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Brief communication

Processing of low spatial frequency faces at periphery in choice reaching tasks

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ABSTRACT

Various aspects of face processing have been associated with distinct ranges of spatial frequencies. Configural processing of faces depends chiefly on low spatial frequency (LSF) information whereas high spatial frequency (HSF) supports feature based processing. However, it has also been argued that face processing has a foveal-bias (HSF channels dominate the fovea). Here we used reach trajectories as a continuous behavioral measure to study perceptual processing of faces. Experimental stimuli were LSF–HSF hybrids of male and female faces superimposed and were presented peripherally and centrally. Subject reached out to touch a specified sex and their movements were recorded. The reaching trajectories reveal that there is less effect of (interference by) LSF faces at fovea as compared to periphery while reaching to HSF targets. These results demonstrate that peripherally presented LSF information, carried chiefly by magnocellular channels, enables efficient processing of faces, possibly via a retinotectal (subcortical) pathway.

1. Introduction

Our visual system enables fast and seemingly effortless recognition of faces under varying viewing conditions. Various aspects of facial information have been associated with distinct ranges of spatial frequencies (SF). For example, sex identification may rely on low spatial frequency (LSF) information, whereas finer aspects like emotional expression processing may rely on high spatial frequency (HSF) information (Schyns, Bonnar & Gosselin, 2001). LSF features of an image capture large-scale luminance variations (i.e. coarse information) as opposed to HSF features, which represent small-scale luminance variations (i.e., fine information; De Valois & De Valois, 1988). Configural processing, which has been associated with face perception, depends chiefly on LSF information (Goffaux & Rossion, 2006). In contrast, feature based processing is largely dependent on HSF information.

Recent behavioral studies (Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffaux & Rossion, 2006), single cell recordings (Rolls & Baylis, 1986), and neuroimaging studies (Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Rotshtein, Vuilleumier, Winston, Driver, & Dolan, 2007; Vuilleumier, Armony, Driver, & Dolan, 2003) support the differential role of spatial frequency in various aspects of face processing. It has been suggested that low spatial resolution faces are processed primarily through a subcortical route (Johnson, 2005; Morris, deGelder, Weiskrantz, & Dolan, 2001; Vuilleumier et al., 2003). However, it has also been demonstrated that face processing has a central field bias (Kanwisher, 2001; Levy, Hasson, Avidan, Hendler, & Malach, 2001). As HSF channels dominate central vision (De Valois & De Valois, 1988), this creates a conflicting situation: faces are processed configurally (supported by LSF channels), but also centrally (dominated by HSF channels). In order to better understand how faces are processed by the visual system, it is necessary to determine the relative contribution of LSF and HSF information in face processing and how this affects recognition.

Our study examines how LSF–HSF hybrid faces are processed when presented centrally and peripherally. We used hybrid images containing both low and high spatial frequency information within each stimulus to avoid effects due to the stimulation of one or another SF range (Schyns & Oliva, 1994). This 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) to maximize the difference between our conditions.

The LSF–HSF hybrids were utilized in a set of experiments involving sex-categorization tasks. Instead of a discrete button press response, reaching trajectories were used as a continuous behavioral measure. Reaching trajectories reveal perceptual decision making processes in real time (Song & Nakayama, 2009; Spivey & Dale, 2004). We took advantage of this continuous behavioral measure to examine the relative order of processing of LSF and HSF information. We expected to observe interference by LSF information while reaching to HSF targets, reflected through differences in the arm reaching trajectories in congruent and incongruent conditions (outlined in Section 2.2).

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2. Experiment 1

2.1. Subjects

Twelve right-handed subjects (eight females, four males, mean age: 25.1 years, SD = 3.0) were recruited from the Macquarie University community and were paid for their time. All subjects had normal or corrected-to-normal vision and gave written, informed consent before participation. All procedures were approved by the Human Research Ethics Committee of the university.

