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Laterality and (in)visibility in emotional face perception:

Manipulations in spatial frequency content

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Abstract

It is widely agreed that hemispheric asymmetries in emotional face perception exist. However, the mechanisms underlying this lateralization are not fully understood. In the present study, we tested whether (a) these asymmetries are driven by the low spatial frequency content of images depicting facial expressions, and (b) whether the effects differed depending on whether the emotional facial expressions were clearly visible or hidden (i.e., embedded in low spatial frequencies). The manipulation sheds light on the contribution of cortical and subcortical routes to emotional processing mechanisms. We prepared both unfiltered (broadband) and 'hybrid' faces. Within the latter, different bands of spatial frequency content from images of two different expressions were combined (i.e., low frequencies from an emotional image combined with high frequencies from a neutral image). We presented these broadband and hybrid images using the free-viewing emotional chimeric faces task (ECFT) in which two images are presented above and below fixation and asked participants to report which of the two mirror reversed images appeared more emotional. As predicted, the results showed that only broadband expressions produced the well-known left visual field/right hemisphere (LVF/RH) bias across all basic emotions. For hybrid images, only happiness revealed a significant LVF/RH bias. These results suggest that low spatial frequency content of emotional facial expressions, which activates the magnocellular pathway in subcortical structures and bypassing cortical visual processing, is not generally sufficient to induce an LVF bias under free-viewing conditions where participants deny explicitly seeing the emotion, suggesting that the LVF bias in ECFT is primarily cortically mediated.

Keywords: Emotion lateralization, Facial expression, Consciousness, Subcortical, Spatial frequency

Introduction

A broad sweep of research results has demonstrated that the right hemisphere (RH) is dominantly involved in the perception of human faces (e.g., Burt & Perrett, 1997; McCarthy, Puce, Gore, & Allison, 1997). However, the extent to which one finds laterality effects may also depend on the route through which emotional information is processed in the brain. It has been suggested that there are two routes through which information about emotional facial expressions affects behaviour (Ohman, Carlsson, Lundqvist, & Ingvar, 2007). One route is cortical, starting with information reaching the striate cortex via the retino-geniculo-striate pathway, while the other route is subcortical, reaching the amygdala via the superior colliculus and the pulvinar. There is clear evidence that emotional facial expressions can be discriminated very rapidly and probably unconsciously (Morris, Ohman, & Dolan, 1998; 1999; Ohman & Soares, 1994), and it has been suggested that this rapid response to emotional stimuli is mediated by the subcortical route. As it is possible that processing in this second route is not accompanied by conscious experience, it is valuable to assess decisions about emotional facial expressions using stimuli that are both visible and hidden (i.e., embedded in low spatial frequencies).

Although the processing of faces in general is lateralized (Burt & Perrett, 1997; McCarthy, Puce, Gore, & Allison, 1997), a more controversial topic is the laterality associated with the perception of specific *emotions* from faces (Alves, Aznar-Casanova, & Fukusima, 2009; Burt & Hausmann, 2018; Najt, Bayer, & Hausmann, 2013; Prete, Marzoli, Brancucci, Fabri, Foschi, & Tommasi, 2014; Killgore & Yurgelun-Todd, 2007). Some researchers assert that, like face processing, perception of facial emotion is biased in favour of the RH (i.e., RH Hypothesis, e.g., Borod et al., 1998; Gainotti, 2012). An alternative model maintains that the *valence* of the stimulus (i.e., whether the expression represents a positive or negative emotion) is important in characterising the asymmetry (e.g., Reuter-Lorenz & Davidson, 1981; Silberman &

Weingartner, 1986; Stafford & Brandaro, 2010). Though alternative forms of the Valence-Specific Hypothesis can differ slightly by which of Ekman, Friesen and Ellsworth's (1972) six basic emotions (i.e., anger, disgust, fear, happiness, sadness and surprise) are considered positive or negative (Abbott, Cumming, Fidler, & Lindel, 2013; Harmon-Jones, 2004), they generally argue that negative emotions elicit a RH advantage and positive emotions elicit a left hemisphere (LH) advantage.

