parameters. In model comparison procedures, the preferred model is the one that minimizes AIC and BIC and maximizes the log likelihood. Below, we report the results of the likelihood ratio test for each model comparison instance. Where appropriate, we also report the coefficients, standard errors (*SE*s), and *t* values for terms included in the final model selected. As is typical for LMM analyses, we took a coefficient magnitude of at least twice its standard error (i.e., $|t| > 2$) as our criterion for significance (Kliegl, Masson, & Richter, 2010; Kliegl, Wei, Dambacher, Yan, & Zhou, 2011).[4] For each model evaluation, we also report conditional $R^2$ (notated as $R^2_{COND}$), or the proportion of variance in the data explained by all factors contained in the model being evaluated. Owing to our use of an incremental model-comparison procedure (i.e., a single factor added for each new comparison), conditional $R^2$ in the present case provided

some indication of the *degree* to which each new term improved the model's fit.

## Results

### Accuracy

After excluding trials on which a movement-initiation error occurred (<1%, averaged across participants), the overall mean target classification accuracy was 90.81%. High accuracy rates are typical of the reach-to-touch paradigm, owing to the fact that participants are able to correct any initially wayward reaching movements midflight (see Finkbeiner et al., 2014; Quek & Finkbeiner, 2013). Using LMM with Participant as a random factor, we verified that the fixed effect of experiment (1a or 1b) did not contribute to the fit of the model, $\chi^2(1) = 2.48$, $p = .115$, $R^2_{COND} = .070$. We therefore combined the data from both experiments for further analysis. We first verified the efficacy of our masked-priming paradigm by confirming a significant main effect of prime type, $\chi^2(1) = 242.66$, $p < .001$, $R^2_{COND} = .122$. As can be seen in Fig. 4, our participants were *less likely* to classify the target correctly if it was preceded by an incongruent prime ($M = 87.30\%$) rather than a congruent prime ($M = 94.32\%$), $b = –0.90$, $SE = 0.06$, $z = –15.02$.[5] The main effect of visual field was also reliable, $\chi^2(1) = 15.15$, $p < .001$, $R^2_{COND} = .125$, indicating that target sex classification was *less likely* to be correct if the target appeared below-fixation ($M = 89.86\%$) rather than above- ($M = 91.76\%$), $b = –0.22$, $SE = 0.06$, $z = –3.94$. In contrast, including Cue Validity as a factor did not significantly improve the fit of the model, $\chi^2(1) = 0.34$, $p = .563$, $R^2_{COND} = .125$, nor did the interactions between any of the factors.

### Movement initiation time

LMM analysis of MIT latencies (correct classification trials only) indicated no significant effects of interest, save for a strong main effect of experiment, $\chi^2(1) = 39.25$, $p < .001$, $R^2_{COND} = .462$. Owing to the use of the auditory go-signal in Experiment 1b, participants in this experiment initiated their movements around 100 ms earlier ($M = 145.77$) than did participants in Experiment 1a ($M = 250.40$ ms), $b = –104.21$, $SE = 13.09$, $t = –7.96$.

### Reaching trajectories

The OPTA procedure described above yielded 14,151 initial *x*-velocities obtained from 40 participants. These data were

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[4] Although the exact degrees of freedom for *t* values are not known for LMM analyses, Kliegl and colleagues have argued that incorporating a large number of observations results in a *t* distribution that converges to the standard normal distribution, allowing the two *SE* criteria to approximate the convention of two-tailed 5% significance (Baayen et al., 2008; Kliegl et al., 2010).

[5] For binomial data, positive and negative coefficients obtained using LMM indicate increasing and decreasing probabilities, respectively (Baayen et al., 2008).
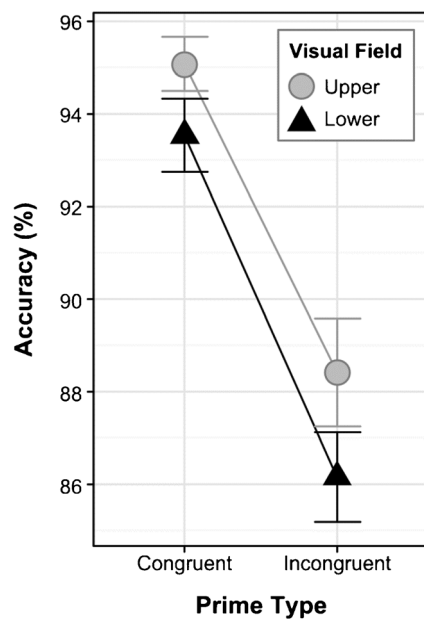
**Fig. 4** Mean accuracy values, by prime type and visual field. Sex identification was significantly more reliable when (i) the prime–target pair was congruent, rather than incongruent, and (ii) the target appeared in the upper, rather than the lower, visual field. The effect of cue validity on accuracy scores was not reliable and is not depicted here

