

# Faster, stronger, lateralized: Low spatial frequency information supports face processing

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## ARTICLE INFO

### Article history:

Received 24 May 2011

Received in revised form 25 August 2011

Accepted 31 August 2011

Available online 16 September 2011

### Keywords:

Face perception

Place perception

Low spatial frequency

Visually guided reaching

## ABSTRACT

Distinct visual pathways are selectively tuned for processing specific spatial frequencies. Recently, Awasthi, Friedman, and Williams (2011) reported fast categorisation of faces at periphery, arguing for primacy of low spatial frequency (LSF) information in face processing. However, previous studies have also documented rapid categorization of places and natural scenes. Here, we tested if the LSF advantage is face specific or also involved in place perception. We used visually guided reaching as a continuous behavioral measure to examine the processing of LSF and high spatial frequency (HSF) hybrids, presented at the periphery. Subjects reached out and touched targets and their movements were recorded. The trajectories revealed that LSF interference was both 95 ms earlier and stronger for faces than places and was lateralized to the left visual field. The early processing of LSF information supports the assumption that faces are prioritised and provides a (neural) framework for such specialised processing.

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## 1. Introduction

The visual system breaks down input from the environment into discrete neural signals that are processed by distinct channels tuned to specific spatial frequency information (De Valois & De Valois, 1988; De Valois, Albrecht, & Thorell, 1982). Decades of research have explored the role of spatial frequency (SF) in visual processing. Extraction of spatial frequency happens early in visual processes (De Valois & De Valois, 1988; Sowden & Schyns, 2006). Two separate channels, namely magnocellular and parvocellular pathways, are known to be selectively tuned to bands of spatial frequency. The low spatial frequency (LSF) channels are anatomically structured for faster transduction of visual signals to the subcortical and cortical regions carrying large-scale luminance variations (i.e., coarse information). High spatial frequency (HSF) information represents small-scale luminance variations (i.e., fine information) and has a comparatively slower transmission via the parvocellular pathway (Bullier, 2001; Livingstone & Hubel, 1988).

Early research suggested that LSF information facilitates global processing of the stimulus while HSF information supports feature based processing (Sergent & Hellige, 1986; Sergent, 1985). In recent years, researchers have argued that configural processing of facial information is supported by LSF information (Goffaux & Rossion, 2006; Goffaux, Hault, Michel, Vuong, & Rossion, 2005). More recently, Crouzet, Kirchner, and Thorpe (2010) reported that

face detection is ultra-rapid and saccades towards human faces are fast and not completely under instructional control. Others have also reported rapid detection of threat cues carried via LSF information (Mermillod, Droit-Volet, Devaux, Schaefer & Vermeulen, 2010; Vlamings, Goffaux, & Kemner, 2009).

Recent ERP studies also reported a relatively higher LSF contribution to early processing differences between face and object perception (Goffaux, Gauthier, & Rossion, 2003; Goffaux, Jemel, Jacques, Rossion, Schyns, 2003; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005). Other studies (Goffaux et al., 2003a,b, 2005) have discussed the preferential role of LSF wherein frequencies below 1.86 cycles/degree (8 cycles/image) were found to be more important in face processing. Examining the role of low and high SF in configural and featural processing of faces, Goffaux et al. (2005) reported a strong performance advantage using LSF information (<8 cpf) for configural processing and HSF (>32 cpf) support for featural processing.

In contrast, Halit, de Haan, Schyns, and Johnson (2006) argued that although LSF faces elicited a robust N170 compared to HSF faces (which elicited a significantly smaller response), HSF information is not redundant and contains important information. Further, Flevaris, Robertson, and Bentin (2008) reported that both LSF and HSF are equally important when faces are not the targets. Through an ERP study, Flevaris et al. (2008) suggested that the distinction between faces and cars can be made efficiently using both LSF and HSF information, and argued for relatively automatic access of LSF and HSF during early face categorization.

It has been discussed that face processing is more sensitive to SF than the processing of other visual object categories (Biederman & Kalocsai, 1997; Collin, Liu, Troje, McMullen, & Chaudhuri, 2004;

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Goffaux et al., 2003a,b; Liu, Collin, Rainville, & Chaudhuri, 2000; also see Williams, Willenbockel, & Gauthier, 2009). However, rapid detection and categorisation of scenes, is also documented by previous research (Johnson & Olshausen, 2003; Thorpe, Fize, & Marlot, 1996) and has implicated a possible role of the magnocellular pathway (Delorme, Richard, & Fabre-Thorpe, 1999; Delorme, Richard, & Fabre-Thorpe, 2000; Nowak & Bullier, 1997; Schyns & Oliva, 1994). Rousselet, Macé, and Fabre-Thorpe (2003) reported that besides faces, scenes and other visual categories can all be categorized rapidly with high accuracy. Other studies by Li, VanRullen, Koch, and Perona (2002) as well as VanRullen and Thorpe (2001) have also reported rapid processing of briefly viewed natural scenes and other non-face stimuli.