The RH Hypothesis is reliably supported by the Emotional Chimeric Face Task (ECFT, Sackheim & Gur, 1978) in neurotypical individuals (Levy, Heller, Banich & Burton, 1983). In the classic example of this task, participants are presented with graphically manipulated faces which display an emotion (e.g., happiness) only in the left hemiface with the right hemiface being neutral. The mirror image of such a chimeric face is used to present emotional stimulus to the right hemiface. Participants explore these images before deciding on which is most emotional. Over a number of trials, a reliable bias emerges whereby participants indicate the left-hemiface emotion is more salient, despite the identical composition of the faces. This is thought to result from the left hemiface being processed primarily by the RH. One critical feature of the task is that lateralized effects are reliably found when stimuli are presented without any time restrictions and without maintaining fixation. In fact, Levy et al. (1983) assumed that the LVF/RH bias typically found was due to selective dominant activation of the RH, and thus should be found regardless of the time spent looking at the stimuli. These results are in line with findings of a meta-analysis which suggested that free-viewing laterality tasks, such as the ECFT task, are reliable and easy to administer tool for the assessment of RH integrity (Voyer, Voyer, & Tramonte, 2012). The LVF/RH bias consistently found in ECFT does not appear to differ according to stimulus valence (Bourne, 2010, 2011; Christman & Hackworth, 1993; Hausmann & Burt, 2018; Innes, Burt, Birch, & Hausmann, 2016; Workman, Peters, & Taylor, 2000). Given also that studies consistently report left hemiface biases using *only* expressions of happiness (Bourne & Gray, 2011; Levy et al., 1983), this is taken as strong evidence against the Valence-Specific Hypotheses in favour of the RH Hypothesis.

Processing emotional facial expressions may be particularly sensitive to information carried in specific bands of spatial frequencies within an image. It is therefore possible that laterality effects arise because the two hemispheres differ in the effectiveness with which they process different bands of spatial frequencies. The Spatial Frequency Hypothesis (Sergent, 1982, 1987) assumes that while both cerebral hemispheres are broadly equivalent in their ability to *detect* the full range of spatial frequencies, for more *perceptual* tasks, an asymmetry arises with the RH being dominant in the processing of low frequencies, providing information about the global structure of the image. In contrast, the LH is superior in processing high spatial frequency content, providing information about the 'local' detail of the image. So, what might first appear as hemispheric specialization in processing emotional expressions could in fact simply be a consequence of putative differences in spatial frequency processing. If the importance of different spatial frequencies differs between emotions then we might expect to find differences in emotion lateralization. For example, it has been suggested that for fearful faces, low spatial frequencies are the most important for rapid detection (Mermillod, Vuilleumier, Peyrin, Alleysson, & Marendaz, 2009; Vuilleumier, Armony, Driver, & Dolan, 2003), although Smith and Schyns (2009) also observed that lower spatial frequency information is used to discriminate happiness, surprise, anger, and disgust, but expressions of sadness, or fear, were more reliant on high spatial frequency content.

Only a few studies have directly manipulated emotional faces for spatial frequency content in conjunction with laterality measures in free viewing. As low spatial frequencies are thought to be processed before high frequencies (e.g., Goffaux et al., 2011; Kauffmann et al., 2014), this might explain why positive facial expressions, like happiness, sometimes demonstrate a left visual field (LVF) advantage when presented tachistoscopically (e.g., Alves et al., 2009;

Schweinberger et al., 2003). A divided half-field study by Kumar and Srinivasan (2011), which used short (150 ms) stimulus presentation, investigated whether filtering spatial frequency content affected participants' ability to identify facial expressions. Low spatial frequencies were important for correctly identifying happiness, while high spatial frequencies were important for identifying sadness (as in Smith & Schyns, 2009). A more comprehensive study of the effect of spatial frequency filtering on basic emotions is therefore necessary.

One interesting approach to this problem has been the use of 'hybrid' stimuli (Schyns & Oliva, 1999). These faces contain a typical range of spatial frequency information. However, low and high frequency components are extracted from faces with emotional and non-emotional content and then combined into a single image. Laeng et al. (2010) have shown that information from emotional expressions (i.e., anger, fear, happiness, sadness) presented only in the lower spatial frequencies of an otherwise neutral face can significantly influence participants' judgements of friendliness, although the emotional content in these emotional hybrid faces was largely 'invisible' and not consciously perceived by the observers (Burns, Martin, Chan, & Xu, 2017; Laeng et al., 2010; Prete, Laeng, & Tommasi, 2018).