subjected to an LMM analysis that included random slopes between participant and MIT quantile. As described above, we inspected AIC, BIC, and log likelihood values to identify the terms that significantly improved the fit of the model, beginning with main effects. We observed a clear main effect of MIT quantile, $\chi^2(1) = 34.75$, $p < .001$, $R^2_{COND} = .844$, indicating that the initial $x$-velocity tended to increase with each subsequent MIT quantile ($b = 5.76$, $SE = 0.77$, $t = 7.52$). That is, the longer that participants viewed the target prior to beginning their movement, the faster their finger moved *in the correct direction* during the initial portion of the reaching movement. Figure 5 shows this effect clearly, in that initial $x$-velocity values increase dramatically as a function of target-viewing time (i.e., MIT latency). The critical MCE was realized in a strong main effect of prime type, $\chi^2(1) = 1040.6$, $p < .001$, $R^2_{COND} = .855$, in that initial $x$-velocity was significantly higher, on average, for congruent than for incongruent trials ($b = -17.06$, $SE = 1.22$, $t = -14.02$). That is, the participant's finger moved in the correct classification direction faster when the prime and target were associated with the same sex-classification response. The main effect of cue validity was also significant, $\chi^2(1) = 30.79$, $p < .001$, $R^2_{COND} = .855$, with the mean initial $x$-velocity on invalidly cued trials being slightly higher than that on validly cued trials ($b = 3.20$, $SE = 1.22$, $t = 2.63$). Notably, including the main effect of visual field did not improve the fit of the model, $\chi^2(1) = 2.06$, $p = .151$, $R^2_{COND} = .855$, so this was not included as a fixed effect in the final model. Importantly, however, several interactions incorporating visual field were highly significant, as we discuss below.

Owing to the multifactorial nature of our design, it was impractical to test the significance of each and every interaction term incrementally. Instead, we restricted ourselves to a series of model comparisons that evaluated interactions of interest identified a priori. First, we examined whether the magnitude of MCE reflected in the initial $x$-velocity depended on how long participants viewed the target before commencing their reaching movement, observing that the interaction between prime type and MIT quantile did improve the fit of the model, $\chi^2(1) = 3.56$, $p = .058$, $R^2_{COND} = .855$. Second, and more importantly, we confirmed that the effect of target-viewing time on the magnitude of the MCE was qualified by vertical hemifield (significant three-way Prime Type × MIT Quantile × Visual Field interaction, $\chi^2(2) = 17.05$, $p < .001$, $R^2_{COND} = .855$). As can be seen in Fig. 5, the stage of target-viewing time at which the MCE became significant very much depended on whether the prime–target pair appeared in the UVF or LVF. The prime affected the target-classification response much sooner (i.e., the MCE was significant) when the stimuli were presented above- rather than below-fixation. Follow-up $t$ test comparisons between the congruent and incongruent initial $x$-velocities at each MIT quantile confirmed that prime–target pairs presented in the UVF elicited a significant MCE in participants' initial $x$-velocity values at all target-viewing times, from as early as 90 ms ($\alpha = .05$, corrected using false discovery rate, FDR). Moreover, effect size estimates of the MCE for the UVF were very reasonable, ranging between $r = .42$ and $.58$ (see the supplementary materials for a more detailed discussion of the effect size estimates and the statistical power associated with the MCE in each vertical hemifield).

In contrast, the ability of the prime to influence the target-classification response was substantially delayed when the prime–target pair appeared below-fixation, with the MCE only emerging at ~180 ms of target-viewing time (6th MIT quantile). For those MIT quantiles in which the MCE for the LVF was significant, effect size estimates were comparable to those obtained for the UVF ($r = .45$ to $.58$; see the supplementary materials for further details). Interestingly, this difference between the vertical hemifields in the time courses of the MCE appeared to be carried predominantly by the incongruent trials, in that incongruent primes were able to interfere with the target classification response much sooner in the UVF than in the LVF.