In recent times, the diagnostic approach to visual processing suggests that task requirements determine the information (either LSF or HSF) that could support quick processing of a variety of stimuli such as faces, houses, natural scenes and other objects (Schyns & Oliva, 1997). In a previous study exploring the relative role of LSF and in LSF–HSF hybrid faces, we demonstrated interference by LSF information at periphery (Awasthi, Friedman & Williams, 2011). Here we extend those findings to examine if the LSF bias for faces also extends to the non-face object category using visually guided reaching as a continuous behavioral measure. We used spatially filtered hybrids of faces and places to explore the relative role of LSF in processing of place vis-à-vis face images.

We used reaching trajectories as our dependent measure because of our interest in the evolution of the perceptual dynamics of LSF processing in faces and places. Here, the targets are in HSF condition and subjects are not privy to the LSF images in the hybrids. Reaching trajectories as a continuous behavioral measure can provide a window to the perceptual decision making process in real time (Song & Nakayama, 2009; Spivey & Dale, 2004). Tracking of hand movements are reported to provide unusually high-fidelity, real-time access to fine-grained traces of the perceptual phenomena (Freeman & Ambady, 2011; Freeman, Dale & Farmer, 2011; Spivey & Dale, 2006). In the present study, subjects start moving before they arrive at a decision and their arm movements allow us to observe how the decision evolves. Consequently, as we forced subjects to move early, reliable reaction time measures cannot be obtained.

A 'change of mind' in everyday decision-making is reflected in the shifts present in arm movements that accompany perceptual decisions (Walsh & Anderson, 2009). Indirect inferences from stimulus characteristics and discrete behavioral measures, such as reaction times and accuracy (as well as errors) provide, at best, the final decision parameters of perceptual processes. Eye movements and hand reaching have their distinct benefits. However, hand movements serve as a *continuous* measure as opposed to *discrete* saccades involved in eye tracking (Magnuson, 2005). Reaching trajectories can index rapid shifts in processing stages and can reveal "hidden" cognitive states that are otherwise not captured by discrete traditional measures (Resulaj, Kiani, Wolpert, & Shadlen, 2009; Song & Nakayama, 2009).

In reaching, the continuous nature of arm movements allows subjects to make partial responses on a trial-by-trial bases, as opposed to eye-movements where saccades are not partial movements. Analyzing the shapes of the trajectories allows early access to the state of the decision making process while the subjects reach to the targets. We expected to observe early LSF processing through differences in the arm trajectories in congruent and incongruent conditions (outlined in the experiments-design section).

## 2. Methods

### 2.1. Stimuli

We used a customized code (adapted from Schyns & Oliva, 1999) for band pass filtering the images of faces and places. Contrast and luminance for the images was

approximately the same. The overlap of spatial frequency (SF) bands in the hybrids facilitates recognition as well as makes the stimuli balanced and comparable in terms of low-level visual presentation, contrast and luminance. We excluded the medium spatial frequencies (8–25 cycles per face-width, cpf) – thought to be the best combination of coarse and fine cues for face recognition (Liu et al., 2000) – to maximize the difference between our conditions. (Medium spatial frequency can convey both configural and feature-based information, thus being irrelevant to the issues being addressed in this study.)

Unfamiliar face and place images were collected from the internet and were converted to gray scale using the Gimp image manipulation program (<http://www.gimp.org>) to remove external features (neck and hairline) from faces and background information from places. The images were resized to 400 × 400 pixels and the mean luminance was approximately the same for all pictures. Using Matlab (The Mathworks Inc.), the images were Fourier transformed and multiplied by low-pass and high-pass Gaussian filters to preserve low (below 8 cpf) and high SF (above 25 cpf) information in each image. These were then superimposed to create the final LSF–HSF hybrid images.

### 2.2. Design

Four combinations of hybrid images were used in the experiment (see Fig. 1a). Congruity was defined as the category of the HSF image being the same as that of the LSF image. Thus, **PP** (LSF Place–HSF Place) and **FF** (LSF Face–HSF Face) were congruent whereas **FP** (LSF Face–HSF Place) and **PF** (LSF Place–HSF Face) were incongruent conditions. The within-subjects factors were Target Location (left or right), Target Congruity (congruent, incongruent) and Distractor Conflict (present, absent). All factors were fully crossed, yielding eight experimental conditions (FF vs. FP, FF vs. PP, PF vs. FP, PF vs. PP, FP vs. FF, PP vs. FF, FP vs. PF, PP vs. PF).

Either place or face was assigned as a target at the beginning for each session (in a counter-balanced fashion). That means, each subject had the same target for the entire experiment (e.g., reach out and point to the place). At viewing distance, the HSF image was visible; therefore it was always the target. Along with congruity, we also manipulated whether the hybrid on the other side of the target location held an LSF distractor (e.g., an LSF place) or not (e.g., no LSF place). The HSF stimuli were always a face on one side and a place on the other. Two hybrids were presented at the left- and right-most sides of the touch screen monitor (Fig. 1b). Presentation software (Neurobehavioral Systems) was used to present the stimuli. The stimuli had a mean width of 5.7° visual angle and were presented 21.7° from fixation.

### 2.3. Procedure

Subjects sat in a quiet, dark room at a table with a LCD touch screen (70 × 39 cm, 1360 × 768 pixels, 60 Hz) positioned approximately 70 cm in front of them. Each trial began with subjects placing their right index finger on a centrally located button in front of the touchscreen. Hand movements were tracked with an Optotrak Certus Motion Capture System (Northern Digital Inc.) at a 200 Hz sampling rate. Two small markers (infrared light emitting diodes (LEDs)) were attached to the index fingertip of the right hand. The starting position (a button) was aligned with the body midline, approximately 20 cm in front of the subjects. The tracking system was calibrated at the beginning of each experiment.