Prete, Laeng and Tommasi (2014) presented hybrid stimuli (i.e., low frequency emotional, high frequency neutral hybrids) in a visual half-field paradigm. Specifically, they presented hybrids of happy/neutral, angry/neutral and neutral facial expressions and asked participants to judge their friendliness foveally or in the LVF or RVF. Across all expressions, participants indicated that hybrid faces in the RVF were friendlier than those in the LVF, regardless of short (125 ms, preventing saccadic eye movements) or longer (250 ms) presentation times. There are however two main limitations of this study: (1) only two basic emotions were assessed (i.e., anger and happiness), and (2) the measure of emotion discrimination was not direct and instead had to be inferred from judgements of friendliness. Also, (3) it is unclear to what extent the results depend specifically on the VHF paradigm or whether they could be replicated under free-viewing.

In the present study we aimed to investigate whether the results of Prete et al. (2014) generalise across all basic emotional facial expressions (i.e., anger, disgust, fear, happiness, sadness, and surprise) and under free-viewing in an ECFT. As we tested the full range of emotional facial expressions rather than using an indirect task of judgements of friendliness instead, we simply asked our participants to judge which of a pair of chimeric faces (i.e., carrying exactly the same emotional information but in a chimeric mirror image) appeared more emotional. For broadband stimuli, we predicted a consistent left hemiface bias – a bias towards perceiving face expressions carrying the emotion in the left hemiface to be more emotional (Hypothesis 1). This was expected regardless of the emotional valence of the facial expression (following the RH Hypothesis, Hypothesis 2). In contrast, for hybrid stimuli, we predicted that the low spatial frequency content alone would not be sufficient to produce a RH bias when time restrictions that may favour fast low spatial frequency processing were removed. Therefore, we predicted the well-established left hemiface bias in the ECFT to be significantly reduced under free-viewing conditions, when the emotional expression was only present in the low spatial frequency content of the image and participants were not aware of the emotion (Hypothesis 3).

Method

Participants

Forty right-handed individuals (20 women, 20 men) from the Durham University student population participated in the present study, which was approved by the local research ethics committee. Participants were recruited either through online advertisements (in exchange for course credits) or via opportunity sampling. The sample size was determined by examination of Prete et al. (2014) who used hybrid faces in a visual half-field study with 33 participants in each presentation time condition, and Innes et al. (2016) who tested 59 participants in their ECFT study. Female participants' ages ranged from 18-24 years (*M* ± *SD* = 19.45 ± 1.43), while male participants' ages ranged from 18-33 years (22.15 ± 3.34). Hand preference was measured using the Edinburgh Handedness Inventory (Oldfield, 1971). For each participant, a Laterality Index (LI) was calculated based on the number of activities for which the left or right hand was typically used, expressed as ([R–L] / [R+L]) × 100. LIs thus ranged between -100 and 100, with positive LIs indicating right-handedness and negative LIs indicating left-handedness. The mean handedness LI for the entire sample was 83.87 (*SD* = 18.33, range: 33.33 - 100). An independent *t*-test revealed that handedness LIs for women (84.92 ± 16.46) and men (82.81 ± 20.41) did not differ significantly, $t(38) = .36$, $p = .721$.

Apparatus

All experimental tasks were displayed on a computer monitor with a 1024 × 768 resolution and a refresh rate of 60 Hz. A chin rest was also used to maintain viewing distance at 57 cm from the display.

Emotional Face Stimuli

The broadband chimeric face stimuli used in this experiment were identical to Innes et al. (2016). These were averaged expressions produced with images taken from the Ekman and Friesen (1976) *Pictures of Facial Affect* series. Full-faced emotional expression stimuli were constructed by warping the individual expressions of 8 posers (4 women, 4 men) to a symmetrical average for each basic emotion and a neutral face (for details on averaging, see Perrett et al., 1999; Tiddeman, Burt, & Perrett, 2001). Stimuli were constructed by fitting these full-faced emotional stimuli to a 'mask' which took the average shape and pixel luminance from the left hemiface of one stimulus and the right hemiface of another. Stimuli were blended across the vertical midline to produce the effect of a typical face (for full details on chimeric stimuli production see Burt & Perrett, 1997). Prior to spatial frequency manipulations, all source (i.e., broadband) stimuli were resized to 180 × 256 pixels. All source images were adjusted so that the mean luminance of each image matched the mean luminance of the stimulus set.