2.2. Apparatus, stimuli and design

Unfamiliar face images were converted to gray scale using Gimp (http://www.gimp.org) to remove external features (neck and hairline). The images were resized to 400 × 400 pixel resolutions and the mean luminance was approximately the same for all pictures. Using Matlab (The Mathworks, Inc.), they were Fourier transformed and multiplied by low-pass and high-pass Gaussian filters to create LSF (below 8 cpf) and HSF (above 25 cpf) versions of each image with the algorithm adapted from Schyns and Oliva (1999). These were then superimposed to create the final LSF–HSF hybrid images.

Four combinations of hybrid images were used in the experiment. A three-factor within-subjects design was used, the factors being Target Location (left or right), Target Congruity (congruent, incongruent) and Distractor Conflict (present, absent). All factors were fully crossed, yielding eight experimental conditions. Congruity was defined as the sex of the HSF face of being the same as that of the LSF face in a hybrid. Thus, MM and FF were congruent whereas FM and MF were incongruent conditions. For instance, in the hybrid image **MM**, the first letter (**M**) of the hybrid indicates the sex of the LSF face (**M**ale) and the second letter (**M**) indicates the sex of the HSF face (**M**). For hybrid **FM**, the LSF face is **F**emale and the HSF face is **M**ale (Fig. 1a).

The target was the face of a particular sex for the whole block (e.g., Female). At viewing distance, the HSF face was the most visible; therefore it was effectively always the target. In 'congruent target' trials, the LSF and HSF faces of the target face were the same sex (e.g., both Female; FF). In 'incongruent target' trials, the LSF face was of the opposite sex (e.g., Male; MF). We also manipulated whether the face on the other side of the target location held a sex-match LSF distractor (e.g., an LSF female) or not (e.g., no LSF female). There was no HSF distractor. Two hybrid faces 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 cm × 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.

Subjects were assigned Male or Female as the target sex (counter-balanced across participants). They were instructed to maintain fixation on a cross at the centre of the screen (that appeared for 1000 ms followed by the hybrid faces) before reaching out and touching the target. Subjects had to begin their reaching

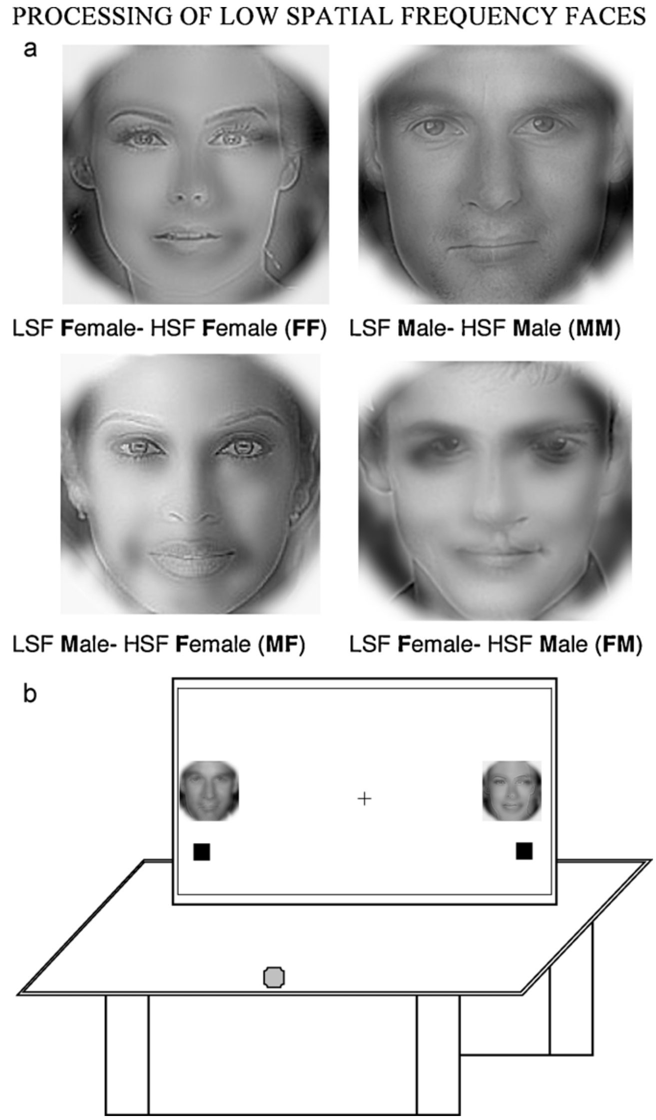

Fig. 1. (a) Stimuli: LSF–HSF hybrid images used in the experiments. To see the LSF content, squint, blink, or step back from (b). Setup for Experimental setup 1 showing the touchscreen where two hybrid images were presented peripherally. Subjects start each trial at gray button to reach out and touch the respective black target box on the screen. In Experiment 2, one hybrid was presented centrally, whereas in Experiment 3, two hybrids were presented peripherally and centrally in alternate blocks.