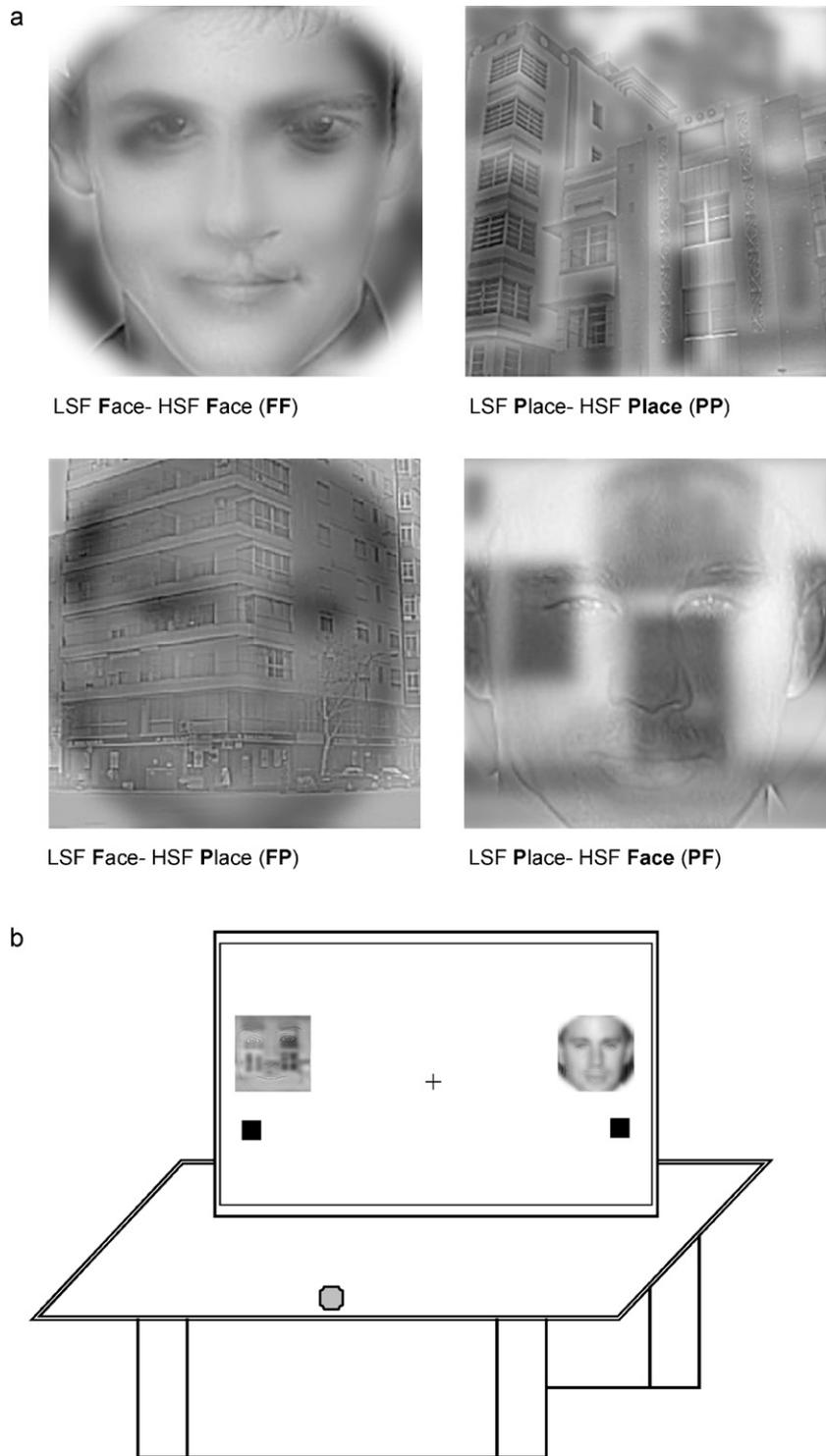
The subjects were instructed to maintain fixation on a cross at the centre of the screen (that appeared for 1000 ms followed by the hybrid images) before reaching out and pointing to the target. Subjects had to begin their reaching response within 350 ms of target onset. The trials were aborted when started too early (before the target onset) or too late (after 350 ms). For all responses, feedback was provided onscreen. In addition to two blocks of training, ten blocks of 40 trials each were carried out with adequate breaks and the experiment finished within an hour. Only the correct response trials were used for further data analysis.

### 2.4. Subjects

Twenty-four right-handed subjects (target place: 8 F, 4 M, mean age: 26.6 years, SD = 7.1; target face: 10 F, 2 M, mean age: 25.2 years, SD = 5.3) were recruited from the Macquarie University community and were paid for their time. All subjects had normal or corrected-to-normal vision. The experimental protocol was approved by the Human Research Ethics Committee of the university and the subjects gave written, informed consent before participation. The subjects had a mean accuracy rate of 93.3% (SD = 8.6) for place targets and 94.3% (SD = 7.1) for face targets.