Having confirmed that the temporal unfolding of the MCE is sensitive to spatial position, we then considered the possibility that our manipulation of spatial attention affected the unfolding of the MCE differently in the upper- and lower-hemifields. We first verified that there was a three-way Prime Type × MIT Quantile × Cue Validity interaction, $\chi^2(2) = 13.68$, $p < .005$, $R^2_{COND} = .856$, and then confirmed that this interaction was further qualified by visual field, $\chi^2(2) = 12.92$, $p < .005$, $R^2_{COND} = .856$. The nature of this four-way interaction is clear in Fig. 6. For faces in the UVF, cue validity made little difference to the
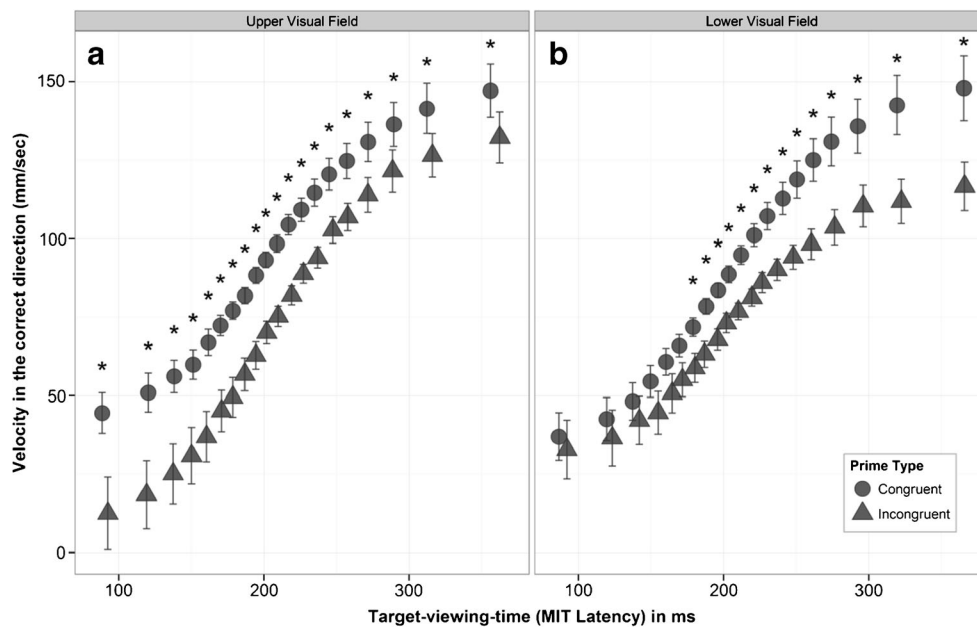
**Fig. 5** Initial *x*-velocity, or *x*-velocity values collapsed across the initial 300 ms of the reaching movement, shown as a function of MIT latency for the (**a**) upper and (**b**) lower visual fields (UVF and LVF, respectively). Initial *x*-velocity reflects the velocity of the hand in the correct direction: Negative values indicate that the finger is headed toward the incorrect response panel, and positive values that the finger is headed toward the correct response panel. The masked congruence effect (MCE) is evident in the higher initial *x*-velocities in the congruent condition (circles) than in the incongruent condition (triangles). The contrast of interest between the UVF and LVF is in the time course over which this MCE becomes significant. In the UVF (**a**), the MCE is significant at even the shortest target-viewing times (~90 ms). In contrast, an additional ~90 ms of target-viewing time is needed before an MCE emerges in the LVF (**b**). This suggests that participants extracted the sex information contained in the masked prime faces more efficiently when they appeared in the UVF than in the LVF. Asterisks denote .05 significant contrasts between congruent and incongruent values at each movement initiation time (MIT) quantile (false discovery rate corrected)

time at which the MCE emerged (Fig. 6, panels a and b). Follow-up *t* tests (FDR corrected) of congruent and incongruent initial *x*-velocities at each MIT quantile indicated that the onset of the MCE in the UVF did not differ as a function of cue validity. That is, both validly and invalidly cued trials showed a significant MCE from the earliest MIT quantile (i.e., ~90 ms of target-viewing time) until around 265 ms of target-viewing time. Effect size estimates of the MCE for the valid and invalid cue conditions were also comparable (see the supplementary materials for details of this analysis). Taken together, these results suggest that when the prime and target faces appeared in the UVF, participants did not require focused spatial attention in order to extract the task-relevant sex information from the masked prime.

