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Lateralized hybrid faces: Evidence of a valence-specific bias in the processing of implicit emotions

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It is well known that hemispheric asymmetries exist for both the analyses of low-level visual information (such as spatial frequency) and high-level visual information (such as emotional expressions). In this study, we assessed which of the above factors underlies perceptual laterality effects with "hybrid faces": a type of stimulus that allows testing for unaware processing of emotional expressions, when the emotion is displayed in the low-frequency information while an image of the same face with a neutral expression is superimposed to it. Despite hybrid faces being perceived as neutral, the emotional information modulates observers' social judgements. In the present study, participants were asked to assess friendliness of hybrid faces displayed tachistoscopically, either centrally or laterally to fixation. We found a clear influence of the hidden emotions also with lateral presentations. Happy faces were rated as more friendly and angry faces as less friendly with respect to neutral faces. In general, hybrid faces were evaluated as less friendly when they were presented in the left visual field/right hemisphere than in the right visual field/left hemisphere. The results extend the validity of the valence hypothesis in the specific domain of unaware (subcortical) emotion processing.

Keywords: Emotion perception; Hybrid faces; Spatial frequencies; Hemispheric specialization; Subcortical route.

Evidence accumulated since many decades support the idea that the right hemisphere is specialized for face processing, given that observers are better able to analyse faces in the left than in the right half of the visual space. Other evidence indicates that the right hemisphere is also specialized in global, configural processing (Hellige, 1996; Nishimura & Yoshizaki, 2007), and it is

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commonly accepted that faces are primarily elaborated as global configurations (Han et al., 2002; Peters, Vlamings, & Kemner, 2013; Piepers & Robbins, 2012; Young, Hellawell, & Hay, 1987). Also, holistic processing may be strongly based on information contained in the lower spatial frequencies of the visual input (Goffaux, Hault, Michel, Vyong, & Rossion, 2005; Goffaux & Rossion, 2006; Harel & Bentin, 2013). Considering together the above evidence, the right hemisphere should perform better than the left hemisphere in face and global processing, since these aspects are related to one another (Awasthi, Friedman, & Williams, 2011).

However, a debate has been ongoing about a right-hemispheric dominance for emotional expression processing. On one hand, there are studies suggesting that the right hemisphere is better than the left in processing emotional stimuli, whether positive or negative (Borod et al., 1998; Levy, Heller, Banich, & Burton, 1983; McLaren & Bryson, 1987; Moreno, Borod, Welkowitz, & Alpert, 1990). On the other hand, a number of studies also suggest that the right hemisphere may be particularly prone to processing stimuli with negative valence (Najt, Bayer, & Hausmann, 2013), whereas the left hemisphere may be prone to processing stimuli with positive valence (Adolphs, Jansari, & Tranel, 2001; Ahern & Schwartz, 1979; Baijal & Srinivasan, 2011; Heilman, 1997; Jansari, Tranel, & Adolphs, 2000; Reuter-Lorenz & Davidson, 1981). For example, Rodway, Wright, and Hardie (2003) presented two neutral faces in the two visual hemifields and asked participants to judge which of the two faces showed a target emotional expression, confirming the valence laterality effect: although all stimuli were neutral, a negative expression was attributed more frequently to faces presented on the left side, whereas a positive expression was attributed more frequently to faces presented on the right side (Rodway et al., 2003).

Importantly, hemispheric asymmetries are associated with the differential processing of low and high spatial frequencies (Kitterle & Selig, 1991; Sergent, 1982). For instance, observers are more rapid at correctly discriminating sinusoidal gratings in the range of low frequencies when stimuli are presented in the left visual field, and in the range of high frequencies when the stimuli occur in the right visual field (Proverbio, Zani, & Avella, 1997); similar results were also collected with filtered complex scenes (Peyrin, Chauvin, Chokron, & Marendaz, 2003; Peyrin, Mermillod, Chokron, & Marendaz, 2006). Keenan, Whitman, and Pepe (1989) used face stimuli shown in isolation or superimposed to square wave gratings that would selectively hide either the low or high spatial frequencies; more errors were made when stimuli that lacked the low spatial frequencies were presented in the left visual field, whereas more errors were made with stimuli that lacked the high spatial frequencies when they were presented in the right visual field (Keenan et al., 1989).