Image Manipulation

Filtered images were prepared in MATLAB using a custom-written function. In a similar manner to that described by Laeng and colleagues (Laeng et al., 2010; Prete et al., 2014), a low-pass filter was used to extract frequencies < 7 cycles per image (cpi) for each emotional image, and a high-pass filter was used to extract frequencies > 7 cpi from the full-faced neutral image. These two images were then combined in the Fourier domain before being transformed to produce a real hybrid image containing emotional low spatial frequencies and neutral high spatial frequencies (see Figure 1). Broadband and hybrid chimeric faces were then constructed as described above (see Figure 2).

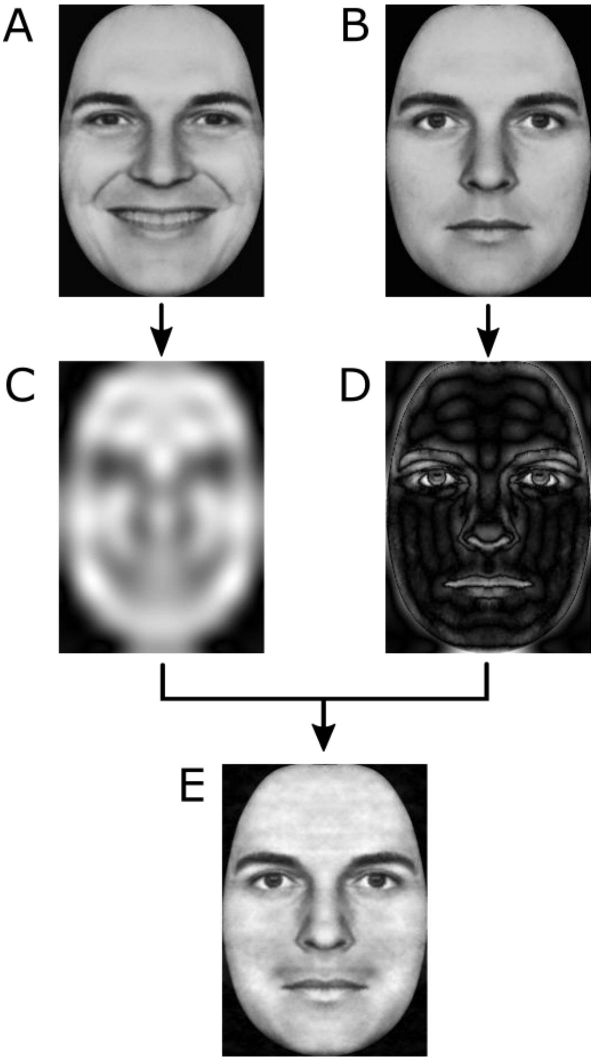

Figure 1. Hybrid face production method. An emotional (A) and a neutral (B) expression were first specified. A low-pass filter (< 7 cpi) was applied to the emotional image to produce a stimulus containing only low spatial frequencies (C). A high-pass filter conversely extracted only high frequencies (> 7 cpi) from the neutral face (D). The hybrid stimulus (E) is the sum of low emotional (C) and high neutral (D) frequencies. Face images were designed by averaging individual face images. Individuals who went into making these average face stimuli cannot be identified. Copyrights: Dr Mike Burt and Dr Robert W. Kentridge. Reprinted with permission.