In contrast, when the prime–target pair appeared below-fixation, the MCE *depended* on the allocation of spatial attention. In the validly cued condition (Fig. 6c), the MCE became significant from the 7th MIT quantile onward, indicating that initial *x*-velocity was significantly higher for congruent than for incongruent trials for all responses commencing after ~180 ms of target-viewing time (effect sizes ranged from *r* = .42 to .51; see the supplementary materials). In contrast, in the invalidly cued condition (Fig. 6d), although uncorrected *p* values were significant from the 11th to the 15th MIT quantiles, FDR-corrected *p* values did not reach .05 significance at any MIT quantile (effect sizes ranged from *r* = .07 to

.31; see the supplementary materials). Thus, the MCE in the LVF, invalidly cued condition was very weak, if present at all, suggesting that participants were only able to extract sex information from the masked face primes in the LVF when attention was captured to the prime's location by a valid spatial cue.

### Prime detection

We assessed participants' awareness of the prime by using their prime-detection data to calculate a hit rate, false alarm rate, and *d'* value for each experimental condition. A one-sample *t* test confirmed that participants' mean *d'* scores ($M = 0.085$) were not significantly different from zero [$t(39) = 1.71$, $p = .10$, Cohen's $d = 0.27$], suggesting that our masking procedures were effective in preventing primes from reaching participants' conscious awareness. Additionally, we verified that *d'* did not vary reliably as a function of cue validity [$t(39) = 0.29$, $p = .76$, Cohen's $d = .06$], visual field [$t(39) = 0.40$, $p = .69$, Cohen's $d = .09$], or prime type [$t(39) = –0.11$, $p = .91$, Cohen's $d = .03$].

## Discussion

The present study establishes that the masked congruence priming effect (MCE) for faces in a sex-categorization task
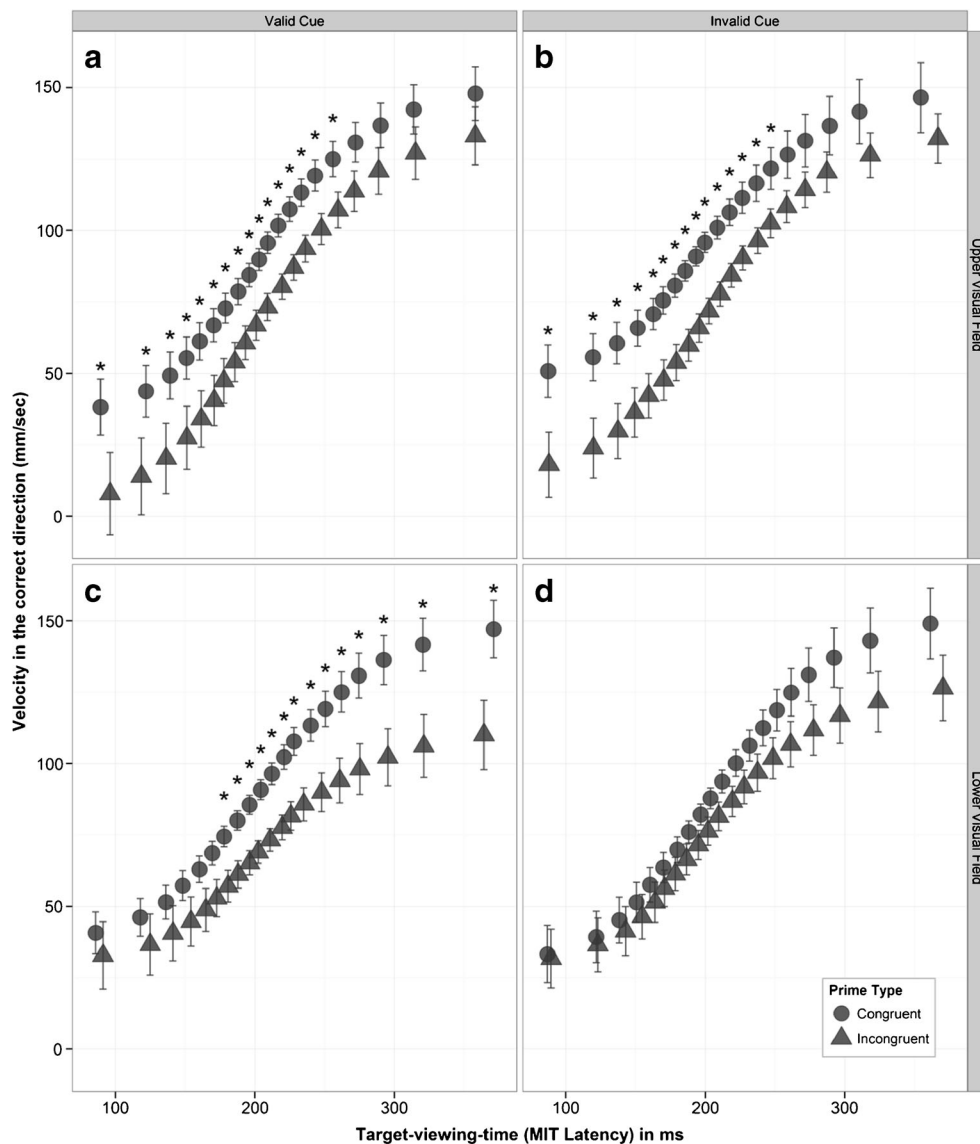
**Fig. 6** The masked congruence effect (MCE) reflected in initial x-velocity, shown as a function of cue validity for the upper visual field (UVF; panels a and b) and lower visual field (LVF; panels c and d). Here we are interested in asking when the MCE becomes significant. It is clear from the panels above that this time course depends on both the vertical hemifield and the validity of the spatial cue. For faces in the UVF, cue validity did not affect when the MCE emerged in stimulus-processing time. Both the (a) valid and (b) invalid cue conditions yielded a significant MCE from ~90 ms of target-viewing time onwards (i.e., from the 1st movement initiation time [MIT] quantile). In contrast, for faces in the LVF, priming depended on the allocation of spatial attention. In the (c) valid cue condition, the MCE emerged around ~180 ms of target-viewing time (7th MIT quantile). However, when the spatial cue was (d) invalid, the MCE failed to ever reach statistical significance. Asterisks denote .05 significant contrasts between the congruent and incongruent values at each MIT quantile (false discovery rate corrected)