Kumar and Srinivasan (2011) asked participants to discriminate happy from sad faces presented either in the left or the right visual field, and the face stimuli were shown as broadband images, or high-pass or low-pass filtered face stimuli.

The authors found that participants recognized better low-pass than high-pass filtered faces but only in the right visual field (left hemisphere), in addition to finding a right-hemispheric superiority in identifying sad faces, especially when presented in the high spatial frequency.

A paradigm introduced recently to investigate the differential contribution of high and low spatial frequencies in the domain of face processing is that of "hybrid faces" (Schyns & Oliva, 1999), in which different information are superimposed within different ranges of spatial frequencies. In a recent series of studies using such a paradigm, the image of a face with an emotional (positive or negative) expression was low-pass filtered, and a high-pass filtered neutral face of the same individual was superimposed to it; participants were asked to rate such hybrid faces' friendliness (Laeng et al., 2010, 2013; see also Leknes et al., 2013). Laeng and colleagues showed that observers are able to process emotional information presented in the low spatial frequencies, despite being "hidden" or invisible to conscious perception in the resulting hybrid faces. Specifically, participants were unable to consciously report the specific emotion contained within the image, judging the faces displaying a "neutral" expression, yet they judged as more friendly a face containing a "hidden" positive expression and the same face as less friendly when it contained a "hidden" negative expression, in comparison to the real (broadband) neutral expression. Laeng and colleagues concluded that the emotion information conveyed by low spatial frequencies in hybrid faces influence the observers' social decision in an unconscious manner.

One aim of the present study was to assess with the hybrid faces whether each cerebral hemisphere would express similar social judgements when the emotion presented in low spatial frequency is seen in the lateralized or divided-visual-fields paradigm. Moreover, given the well-known hemispheric asymmetry for spatial frequency and for emotional valence, we expected that these kinds of asymmetries would interact with one another in the special case of hybrid faces. One question at hand is whether all the expressions conveyed by low spatial frequencies are better detected by the right hemisphere, providing support for the right hemisphere hypothesis, or the emotional valence affects subjects' responses in relation to the presentation side, providing support for the valence hypothesis. To answer these questions, we showed hybrid happy, hybrid angry and neutral female and male faces in central, left or right locations in the visual field of participants, asking them to judge the friendliness of the faces. The choice of the emotional expressions used in the present study (happy, angry and neutral) was based on the results of Laeng and colleagues (2010), who found that participants judged happy faces as more friendly than neutral faces as well as all of the negative expressions, whereas the angry faces resulted to be the least friendly and therefore the most different in valence from happy faces. We also decided to present faces of both sexes to control for possible hemispheric lateralization due to the sex of faces, since previous studies have revealed peculiar asymmetries related to processing this aspect of facial stimuli (e.g., Parente & Tommasi, 2008). As it is known that the sex of faces is recognized even when faces are low-pass filtered (Khalid, Finkbeiner, König, & Ansorge, 2013), we expected that using both male and female hybrid faces as stimuli could shed further light on the interaction between asymmetries for this feature and asymmetries of emotion processing.

In the original study by Laeng et al. (2010), the hybrid faces were shown centrally for 250 ms. In a first experiment, we decided to present hybrid faces for 250 ms to a first group of participants, in order to assess whether we could replicate the original effects in the three positions. Moreover, some studies suggest that processing low spatial frequencies may require between 200 and 500 ms to be processed (Alorda, Serrano-Pedrazza, Campos-Bueno, Sierra-Vázquez, & Montoya, 2007). However, we also tested a second group of participants with a shorter presentation time (125 ms), which is more typical of lateralized presentation paradigms and it is used to rule out the possible influence of saccadic movements (Trottier & Pratt, 2005) and ensure unilateral processing of stimuli.