### 2.5. Data analysis

We used cubic splines for data smoothing and interpolation when markers were occluded (for less than 10% of the trajectory). Movement data was analysed using Matlab. We calculated the deviation from a straight-line path from start to end of the movements. Curvature was then defined as the ratio of this deviation to the length of the straight-line path (Atkeson & Hollerbach, 1985; Smit & Van Gisbergen, 1990). The average maximum curvature was computed for all subjects in the eight conditions and used as the dependent variable in the following statistical analyses.



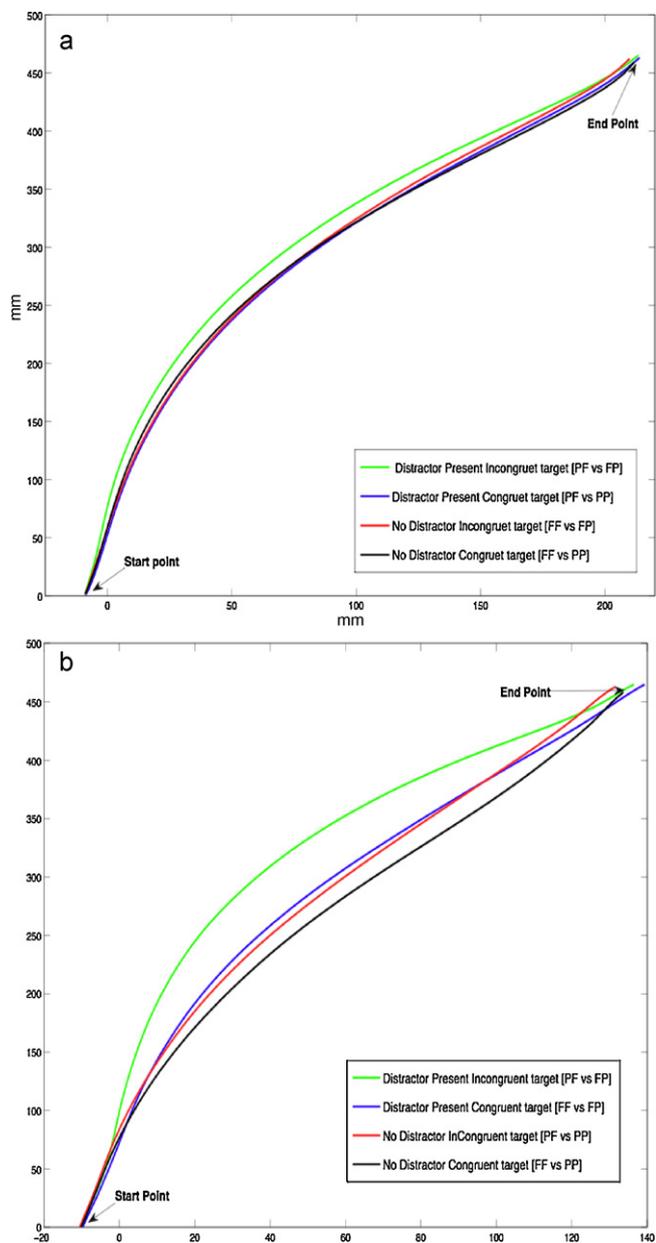
**Fig. 1.** (a) Stimuli: LSF–HSF hybrid images used in the experiment. To see the LSF content, squint, blink, or step back from the figure (b). Experimental setup showing the touchscreen where two hybrid images were presented peripherally. Subjects start each trial at gray button to reach out and touch the respective black target box on the screen.

### 2.6. Statistics and permutation analysis

A mixed-design ANOVA was carried out with the experiment group (target face, target place) as a *between-subjects* factor and target congruity (congruent, incongruent), distractor conflict (present, absent) and target location (left, right) as *within-subjects* factors. We also compared the curvature across conditions as a function of time (from 100 to 550 ms after target onset). To control for the multiple comparisons that are required in the analysis of continuous data, we used a paired sample permutation test based on a *t*-statistic (procedure described in detail by Blair & Karniski, 1993).

This procedure begins by assuming the null hypothesis, i.e., no difference between congruity conditions. In this case, the order of the observed conditional means is arbitrary (i.e., the observed mean in congruent conditions is just as likely to have occurred as in incongruent conditions). We used a one-sided *t*-test (upper tailed test; with tail=1, the alternative hypothesis that the mean of the data is greater than 0).

The means from each subject were systematically re-ordered yielding  $2^N$  permutations where *N* is the number of subjects. For each target type, we used the  $2^{12} = 4096$  permutations and with each permutation, a paired-sample *t*-test was conducted on each time point. We calculated the maximum *t*-statistic for each per-