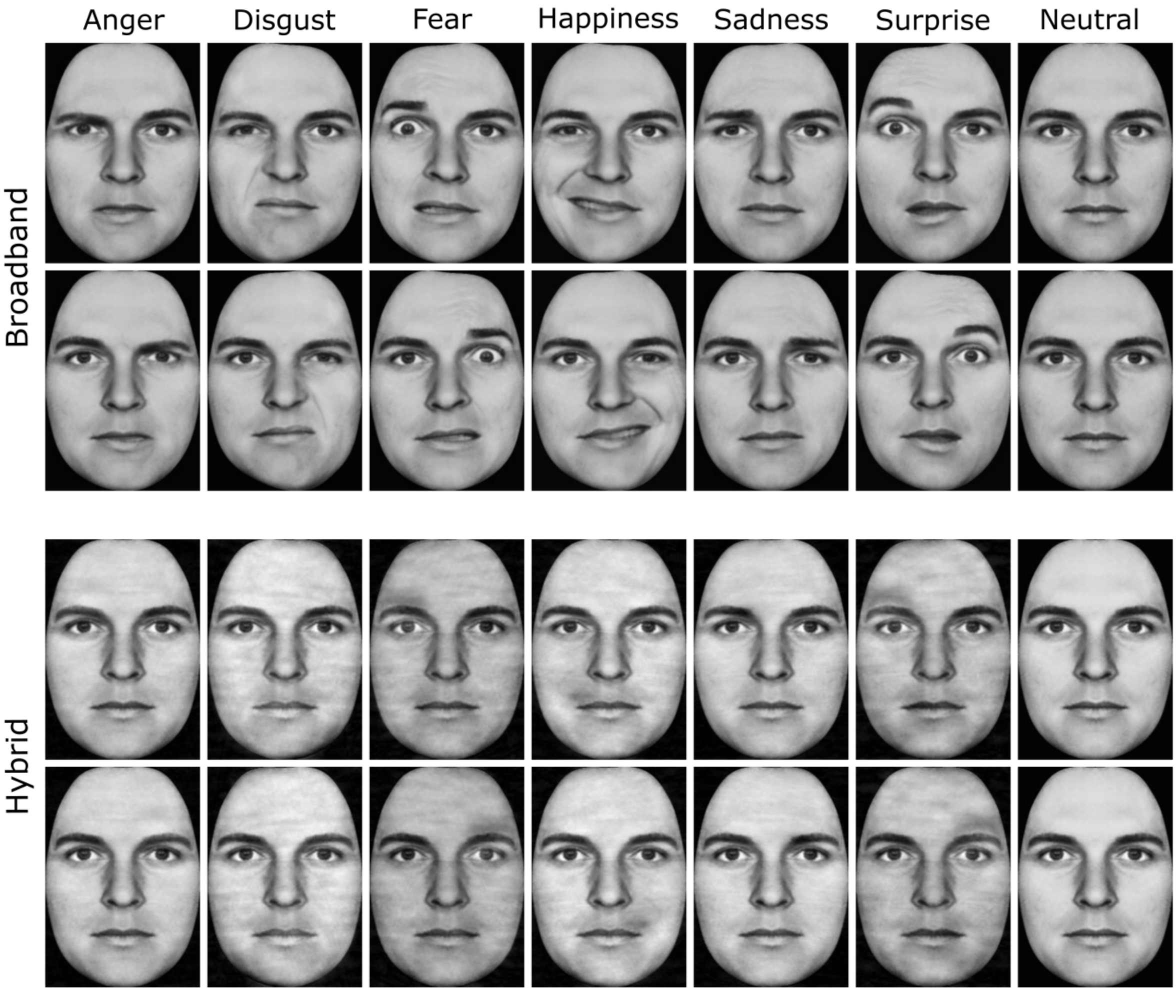

Figure 2. Stimuli used within the ECFT task. The upper row shows broadband stimuli (identical to Innes et al., 2016). The lower row are chimeric images constructed by combining the low spatial frequencies of the broadband chimeric faces with the high spatial frequencies of a full-faced neutral expression. In all cases, the upper image of each pair shows emotion in the left hemiface, and the lower image shows emotion in the right hemiface. Face images were designed by averaging individual face images. Individuals who went into making these average face stimuli cannot be identified. Broadband stimuli (upper panel) reprinted from “A Leftward Bias However You Look At It: Revisiting the Emotional Chimeric Face Task as a Tool for Measuring” by Bobby R. Innes, D. Michael Burt, Yan K. Birch, & Markus Hausmann, 2016, Laterality, 21, Figure 1. Copyright 2016 by Taylor & Francis Group. Reprinted with permission. Copyright of hybrid stimuli (lower panel) reprinted from Dr. Mike Burt and Dr. Robert W. Kentridge. Reprinted with permission.