In accordance with the valence hypothesis, we expect that hybrid happy faces would be evaluated as more friendly by the left hemisphere (in the right-side and central presentation conditions) and that hybrid angry faces would be evaluated as less friendly by the right hemisphere (in the left-side and central presentation conditions) with respect to the neutral pose. Alternatively, as suggested by the right hemisphere hypothesis, social judgements would result to be more congruent with the hidden emotions when hybrid faces are shown in the left visual field (right hemisphere) than in the right visual field (left hemisphere). Moreover, because judgements should be based on the low spatial frequency content of stimuli, the right-hemispheric advantage in this task could lead to an overall right-hemispheric better performance. Thus, we expect a right-hemispheric superiority in (1) face processing, (2) emotional judgement, (3) low spatial frequency analysis and (4) social evaluations. All these aspects should lead to a left visual field advantage.

MATERIALS AND METHODS

Participants

The task was administered to 66 participants: a first group of 33 participants (17 females; age: M = 24.03, SD = 0.99) carried out the 250 ms presentation condition; a second group of 33 participants (20 females; age: M = 23.91, SD = 0.36) carried out the 125 ms presentation condition. All participants were right-handers by self-report, with normal or corrected-to-normal vision.

Stimuli

Stimuli consisted in photographs of faces selected from the Karolinska Directed Emotional Faces (Goeleven, De Raedt, Leyman, & Verschuere, 2008). In order to create hybrid happy and hybrid angry faces (Laeng et al., 2010), images were manipulated with MatLab software (Mathworks Inc., Natick, MA), obtaining one version filtered at low spatial frequency and one version filtered at high spatial frequency of each face. To obtain the happy and the angry hybrid images, the emotional face of a given individual filtered at low spatial frequencies (1–6 cycle/image) was amalgamated to the neutral image of the same individual filtered at high spatial frequencies (7–128 cycle/image). Faces that were presented as "neutral" in the experiment were unfiltered or broadband.

Stimuli were presented in grey-level, at a resolution of 198 × 252 pixels, and measured 5.2° × 6.6° of visual angle. The total number of stimuli was 90: 10 different identities, each showing the three emotional poses (hybrid happy, hybrid angry and neutral), each presented in three positions (centre, left and right).

Procedure

Each stimulus was presented once, on a computer screen (Sony Vaio SVE151D11M) with a resolution of 1280 × 768 pixels. Stimuli were presented either in the centre of the screen, or laterally, at 2.4° of visual angle to the left or to the right of a fixation cross (0.02° × 0.02° of visual angle) positioned in the centre of the screen. Participants sat at a distance of 72 cm from the computer screen.

Ten different identities were presented, five males and five females, and each of these 10 faces was presented in three conditions (hybrid happy, hybrid angry and neutral), each one for three times: in the centre, on the left side and on the right side of the computer screen.

The structure of each trial was the following: after a blank screen lasting 1 s, the fixation cross was presented for 2 s and then the image appeared for a duration of 250 ms for participants in the first group, or for 125 ms for participants in the second group. The screen remained blank until the participant gave her/his rating, after which the next trial started. The presentation order of the stimuli was randomized across and within participants. Participants were asked to keep their gaze at fixation in the centre of the screen until the face was presented. They were then required to evaluate how much the face had appeared friendly, using a 5-point Likert scale, in which 1 corresponded to "very unfriendly" and 5 corresponded to "very friendly" (1, "very unfriendly"; 2, "unfriendly"; 3, "neutrality point"; 4, "friendly"; 5, "very friendly"), by pressing the numeric keys (from 1 to 5) of the computer keyboard.

The task was presented by means of E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) and it lasted about 10 minutes.

RESULTS

Results were analysed by means of the software Statistica 8.0.550 (StatSoft. Inc, Tulsa, USA). A split-plot analysis of variance (ANOVA) was carried out, using presentation time (125 ms, 250 ms) as a between-subject factor, emotion (happy, angry and neutral), sex of face (female, male) and position (left, right and centre) as within-subject factors, and the friendliness ratings of the images as the dependent variable. In a preliminary ANOVA, the participants' sex was considered as an additional between-subject factor, but it did not show a significant effect or interactions with the other factors, so it was excluded from further analyses. Post-hoc comparisons were carried out by Newman-Keuls tests.