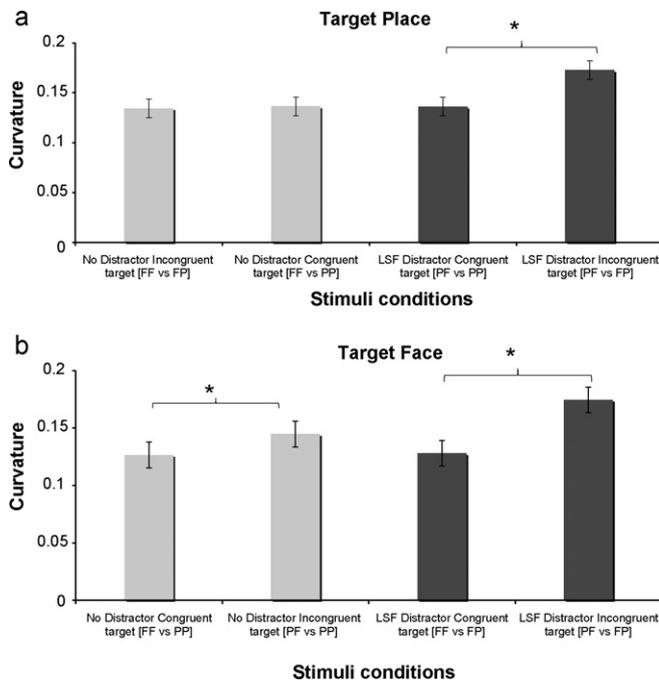
**Fig. 2.** (a) Mean trajectories for place target condition (b). Mean trajectories for face target condition.

mutation and the difference between conditions was then considered significantly different at 0.05 level for a given time, if the *t*-statistic for the correct labeling is greater than the maximum *t*-statistic of 95% of the relabeled combinations.

### 3. Results and discussion

An average of time-normalized trajectories of four conditions for place and face targets for all subjects, is shown in Fig. 2. A mixed-model ANOVA revealed a significant main effect of target congruity  $F(1,22) = 23.95, p < 0.001$  and distractor conflict  $F(1,22) = 38.52, p < 0.001$ . Between-subjects effects revealed no significant difference between the groups ( $F(1,22) = 3.26, p = 0.085$ ). For both experiment groups, maximum curvature per condition, averaged across all subjects is shown against stimuli conditions in Fig. 3.

While the mean curvature across conditions for targets appearing on the left was approximately the same across the two experimental groups (face mean: 0.143; place mean: 0.145),