is modulated by spatial location along the vertical meridian. Specifically, we have reported two results that demonstrate that the human visual system's capacity to extract task-relevant sex information from masked faces is superior in above-fixation locations as compared to below-fixation locations. By using a behavioral measure capable of revealing the gradual unfolding of experimental effects in the early stages of stimulus-processing time, we were able to observe that the *time course* of the MCE, our index of masked face-processing, differed between the vertical hemifields. A clear UVF advantage was evident in this regard, in that masked prime faces

presented above-fixation affected participants' classifications of the subsequent target as early as ~90 ms after target onset. In contrast, when the prime–target pair appeared below-fixation, participants needed to view the target for around ~180 ms before the effect of the prime on target classification was evident. That faces presented in the UVF elicited the MCE some ~80 ms sooner than those exact same faces presented in the LVF would suggest that participants processed the sex information in these faces more efficiently when they appeared above-fixation, allowing the prime to be integrated into the target-classification response sooner in the former

condition. In addition, we found that the MCE elicited by face primes presented in the upper-hemifield did not depend on the appropriate allocation of attention by a spatial cue—whereas it did for face primes presented in the lower-hemifield. That is, participants were able to process the sex information carried by a nonconscious prime face presented in the upper-hemifield even when attention had been captured away from the prime's location. In the lower-hemifield, however, the MCE was restricted to when a valid spatial cue captured attention to the prime. We concluded that this lack of an attentional benefit for faces presented above-fixation suggests that face-sex information is processed more efficiently in the UVF than in the LVF.

Taken together, these findings establish several important points. First, to our knowledge, these findings constitute the first behavioral demonstration that the MCE for face stimuli is sensitive to the influence of spatial location. Together with evidence that we have recently provided concerning the modulatory effects of spatial and temporal attention on masked face processing (Quek & Finkbeiner, 2013), the data reported here undermine the notion that face processing is "special," in the sense that nonconscious face processing is invulnerable to the influence of factors known to modulate masked priming effects for nonface stimuli (Lachter et al., 2004; Marzouki, Grainger, & Theeuwes, 2007; Naccache et al., 2002). However, whereas the presence of priming effects for alphanumeric and picture stimuli is modulated *categorically* as a function of attentional allocation (e.g., Finkbeiner & Palermo, 2009; Naccache et al., 2002), our data suggest that the processes underlying face-sex categorization are subject to a more subtle modulation by both location within the visual field and spatial attention, one that is reflected in the *time course* of the MCE rather than the presence or magnitude of this effect.