The ANOVA yielded no main effect of presentation time ($F_{(1, 32)} = 0.16$, $MSE = 2.27$, $p = .688$, $\eta^2 = 0.005$). The main effect of position was significant ($F_{(2, 64)} = 4.75$, $MSE = 0.23$, $p = .012$, $\eta^2 = 0.13$): faces presented in the left visual field were evaluated as less friendly than faces presented centrally ($p = .009$) and in the right visual field, although the latter comparison was almost significant ($p = .053$; left visual field: $M = 2.65$, $SD = 0.03$; centre: $M = 2.76$, $SD = 0.03$; right visual field: $M = 2.72$, $SD = 0.03$). The main effect of emotion ($F_{(2, 64)} = 54.45$, $MSE = 0.48$, $p < .001$, $\eta^2 = 0.63$) showed that different friendliness impressions were provoked by the three expressions. Post-hoc analyses evidenced that happy faces were judged as more friendly than neutral and angry faces ($p < .001$ for both comparisons) and that neutral faces were judged as more friendly than angry faces ($p = .001$; happy: $M = 2.99$, $SD = 0.03$; neutral: $M = 2.65$, $SD = 0.03$; angry: $M = 2.49$, $SD = 0.03$). The effect of sex of face was significant ($F_{(1, 32)} = 20.55$, $MSE = 1.23$, $p < .001$, $\eta^2 = 0.39$), post-hoc analyses showing that female faces were judged as more friendly than male faces (female: $M = 2.86$, $SD = 0.02$; male: $M = 2.56$, $SD = 0.02$).

The interaction emotion × sex of face was significant ($F_{(2, 64)} = 16.61$, $MSE = 0.11$, $p < .001$, $\eta^2 = 0.34$). With all emotional poses (happy, angry and neutral), female faces were evaluated as more friendly than male faces ($p < .001$ for all comparisons). Moreover, both with female and male faces, the happy expression was evaluated as more friendly than neutral and angry expressions, and the neutral expression was evaluated as more friendly than the angry expression ($p < .001$ for all comparisons, see Figure 1).

The interaction presentation time × position ($F_{(2, 64)} = 5.79$, $MSE = 0.18$, $p = .005$, $\eta^2 = 0.15$) was significant. Stimuli presented centrally for 125 ms were judged as more friendly than all of the other stimuli (left 250 ms: $p < .002$; centre 250 ms: $p < .003$; right 250 ms: $p = .019$, left 125 ms: $p < .001$; right 125 ms: $p = .013$).

Figure 1. Mean ratings of female and male hybrid faces (happy, angry and neutral), on the friendliness scale (range 1–5). Error bars represent standard errors.

The interaction emotion × position was significant ($F_{(4,\ 128)} = 2.78$, $MSE = 0.11$, $p = .029$, $\eta^2 = 0.08$). At all positions, happy faces were judged as more friendly than neutral and angry faces ($p < .001$ for all comparisons), and neutral faces were judged as more friendly than angry faces ($p = .036$ in the left visual field; $p < .001$ centrally and in the right visual field). Moreover, happy faces were judged as more friendly when they were presented centrally than in the left visual field ($p < .001$), or in the right visual field ($p = .009$), and neutral faces were judged as less friendly when they were presented in the left visual field than in the right visual field ($p = .03$), or centrally ($p = .003$; see Figure 2).

Finally, the interaction presentation time × emotion × position was significant ($F_{(4,\ 128)} = 3.41$, $MSE = 0.12$, $p = .011$, $\eta^2 = 0.13$, see Figure 3). Of note, happy faces presented for 125 ms were evaluated as more friendly when they were presented centrally than laterally ($p < .001$ for either visual field), and neutral faces presented for 125 ms were judged as more friendly when they were presented centrally than in the left visual field ($p < .001$). Happy faces presented centrally were evaluated as more friendly when they were presented for 125 ms than for 250 ms ($p < .001$).