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. The subjects had a mean accuracy rate of 92.9% (SD = 4.0).

3. Results and discussion

We used cubic splines for data smoothing and interpolation when markers were occluded (for less than 10% of the trajectories). Movement data was analysed using Matlab. We calculated the maximum deviation from a straight-line path from start to end of the movements. We then defined maximum curvature as the ratio of this deviation to the length of the straight-line path (Atkeson & Hollerbach, 1985; Smit & Van Gisbergen, 1990). The

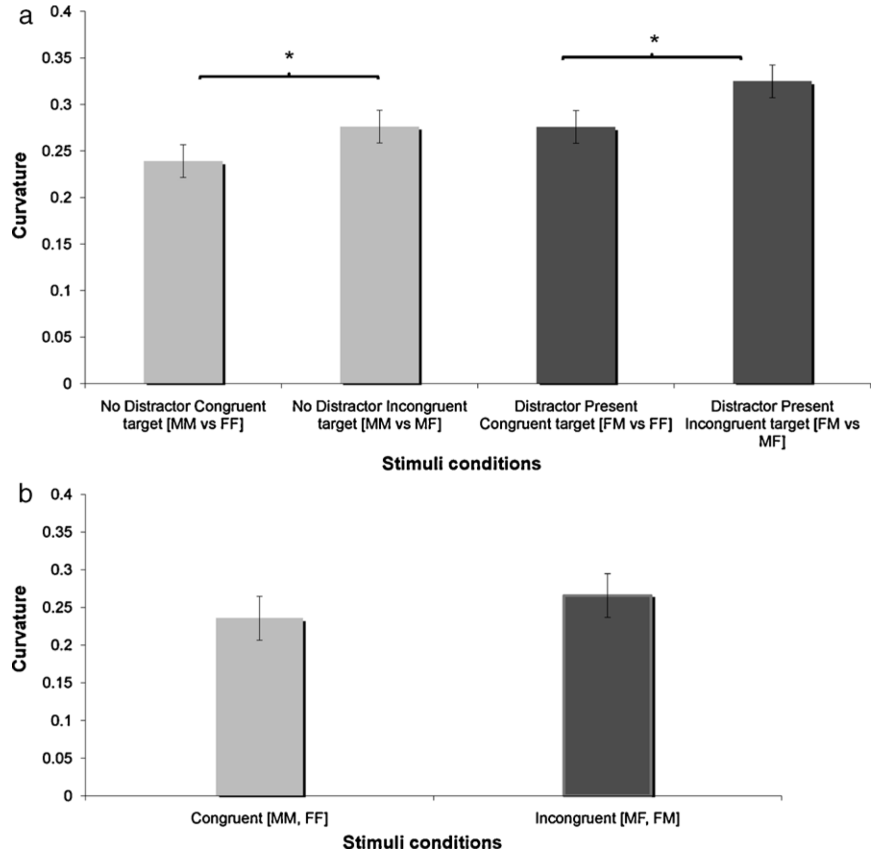

Fig. 2. (a) Experiment 1: Graph showing mean values of the maximum curvature plotted against stimuli conditions. Error bars indicate standard errors of the mean (SEM) and the asterisks denote significant effect. Incongruent trials show significantly larger curvature than congruent trials. (b) Experiment 2: Graph showing mean values of the maximum curvature plotted against stimuli conditions. Incongruent trials do not show larger curvature than congruent trials.

average maximum curvature was computed for all subjects in the eight conditions and used as the dependent variable.