The results reported here also have implications for the wider face processing literature, in that they suggest that an evolutionarily critical behavior elicited by a face—that is, identifying its sex—is faster in the upper- than in the lower-hemifield. This result is consistent with existing neurophysiological data that suggest that UVF faces elicit shorter MEG peak latencies in face-responsive areas than do their LVF counterparts (Liu & Ioannides, 2010). Indeed, the vertical hemifield manipulation in our study modulated participants' behavioral responses to face stimuli within the same early stage of stimulus processing in which neural effects have previously been shown (i.e., <200 ms from target onset). Importantly however, where Liu and Ioannides reported a UVF advantage for face processing in their neurophysiological (MEG) measure, they did not observe any visual field effects in their behavioral measure. Thus, it is not clear how to establish the relevance of their MEG results to human behavior. In contrast, by using a behavioral measure in our study, our results point to a *functional* above-fixation superiority for faces that is clearly

relevant to human behavior. That is, we have provided a compelling demonstration that the processing of faces qua faces (e.g., sex identification) is more efficient in the UVF than in the LVF—a finding that echoes Previc's (1990) suggestion that the visual capabilities of each vertical hemifield have become specialized to support the stimulus processing that tends to occur in that region of space. Where some have previously alluded to the possibility of such a UVF advantage for face processing (Fecteau et al., 2000; Kessler & Tipper, 2004; Liu & Ioannides, 2010), we believe that our findings constitute the first behavioral demonstration of such a vertical asymmetry for faces that is not confounded by hemispheric laterality effects or participant search strategies favoring the UVF.

It is worth noting that the *temporal* UVF advantage for masked face processing that we observed is in opposition to previous work that has suggested that the speed of information accrual is slower in the UVF than in the LVF (Carrasco, Giordano, & McElree, 2004). How might we account for our temporal upper-hemifield advantage for face processing when more low-level tasks (e.g., orientation discrimination) exhibit a disadvantage in the UVF relative to the LVF (Cameron, Tai, & Carrasco, 2002; Carrasco, Penpeci-Talgar, & Cameron, 2001)? Following Previc's (1990) suggestion regarding the functional specialization of visual processing, it may be that differences in processing efficiency between the vertical hemifields are *stimulus-specific.* According to this possibility, since the UVF is disproportionally represented in the ventral regions of striate and extrastriate cortex (Felleman & Van Essen, 1991; Sereno et al., 1995; Wandell, Dumoulin, & Brewer, 2007; Zeki, 1969), perhaps presentation above-fixation facilitates more efficient face-sex categorization due to the more direct projections from early visual ventral areas to the ventral visual pathways that have been suggested to support object recognition (i.e., "vision for perception"; Farah, 1990; Haxby et al., 1991; Ungerleider & Mishkin, 1982). In contrast, the same stimuli presented below-fixation may have to traverse a possibly less efficient pathway for object recognition processing, one that proceeds initially via the dorsal regions of early visual cortex—an area thought to contain more direct projections to the higher dorsal areas predominantly specialized for spatial-relation processing (i.e., "vision for action"; Haxby et al., 1991; Ungerleider & Mishkin, 1982). It is important to note, however, that, whereas Previc's suggestion assumed a preferred relationship between the UVF and faces, it could be that the UVF advantage that we have reported here generalizes to other stimulus types as well. This interesting possibility is outside the scope of the present article, however. We have sought here only to provide behavioral evidence that face processing does indeed exhibit vertical asymmetry—an idea that is far from being well-established in the literature. An obvious avenue for future research, then, will be a contrast of vertical asymmetry effects for face and nonface stimuli.

As a final point, we would suggest that the present findings contribute to the mounting evidence that argues against the long-held assumption of position invariance in object recognition (Cox, Meier, Oertelt, & DiCarlo, 2005; DiCarlo & Cox, 2007; Marr & Nishihara, 1978). Although we do not dispute that the face recognition system is robust to changes in position—after all, we do easily recognize the sex of a face regardless of where it appears—the evidence here suggests that face-sex recognition is not entirely position-invariant. Rather, our capacities for face processing appear to differ between the vertical hemifields in a subtle and brief way that favors the upper-hemifield.

## Conclusion

Using the reach-to-touch paradigm to reveal the gradual emergence of experimental effects in stimulus processing time, we have demonstrated that face-sex information processing is supported better at above-fixation locations than at below-fixation locations. Sex information contained within a masked prime face is able to affect participants' overt responses to a target face sooner when the prime is presented in the UVF rather than the LVF. This finding, observed directly in face-perception performance, rather than in neural activity correlated with face perception, clearly establishes the existence of functional upper-hemifield superiority in face-sex categorization, which could extend to other aspects of face recognition as well.

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