The other interactions did not reach statistical significance (presentation time × emotion: $F_{(2,\ 64)} = 2.14$, $MSE = 0.27$, $p = .125$, $\eta^2 = 0.06$; presentation time × sex of face: $F_{(1,\ 32)} = 2.01$, $MSE = 1.09$, $p = .166$, $\eta^2 = 0.06$; sex of face ×

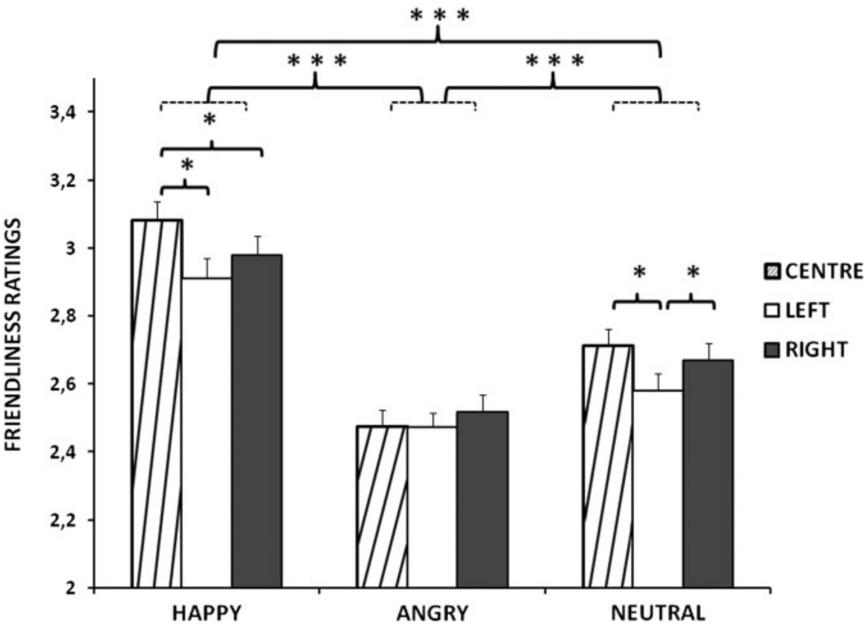

Figure 2. Mean ratings of hybrid faces (happy, angry and neutral) in central (textured bars), left (white bars) and right presentation (grey bars), on the friendliness scale (range 1–5). Error bars represent standard errors.

position: $F_{(2, 64)} = 1.31$, $MSE = 0.09$, $p = .275$, $\eta^2 = 0.04$; presentation time × emotion × sex of face: $F_{(2, 64)} = 1.38$, $MSE = 0.16$, $p = .26$, $\eta^2 = 0.04$; presentation time × sex of face × position: $F_{(2, 64)} = 0.54$, $MSE = 0.14$, $p = .584$, $\eta^2 = 0.016$; emotion × sex of face × position: $F_{(4, 128)} = 1.38$, $MSE = 0.09$, $p = .243$, $\eta^2 = 0.04$; presentation time × emotion × sex of face × position: $F_{(4, 128)} = 1.26$, $MSE = 0.08$, $p = .289$, $\eta^2 = 0.04$).

To better understand the meaning of the three-way interaction, two separate repeated ANOVA measures were carried out, one for each of the two presentation times (125 ms and 250 ms, respectively).

In the ANOVA on the 125 ms condition, the main effect of emotion was significant ($F_{(2, 64)} = 47.02$, $MSE = 16.24$, $p < .001$, $\eta^2 = 0.59$). Post-hoc analyses showed that happy faces were judged as more friendly than neutral and angry faces ($p < .001$ for both comparisons) and that neutral faces were judged as more friendly than angry faces ($p = .022$). The main effect of sex of face was significant ($F_{(1, 32)} = 19.09$, $MSE = 21.12$, $p < .001$, $\eta^2 = 0.37$): female faces were evaluated as more friendly than male faces. The main effect of position was significant ($F_{(2, 64)} = 7.22$, $MSE = 1.89$, $p = .001$, $\eta^2 = 0.18$). Post-hoc analyses showed that faces presented centrally were evaluated as more friendly