3.1. Statistical analysis

A three-way within-subjects ANOVA with target congruity (congruent, incongruent), distractor conflict (present, absent) and target location (left, right) yielded significant main effect of target congruity $F(1,11) = 77.6$, $p < 0.001$, significant effect of distractor conflict $F(1,11) = 99.8$, $p < 0.001$ and main effect of target location $F(1,11) = 0.55$, $p < 0.001$. No other effects or interactions reached significance. Tests of violations of sphericity were performed on the data.

3.2. Trajectory curvature

Maximum curvature mean per condition, averaged across all subjects is plotted against stimuli conditions in Fig. 2a. Mean curvature and the results of the ANOVA reveal that trajectories were significantly more curved ($p < 0.001$) when the target was in an incongruent condition (mean = 0.26, SD = 0.025) than in the congruent condition (mean = 0.23, SD = 0.022). Presence of the distractor conflict added significantly to the curvature of the trajectory.

For instance, when the target is female (F) appearing on the right side of the screen, in a congruent target condition (FF), subjects moved straight towards the right. In contrast, in an incongruent target condition (MF), the trajectories show a larger curvature while reaching to the target. In both conditions, there was no distractor conflict present (i.e., MM on the left). However, when the distractor conflict is present and the target condition is congruent (FM vs FF), subjects started moving towards the left (responding to the LSF female distractor in FM) and then changed direction to reach the target. Finally, when the distractor conflict is present and the target condition is incongruent (FM vs MF), the reaching trajectories show a significantly larger curvature ($p < 0.001$).

3.3. Discussion

The curvature in the reach trajectory is taken as a measure of uncertainty in the decision making process and a larger curvature reflects a conflict due to target congruity conditions and the presence (or absence) of the distractor. The effect of the distractor conflict is due to the presence of the target sex in LSF. However, another interesting aspect of reaching is observed when the target is in incongruent condition and no distractor is present. A statistically significant effect of target congruity implies that in manual reaching to HSF faces, the perceptual response is driven by LSF information. In trials for an incongruent target condition (where the LSF face was of the opposite sex), a larger curvature reflects uncertainty in reaching to the target on the correct side. Significant effect of target location is due to biomechanical bias (it is easier to reach for targets on right for right handed subjects). These results demonstrate that at the periphery, LSF faces interfere with behavioral reaching to HSF face targets.

4. Experiment 2

We then investigated whether the LSF interference in processing of HSF targets found in Experiment 1 is also reflected when the hybrids are presented *centrally*. The apparatus, stimuli, duration and procedure were identical to Experiment 1 except that, instead of two faces, one hybrid face was presented at the centre of the