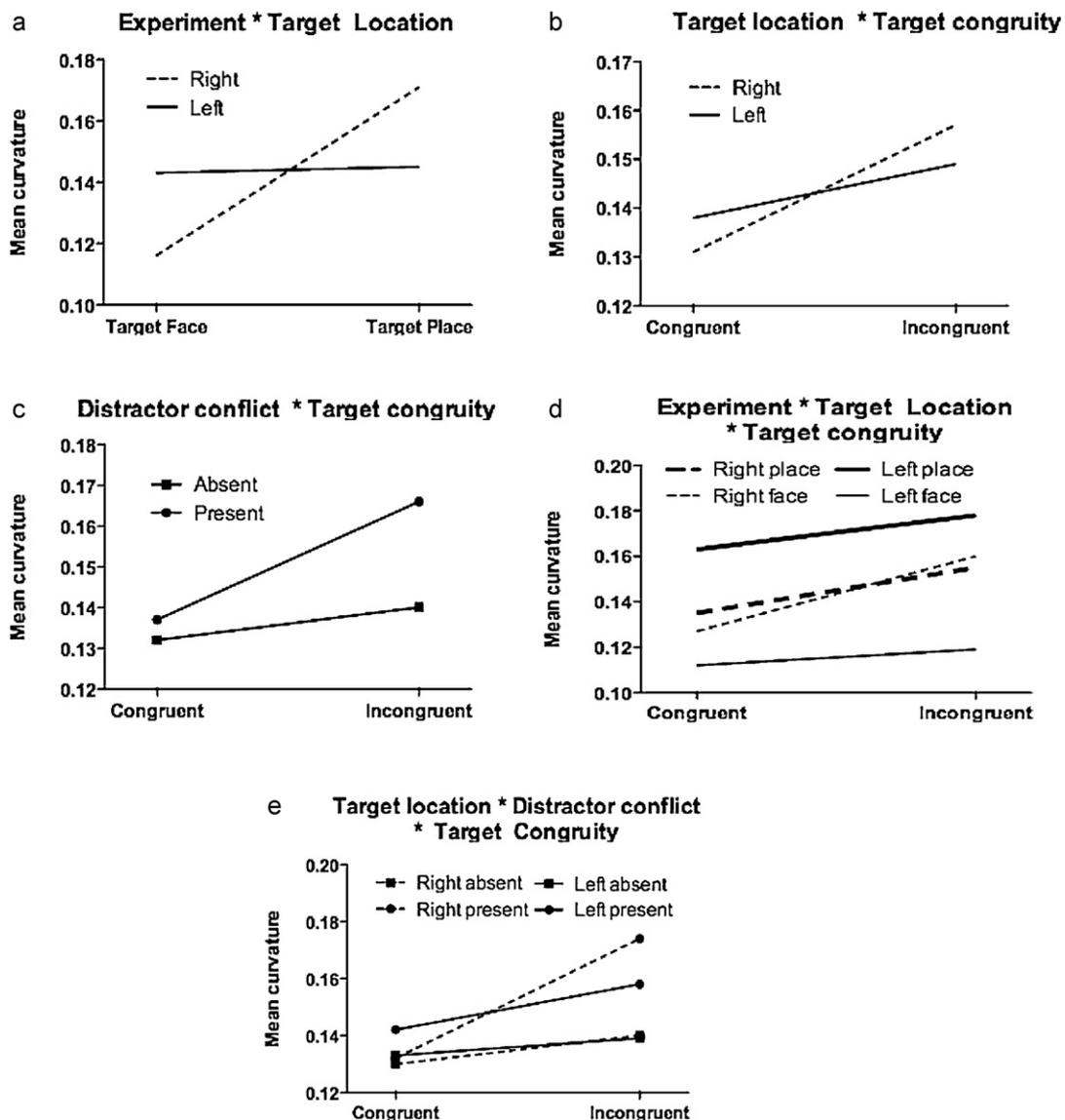


**Fig. 3.** (a) Target Place: Graph showing mean values of the maximum curvature plotted against stimuli conditions. Error bars indicate standard errors of the mean (SEM) and the asterisks (\*) denote significant effect. Incongruent trials show significantly larger curvature than congruent trials. (b) Target face: graph showing mean values of the maximum curvature plotted against stimuli conditions. Error bars indicate standard errors of the mean (SEM) and the asterisks (\*) denote significant effect. Incongruent trials show significantly larger curvature than congruent trials.

targets appearing on the right affected the curvature differently for the two groups. This is observed through a significant interaction between target location and experiment Group  $F(1,22) = 7.45, p < 0.001$  (Fig. 4a). Further, a post-hoc (Tukey HSD) analysis confirmed a significantly larger curvature for face targets ( $p = 0.04$ ) on the left (mean = 0.143) than on the right (mean = 0.116); whereas for place targets, the differences were not significant ( $p = 0.12$ ).

The congruity effect was stronger for targets on the right as shown by a significant interaction between target location and target congruity  $F(1,22) = 8.16, p < 0.001$  (see Fig. 4b). The effect of target congruity and presence of distractor conflict is additive as indicated by the significant interaction between target congruity and distractor conflict  $F(1,22) = 31.95, p < 0.001$  (see Fig. 4c). A significant three-way interaction between experiment group, target location and target congruity  $F(1,22) = 4.28, p < 0.001$  was a significant predictor of the laterality effects for the face target condition (Fig. 4d). For face targets, the congruity effect (for the three-way interaction between experiment  $\times$  target location  $\times$  target congruity) was larger for right, compared to left target locations. The congruity effect was not significantly different between left and right place targets. Post hoc (Tukey HSD) analysis confirmed a significantly larger curvature ( $p = 0.02$ ) for incongruent face targets on the left (mean = 0.15) than on the right (mean = 0.11); whereas for place targets, the differences were not significant ( $p = 0.21$ ). This result further supports the left visual field bias for faces.

The final interaction between target location, target congruity and distractor conflict  $F(1,22) = 15.06, p < 0.001$  (Fig. 4 e) shows that the differences between the congruity effect for right and left target locations is larger when the distractor is present, confirming the additive nature of target congruity and distractor presence. No other effects or interactions reached significance. Tests of violations of sphericity were performed on the data.



**Fig. 4.** Graphs showing significant interactions between conditions: (a) Significant 2-way interaction between Experimental group and Target location. (b) Significant 2-way interaction between Target location and Target Congruity. (c) Significant 2-way interaction between Distractor Conflict and Target Congruity. (d) Significant 3-way interaction between Experimental group, Target location and Target Congruity. (e) Significant 3-way interaction between Target location, Distractor Conflict and Target Congruity.

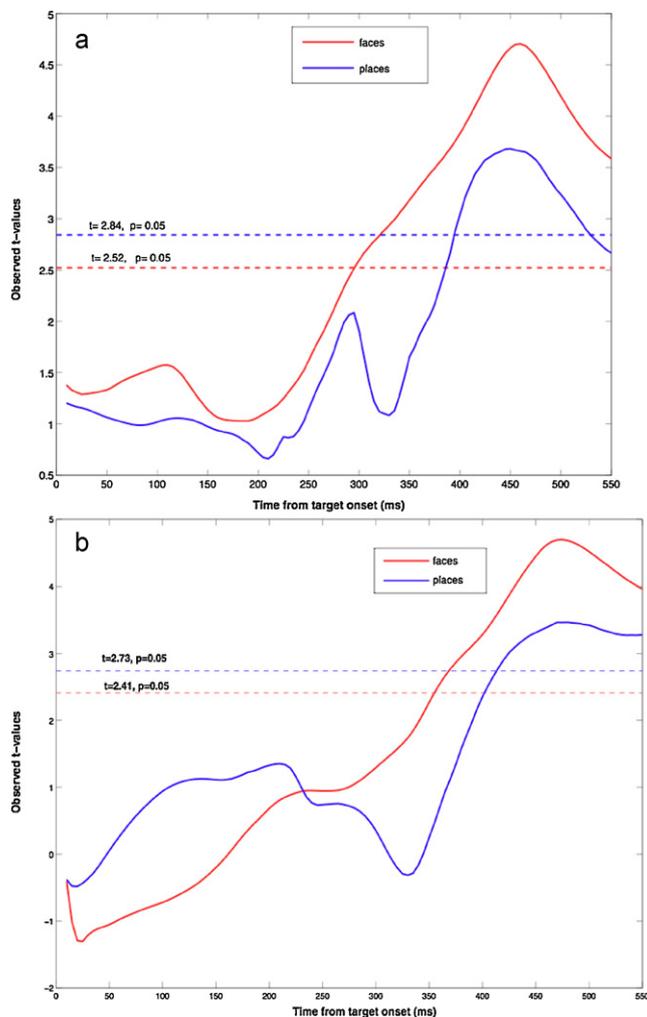
To better understand the time course of the effects of LSF interference, we calculated the difference in curvatures between congruity conditions at each time point from 100 to 550 ms from target onset, using permutation analysis. The curvature means from each subject were systematically re-ordered yielding  $2^{12} = 4096$  permutations for each (face and place target) condition. With each permutation, a paired-sample *t*-test was conducted at each time point. We then calculated the maximum *t*-statistic for each permutation and the difference between conditions was then considered significantly different at 0.05 level for a given time. Since we used a one-sided *t*-test, we take the *t*-value that cuts off 0.05% of the tail of the reference distribution. The critical *t*-values were 2.52 for faces and 2.84 for places. For face targets, the effect of congruity was significant ( $p < 0.05$ ) beginning at 300 ms, whereas the significant differences in congruity for places begin at 395 ms after target onset ( $p < 0.05$ ) (see Fig. 5a). This means that for face targets, congruity differences due to the absence of LSF information begin 95 ms earlier than for place targets.