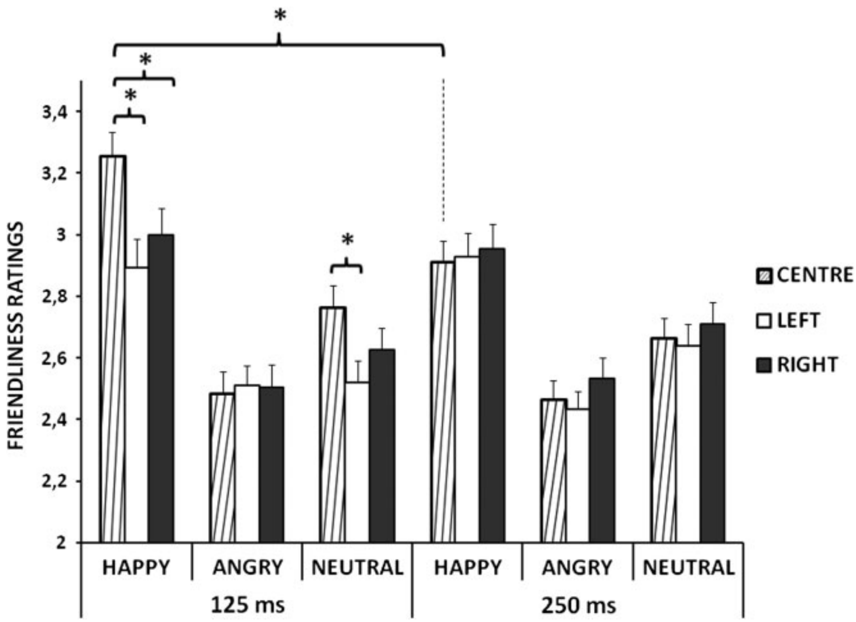

Figure 3. Mean ratings of hybrid faces (happy, angry and neutral) shown for 125 ms and 250 ms in central (textured bars), left (white bars) and right presentation (grey bars), on the friendliness scale (range 1–5). Error bars represent standard errors.

than faces presented either in the left visual field (p = .001) or in the right visual field (p = .019).

The interaction emotion × sex of face was significant ($F_{(2, 64)} = 12.71$, MSE = 1.59, $p < .001$, $\eta^2 = 0.28$). Post-hoc comparisons showed that female faces were evaluated as more friendly than male faces in all emotional poses ($p < .001$ for all comparisons) and that both with female and male faces, the happy expression was evaluated as more friendly than the neutral and angry expressions ($p < .001$ for all comparisons) and the neutral expression was evaluated as more friendly than the angry expression (female: p = .044, male: p = .001).

The interaction emotion × position was significant ($F_{(4, 128)} = 5.15$, MSE = 0.68, $p < .001$, $\eta^2 = 0.14$). Post-hoc comparisons showed that in all positions, happy faces were evaluated as more friendly than angry faces and, only in central position, neutral faces were evaluated as more friendly than angry faces ($p < .001$ for all comparisons). Also, both happy and neutral faces were evaluated as more friendly when presented centrally than laterally (happy: $p < .001$ for both comparisons, neutral: central versus left visual field, $p < .001$, central versus right visual field, p = .031). The difference between left and right visual field presentations was almost significant with both happy and neutral expressions, with a higher friendliness rating for stimuli presented in the right than in the left visual field (p = .093 in both cases).

The other interactions did not reach statistical significance (sex of face × position: $F_{(2, 64)} = 0.11$, $MSE = 0.02$, $p = .894$, $\eta^2 = 0.003$; emotion × sex of face × position: $F_{(4, 128)} = 2.08$, $MSE = 0.18$, $p = .087$, $\eta^2 = 0.06$).