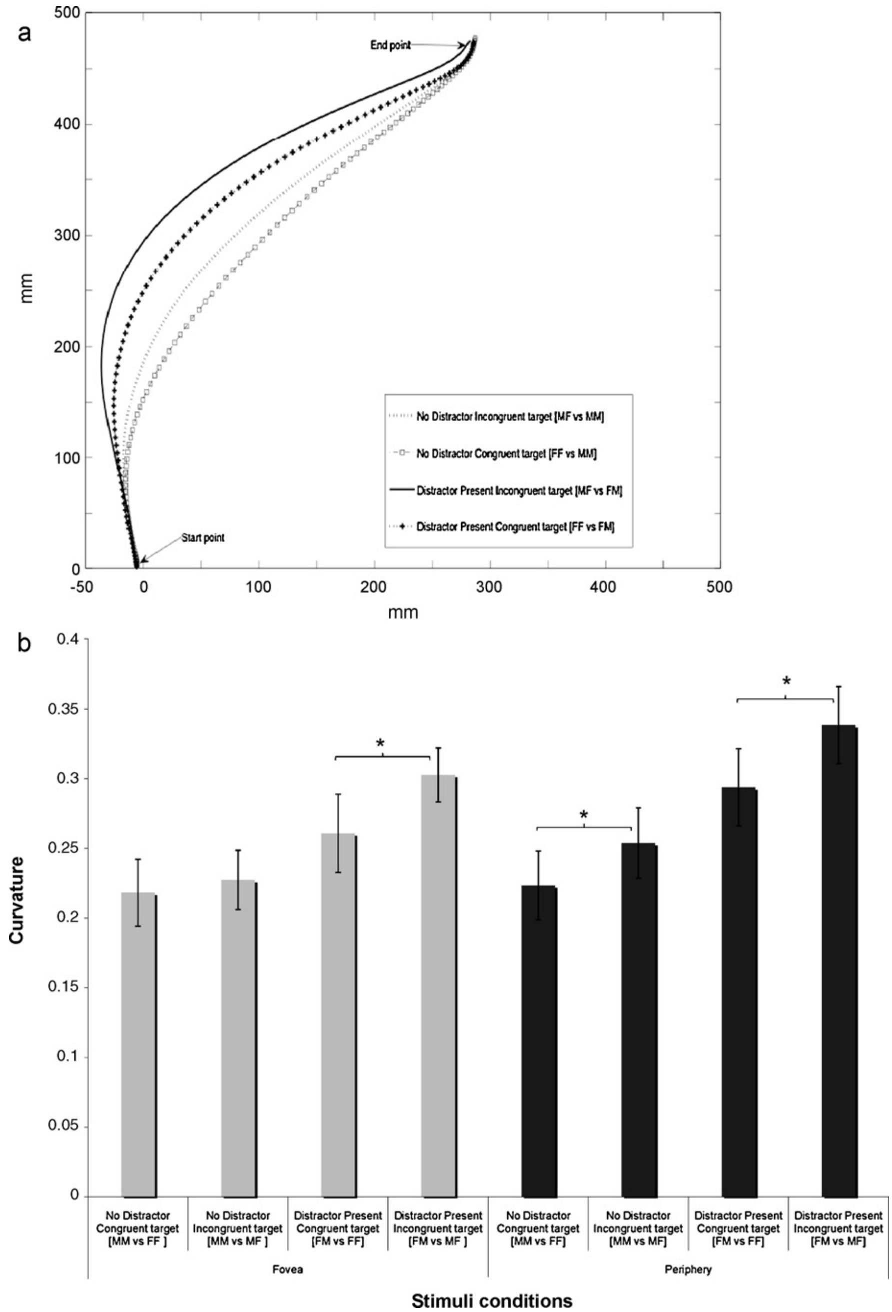

Fig. 3. Experiment 3: (a) Mean time-normalized reaching trajectories for peripheral conditions, for a target appearing on the right. (b) Graph showing mean values of the maximum curvature plotted against stimuli conditions. Error bars indicate standard error of the mean and the asterisks (*) denote significant effect. Incongruent trials show significantly larger curvature than congruent trials. Trajectories are more curved in peripheral conditions than in foveal conditions.

screen. Twelve right-handed subjects (five females, seven males, mean age: 26.9 years, SD = 2.8) participated in this experiment, of which nine had also participated in Experiment 1. There were four experimental conditions (MM, MF, FM and FF) and subjects indicated their response by reaching out and touching a 'M' or 'F' box presented onscreen. The mean accuracy rate was 89.9% (SD = 4.7). Data were analysed as in Experiment 1.

4.1. Results

Maximum curvature mean per condition, averaged across all subjects was plotted against target distractor conditions (Fig. 2b). A one-way repeated measures ANOVA conducted on the mean curvature data yielded no significant effect of target congruity ($F(1,11) = 0.540$, $p = 0.485$) on reaching behavior. No other effects or interactions reached significance. Maximum curvature mean was not significantly different in congruent (MM and FF) and incongruent conditions (MF and FM) and did not reveal a consistent pattern of movement. This suggests that when presented centrally, at the fovea, LSF faces do not seem to interfere with behavioral reaching to HSF targets.

5. Experiment 3

Based on the findings of Experiment 2 (which reveals a null result), we combined Experiments 1 and 2 and designed a third experiment wherein two hybrids were presented *peripherally* and *centrally* in alternate blocks. Thus, the peripheral and central presentation of hybrids is equivalent in terms of stimuli and the apparatus and procedure were identical to Experiment 1. Fifteen right-handed subjects (eight females, seven males, mean age: 24.7 years, SD = 3.7) participated in this experiment. Task instructions were same as that of Experiment 1 (i.e. reach out and point to a target sex). The mean accuracy rate was 93.4% (SD = 4.0). Data were analysed as in Experiment 1.