Further, to ascertain differences caused by the LSF distractor presence versus absence conditions, we ran another permutation analysis while keeping the congruity conditions constant. The

critical *t*-values were 2.41 for faces and 2.73 for places. For face targets, the effect of congruity was significant ( $p < 0.05$ ) beginning at 355 ms, whereas the significant differences in congruity for places begin at 415 ms after target onset ( $p < 0.05$ ) (see Fig. 5b). This suggests that for face targets, LSF interference by the distractor begins 60 ms earlier than for place targets. Overall, these results confirm that LSF information supports faster categorisation of faces than places.

#### 4. General discussion

The curvature in the reach trajectory is taken as a measure of uncertainty in the decision making process. This uncertainty may be due to target congruity (i.e., absence of rapid facilitatory effects of LSF information in incongruent targets) or the presence of the target-match LSF distractor. When subjects select a target and do not change their mind (i.e., when the LSF and HSF components unambiguously correspond to one target), they reach directly to the target, and the curvature is low. When there are competing sources of information (i.e., the LSF and HSF are incongruent, or



**Fig. 5.** a. Timing differences in trajectories at the point of significant difference in congruity conditions. Face target condition showing  $t$ -values starting to become significantly different at 300 ms from target onset. Place target condition showing  $t$ -values starting to become significantly different at 395 ms from target onset. (b) Timing differences in trajectories at the point of significant difference for distractor present versus absent condition. Face target condition showing  $t$ -values starting to become significantly different at 355 ms from target onset. Place target condition showing  $t$ -values starting to become significantly different at 415 ms from target onset.

there is an LSF distractor on the other side), this uncertainty in the decision making process is reflected through a greater curvature.

For both place and face target conditions, the significant effect of target congruity as well as that of distractor conflict indicates LSF interference while reaching to HSF targets. Further, a main effect of target location for faces as well as significant interactions between location and congruity suggest a lateralization effect by LSF information for faces. Contrary to the place target condition, for the face target condition, the curvature means were larger for LSF distractor faces in the left visual field than in the right. Temporal analysis of the trajectories revealed that LSF interference for faces is faster than places.

An interesting aspect of reaching is observed when the target is incongruent and no distractor is present. If subjects used only salient HSF information, no difference would be observed due to target congruity (i.e., between congruent and incongruent trials). A statistically significant effect of target congruity implies that in reaching to HSF targets, the early perceptual response is driven by LSF information. For instance, for a face target (F) appearing on the right side of the screen, in a congruent condition (FF), subjects

moved straight towards the target. In contrast, in an incongruent condition (PF), the trajectories take a more curved path while reaching to the target. In both conditions, there was no LSF distractor conflict present (i.e., PP on the left). However, when the LSF distractor conflict is present and the target condition is congruent (FP vs FF), subjects started moving towards the left (responding to the face in the LSF distractor, in FP) and then changed direction to reach the target. Finally, when the LSF distractor conflict is present and the target condition is incongruent (FP vs PF), the reaching trajectories show a significantly larger curvature than in all the previous conditions.

There is a possible confound of non-target incongruity and distractor presence, because whenever the distractor is present, the non-target is incongruent. However, based on our other findings, it seems unlikely that non-target incongruity would cause larger curvature—there is no reason why this incongruity would cause subjects to move more towards the non-target. Rather, it is more likely that the larger curvature is due to distractor presence, where the presence of the target sex in the LSF component on the opposite side causes the arm movements to be “drawn” towards the non-target. This explanation is parsimonious with the other findings.

Permutation analysis, to ascertain time differences between the congruent and incongruent reaching conditions revealed important findings. For the place target condition, trajectory differences in target congruity (congruent and incongruent target conditions) reach significance at about 395 ms after target onset. In contrast, for the face target condition, trajectory differences for congruity reach significance much earlier, at about 300 ms from target onset. In the second analysis examining differences between distractor present versus absent conditions while keeping the other information constant, the trajectory differences were 60 ms faster for faces. These results suggest that LSF information is processed faster for faces than for places.