In the ANOVA on the 250 ms condition, the main effect of emotion was significant ($F_{(2, 64)} = 25.48$, $MSE = 10.26$, $p < .001$, $\eta^2 = 0.44$). Post-hoc analyses showed that happy faces were judged as more friendly than neutral and angry faces and that neutral faces were judged as more friendly than angry faces ($p < .001$ for all comparisons). The main effect of sex of face was significant ($F_{(1, 32)} = 5.18$, $MSE = 6.26$, $p = .03$, $\eta^2 = 0.14$), female faces being evaluated as more friendly than male faces. The main effect of position failed to reach statistical significance ($F_{(2, 64)} = 1.61$, $MSE = 0.24$, $p = .208$, $\eta^2 = 0.05$).

The interaction emotion × sex of face was significant ($F_{(2, 64)} = 3.64$, $MSE = 0.54$, $p = .032$, $\eta^2 = 0.10$). Post-hoc comparisons showed that female faces were evaluated as more friendly than male faces in all emotional poses (happy: $p < .001$, angry: $p = .028$, neutral: $p = .003$) and that both with female and male faces, the happy expression was evaluated as more friendly than the neutral and angry expressions, and that the neutral expression was evaluated as more friendly than the angry expression (female: $p < .001$ for all comparisons; male: happy versus angry $p < .001$, happy versus neutral $p = .004$, neutral versus angry $p = .008$).

The other interactions did not reach statistical significance (emotion × position: $F_{(4, 128)} = 0.25$, $MSE = 0.02$, $p = .91$, $\eta^2 = 0.01$; sex of face × position: $F_{(2, 64)} = 2.26$, $MSE = 0.18$, $p = .112$, $\eta^2 = 0.07$; emotion × sex of face × position: $F_{(4, 128)} = 0.63$, $MSE = 0.06$, $p = .641$, $\eta^2 = 0.02$).

DISCUSSION

Emotional expressions conveyed only by the low spatial frequency component of hybrid faces modulated the responses of the participants to our study, whether these were shown very rapidly at fixation or to the side, in either the left or the right visual field. Hence, our results not only replicate Italian participants those obtained with Norwegian participants by Laeng and colleagues (2010, 2013) (Leknes et al., 2013), but they also show that very brief presentations as those used here can yield the same effects observed with presentations of several seconds. Participants' judgements reflected the emotional content of hybrid faces, with higher evaluations of friendliness to happy faces compared to neutral and angry faces, and higher friendliness evaluations to neutral faces compared to angry faces. Thus, our results are consistent with studies showing that emotional information is mainly conveyed by the low spatial frequency (Bar, Neta, & Linz, 2006; Mermillod, Bonin, Mondillon, Alleysson, & Vermeulen, 2010; Smith & Schyns, 2009).

We also expected to find differences in participants' ratings according to emotional valence and side of presentation: if the right hemisphere hypothesis were true, one would predict more extreme choices in the social judgements with emotional faces presented in the left visual field than in the right visual field and more variable judgements with stimuli presented in the right visual field. Instead, if the valence hypothesis were true, we would predict higher friendliness ratings for positive stimuli directly processed by the left hemisphere, and lower friendliness ratings for negative stimuli directly processed by the right hemisphere (Heilman, 1997). Our results appear to be partially in line with the latter hypothesis: hybrid faces were evaluated as less friendly when they were presented in the left visual field. Our results show that the same "hidden" expression, if presented tachistoscopically, is differently evaluated in the two visual fields so that it will be judged more positively when presented in the right visual field/left hemisphere, and less positively when presented in the left visual field/right hemisphere. This kind of hemispheric specialization for positive/negative valence is well known for explicit emotion processing (Adolphs et al., 2001; Ahern & Schwartz, 1979; Baijal & Srinivasan, 2011; Gainotti, 2012; Heilman, 1997; Jansari et al., 2000; Najt et al., 2013; Reuter-Lorenz & Davidson, 1981; Rodway et al., 2003), but the present results suggest that the same holds true in the domain of implicit perception. Importantly, the different friendliness ratings between hemifields could not be attributable to the well-known right hemispheric superiority for face processing (Kanwisher & Yovel, 2006), or to a superiority of the right hemisphere in processing and remembering familiar stimuli and objects of perceptual expertise (Gauthier & Tarr, 2002), faces being a subcategory included in this definition (Diamond & Carey, 1986; Dickinson & Intraub, 2009; Laeng, Øvervoll, & Steinsvik, 2006; Turk, Handy, & Gazzaniga, 2005). In other words, the hemispheric asymmetries found in the present study are not attributable to the special role of this category of stimuli or to the right-hemispheric specialization in face analyses, because if this were the case, one should expect a right-hemispheric advantage in the processing of all stimuli, regardless of their emotional expressions.