5.1. Results and discussion

Within-subjects ANOVA was carried out with eccentricity (periphery, fovea), target location (left, right), target congruity (congruent, incongruent) and distractor conflict (present, absent) as factors. Similar to the results of Experiment 1, we found a significant main effect of eccentricity $F(1,14) = 11.7$, $p < 0.001$, a main effect of target congruity $F(1,14) = 107.3$, $p < 0.001$ and a main effect of distractor conflict $F(1,14) = 31.5$, $p < 0.001$. Importantly, we found significant interaction between eccentricity and target congruity $F(1,14) = 6.04$, $p < 0.001$ and between eccentricity and target location $F(1,14) = 5.3$, $p < 0.001$. No other effects or interactions reached significance. Tests of violations of sphericity were performed on the data. Further post hoc (Tukey HSD) analysis revealed that at the periphery, the mean curvature is larger for incongruent conditions ($M = 0.32$) than congruent conditions ($M = 0.24$). At the fovea, the post hoc analysis did not show a significant difference in the means for target congruity. In contrast to the results of Experiment 2, when faces were presented at the fovea, the results of Experiment 3, for peripheral presentation, show a significantly higher curvature for target congruity. The interaction between eccentricity and target congruity, together with post hoc results, suggests that the curvature is significantly larger at the periphery than at the fovea. This confirms the significantly higher effect of LSF at the periphery (Fig. 3).

6. General discussion

Our study aims to establish the relative order of processing of LSF and HSF information in face processing. We examined how LSF–HSF hybrid faces are processed when presented centrally and at the periphery. Using reach trajectories as a continuous behavioral measure, we find that LSF information has primacy in face processing at the periphery.

Trajectories as a continuous measure of hand movements reveal the early stages of a decision before a final selection is made. When faces were presented at the periphery in Experiment 1, the significantly larger curvature of the trajectories reflects processing of LSF while reaching to HSF face targets. Findings from Experiment 2 provide null result (at the fovea, the curvature measure did not reveal any interference from LSF faces). In contrast, in Experiment 3, when faces were presented at the fovea and periphery, the curvature is significantly higher for peripheral presentation. The most interesting aspect is the interaction between eccentricity and target congruity and further post hoc results reporting higher means for incongruent conditions than the congruent conditions.

Significantly lower curvature at fovea suggests that there is less effect of LSF at fovea (rather than no effect) as compared to Periphery. This is consistent with previous findings that LSF carrying magnocellular channels have a lesser density distribution at the fovea and a larger representation of the peripheral visual field than the higher acuity parvocellular channels (Dacey & Petersen, 1992; Silveira & Perry, 1991). HSF information, carried by parvocellular channels, is more sensitive at the fovea (Lynch, Silveira, Perry, & Merigan, 1992; Merigan & Katz, 1990). At the periphery, a dense network of magnocellular channels provides a mechanism for the LSF interference that we have observed.

In a similar vein, in a recent masked priming study exploring the initial role of LSF and HSF in unconscious processing, de Gardelle and Kouider (2010), reported that for centrally presented faces, both LSF and HSF influence recognition during the initial, unconscious steps of processing. However, HSF dominates during the later stages associated with perceptual awareness and the effect of LSF actually tended to disappear when the effect of HSF increased and this might also explain the absence of LSF influences at central position in our study.

Our findings support the view that faces are processed in part through a subcortical route (Johnson, 2005; Vuilleumier et al., 2003; Williams, Morris, McGlone, Abbott, & Mattingley, 2004), subserved by fast, magnocellular channels that enable rapid top-down facilitation for later, fine-grained cortical processing (Bar, 2003). Magnocellular LSF inputs may serve as a header for the initial detection and holistic percept of a face that unfolds progressively for fine-grained categorization later supported by HSF. This suggests visual integration of spatial information in the early stages of face perception and reflects a pattern of organization of visual processing in the brain. Multiple features of facial stimuli are known to be processed in several steps and bound together to form a conscious percept. Future research could shed light on the time course of the differential role of LSF and HSF information in visual processing of face and non-face stimuli.

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