This work extends our recent findings that low spatial frequency information supports processing of faces at periphery (Awasthi et al., 2011). We have found that LSF information at the periphery supports processing of both places and faces, though the (LSF) interference for faces is stronger, earlier and shows a lateralization effect. Previous research reports of early behavioral and ERP components (Alorda, Serrano-Pedraza, Campos-Bueno, Sierra-Vazquez, & Montoya, 2007; Goffaux et al., 2003a,b) elicited by LSF filtering of stimuli also argue for LSF-driven early visual processing of faces. Goffaux et al. (2003a,b) ascribe extraction of LSF information to be the source of early processing differences between faces and objects. Alorda et al. (2007) reported that affective LSF faces elicited an enhancement of brain responses at early, but not at later latencies. Our findings provide further support to the proposal by Goffaux et al. (2003a,b, 2005) and Alorda et al. (2007) that LSF could support differential and specialized processing of stimuli with emotional or motivational relevance.

In a recent eye movement study, Honey, Kirchner, and VanRullen (2008) reported a fast saccadic bias towards faces and attributed this bias to low-level information, in particular the 2-D fourier amplitude spectrum (orientation and phase information). Similarly, in another eye-movement study, Morand, Grosbras, Caldara, and Harvey (2010) used an anti-saccade paradigm to investigate whether face-specific biases rely on automatic (involuntary) or voluntary orienting responses. Morand et al. reported a significant increase in anti-saccade error rates for faces, compared to cars and noise patterns, and faster pro-saccades for faces and cars in comparison to noise patterns. Their findings show that humans can respond with a saccadic eye movement towards faces much faster and with less error than towards other objects.

Saccadic eye movements are believed to be controlled by a variety of cortical (frontal eye fields, dorsolateral prefrontal cortex,

lateral intraparietal area) and subcortical regions (superior colliculus). Superior colliculus is known to be responsive to LSF information and according to Kirchner and Thorpe (2006), a rapid and parallel update of visual information between V4 and cortical areas like frontal eye fields, lateral intraparietal area and superior colliculus, could account for fast saccadic responses to faces, thereby escaping slower-grained processing along the ventral pathway.

Jebara, Pins, Despretz, and Boucart (2009), reported superiority for face categorisation compared with buildings in peripheral vision. In contrast, our study shows that LSF supported rapid categorisation can be performed at large eccentricities for both faces and buildings when the task does not require detailed analysis. In an fMRI study, Peyrin, Baciú, Segebarth, and Marendaz (2004) also reported that rapid visual recognition of natural scenes relies mainly on LSF information. They found higher activation by LSF (relative to HSF) within brain areas involved in place processing but speculated that the LSF bias could be due to a property of spatial frequency per se, rather than the reliance on LSF for fast categorisation of places. Our study, however, provides behavioral evidence for LSF support for rapid processing of places. In accordance with the diagnostic approach, it seems that LSF information facilitates the processing of peripherally presented faces and places.

There has been much debate regarding the role of LSF and HSF information in face processing (Cheung, Richler, Palmeri, & Gauthier, 2008; Richler, Mack, Gauthier, & Palmeri, 2009). We demonstrate a novel way to look at the issue. Using LSF–HSF hybrids and reaching trajectories as a continuous behavioral measure, we were able to tease apart the relative role of LSF and HSF information. Previous behavioral research has suggested that faces are processed more globally or configurally than other visual stimuli (Behrmann, Winocur, & Moscovitch, 1992; Farah, Wilson, Drain, & Tanaka, 1998; Maurer, Le Grand, & Mondloch, 2002; Tanaka & Farah, 1993; Young, Hellawell, & Hay, 1987). This global processing of faces could be facilitated by greater LSF support for faces.

Our findings confirm and extend previous studies that demonstrate a left hemifield bias for faces. Several behavioral studies (Butler et al., 2005; Gilbert & Bakan, 1973; Le Grand, Mondloch, Maurer, & Brent, 2003; Newcombe, deHaan, Ross, & Young, 1989) report a left visual field bias for face perception. In addition, ERP (Bentin, Allison, Puce, Perez, & McCarthy 1996; George, Evans, Fiori, Davidoff, & Renault, 1996) and positron emission tomography studies (Haxby, Ungerleider, Horwitz, Rapoport, & Grady, 1995; Horwitz et al., 1992) argue for a right hemispheric advantage for face processing. Several fMRI studies (Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996) also report strong right-lateralized activation in the fusiform gyrus. Peyrin, Chauvin, Chokron, and Marendaz (2003), and Peyrin, Mermillod, Chokron, and Marendaz (2006) have suggested right hemispheric superiority for processing of LSF information. The left visual field bias for faces observed in the current study is likely to be supported by LSF information.

Faces are visual stimuli of high biological significance that serve as a valuable signalling system and hence require rapid processing (to detect threat cues) supported by LSF information (Mermillod et al., 2010). The temporal precedence of LSF information for faces, in contrast to places, conveys coarse configuration cues, particularly salient in face processing. Our novel findings of early preferential processing of LSF faces at the behavioral level as well as hemispheric specialization adds to the body of evidence that human faces are 'special' – i.e., they are processed in a qualitatively different manner than other visual stimuli. Taken together, our findings demonstrate faster and stronger LSF support for face processing, as well as reinforce the claim that spatial frequency processing is one of the early driving factors in the organization of visual representations.

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