Neuroimaging and patient studies have shown clear subcortical processing of emotional faces (e.g., in the amygdala), which is exclusively driven by low spatial frequency information, as used in the present study (<6 cycles per image; Vuilleumier, Armony, Driver, & Dolan, 2001, 2003). However, it must be remarked that a number of studies that investigated the subcortical route underpinning emotional processing have provided contrasting results with regard to lateralization, some of them suggesting right-hemispheric lateralization (Vuilleumier et al., 2003), others indicating left-hemispheric lateralization (Baas, Aleman, & Kahn, 2004) and some others supporting bilateral involvement (Whalen et al., 1998). For example, behavioural and neuroimaging studies showed evidence of a rightward asymmetry in subliminal emotional processing (see Gainotti, 2012 for a recent review): the right amygdala appears to be more engaged than the left amygdala in processing subliminal emotions. A subcortical network, also including the superior colliculus and the pulvinar, has been proposed to be already present in the newborn and is believed to be the base for the "social brain" network (Brooks et al., 2012; Johnson, 2005). In this scenario, the results of the present study may contribute to support a dominant role of the right hemisphere in the subcortical route for the processing of affective information (see Johnson, 2005 for a review). In fact, positive and negative hidden emotions presented in low spatial frequencies were evaluated according to valence by both hemispheres, but the left hemisphere appeared to be relatively more sensitive to the positive expression. Moreover, as we hypothesized, a right-hemispheric specialization for low spatial frequency information processing might have further enhanced the processing of hybrid faces in the left hemifield. However, in a fMRI study, Rotshtein, Vuilleumier, Winston, Driver, and Dolan (2007) presented hybrid faces of different identities, superimposing low and high spatial frequencies, and they found that the low spatial frequency (<8 cycles per image) modulated the activation in the bilateral middle occipital gyrus, whereas the high spatial frequency (>24 cycles per image) modulated the activation in the right inferior occipital gyrus and in the left inferior temporal gyrus. The authors also found that the output of these analyses reached the right fusiform gyrus. Our results are consistent with the bilateral involvement in low-frequency processing found by Rotshtein et al. (2007), showing with a behavioural paradigm the ability of either hemisphere in detecting the low spatial frequency information. One possible speculation is that a subcortical route projects forward to the cortical areas of both hemispheres, leading to a substantially symmetric, bilateral processing of stimuli presented for longer (250 ms), but a more asymmetric processing with shorter presentations (125 ms), due to the asymmetries in the rapid and unconscious subcortical processing (rightward bias, especially for the stimuli with negative valence). Asymmetries in the unconscious processing of emotions have also been found in neurological patients (Gainotti, 2012) and in split-brain patients (Prete et al., in press).

We also found an interaction between sex of faces and emotion: female faces were judged as more friendly than male faces in happy, angry and neutral poses. Some studies suggested that female faces are perceived as more positive than male faces. For instance, Becker, Kenrick, Neuberg, and Blackwell (2007) found a clear association between female faces and perceived happiness, even when neutral faces were shown and subjects were asked to choose the emotion expressed by the stimuli (Becker et al., 2007); in the same way, Hess, Adams, Grammer, and Kleck (2009) showed a similar effect using androgynous faces (Hess et al., 2009).

In conclusion, we found that hidden emotions, shown only in the low spatial frequencies component of hybrid faces, exert a similar effect in lateralized presentation as they do in central presentation, suggesting the involvement of both hemispheres in the subcortical route for processing emotions. However, hybrid faces presented laterally can be evaluated as more or less friendly, depending on which hemisphere receives the input, lending further support to the valence hypothesis for the specific case of implicit emotion processing.

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