Emotional Chimeric Face Task

In the ECFT, an initial central fixation cross was presented against a white background for 2000 ms at the start of each trial. A pair of mirror-reversed chimeric faces then appeared one above the other. In one of the pair, the emotional component of the chimeric face was on the left and in the other, it was on the right (top/bottom randomised, equal numbers across trials). The individual faces were presented 0.5° visual angle above/below central fixation. Each face stimulus measured 4.5° × 6.5° visual angle and the pair remained onscreen for 4000 ms. Participants responded via keyboard within this period whether they believed the upper or lower face appeared 'more emotional' ('1' indicating the upper face, '2' indicating the lower face). Response hand was counterbalanced across conditions with half of the trials using the left hand. If no response was received within 4000 ms, the next trial was initiated and the no-response trial was repeated at the end of the presentation set. If this trial also received no response, the trial was marked as having no-response.

A total of 112 (56 standard, 56 hybrid) face pairs were presented in two test blocks. Each test block contained either only broadband faces or only hybrid faces. Within each of these 56 trial blocks each of the six emotional expression trial types (i.e., anger, disgust, fear, happiness, sadness, surprise) and one neutral expression trial type were presented 8 times pseudo-randomized and counterbalanced for hemiface arrangement. Trials with neutral face expressions were used as catch trials to uncover a potential top-bottom response bias. The statistical analysis on catch trials was not presented because no such bias was found. Laterality Quotients (LQs) were computed for emotional chimeric faces by first subtracting the number of trials where the emotional expression presented on the right was reported as more emotional from the number of trials where the emotional expression on the left was reported as more emotional. Second, this score was then divided by the total number of trials. The resulting LQs range between -1 and 1, where negative LQ scores indicate a stronger right hemiface bias and positive LQs indicate a stronger left bias, with 0 indicating no bias.

Procedure

Participants read the information sheet, signed the consent form, and completed the Edinburgh Handedness Inventory (Oldfield, 1971). The experimenter then read aloud the instructions for the chimeric face task. Participants were informed that some blocks of trials might be more difficult than others, and that on some trials, the faces had been manipulated to appear ‘blurry’ or ‘cloudy’. Participants were not explicitly told that the stimuli had been manipulated in spatial frequency content. After half of the trials had been completed for each block, the program paused and participants began responding with the opposite hand. Response hand was changed after half of the trials.

Results

In the repeated-measures ANOVAs, if the sphericity assumption was violated, the degrees of freedom were subjected to Greenhouse-Geisser correction. Post hoc tests were Bonferroni corrected.

Experiment 1

LQs for broadband and hybrid chimeric faces (Figure 3) were submitted to a 2 × 6 ANOVA, with Spatial frequency manipulation (broadband/hybrid) and Emotion as the within-subject factors. In line with Hypothesis 1, the ANOVA revealed a significant intercept effect, $F(1, 39) = 28.37$, $p < .001$, $\eta_p^2 = .42$ indicating an overall LVF/RH bias (0.18 ± 0.03). As predicted in Hypothesis 3, the main effect of Spatial frequency manipulation was significant, $F(1, 39) = 34.21$, $p < .001$, $\eta_p^2 = .47$, indicating a larger LVF/RH bias for broadband stimuli (0.34 ± 0.06) than hybrid stimuli (0.02 ± 0.03). The main effect Emotion did not approach significance, *F*(5,

195) = 0.58, n.s., $\eta_p^2 = .02$. The Spatial frequency manipulation by Emotion interaction was also significant, $F(5, 195) = 2.28$, $p < .05$, $\eta_p^2 = .06$. To elucidate the nature of the interaction six separate paired t-tests were performed, comparing LQs between broadband and hybrid stimuli for each emotion. The analysis revealed significant LQ differences (i.e., stronger LVF/RH bias) for all negative emotions (i.e., anger, disgust, fear and sadness), all $t(39) > 3.62$, $p < .001$. For happiness, no significant LQ difference between broadband and hybrid stimuli was found, $t(39) = 1.39$, *ns*. For surprise, the LQ difference between broadband and hybrid stimuli revealed a non-significant trend, $t(39) = 2.28$, p = .028, which did not survive Bonferroni correction. In addition, we conducted one-sample t-tests on the LQ for each individual condition. For the broadband condition, one sample *t*-tests revealed significant LVF/RH biases for all emotions (all $t(39) > 3.54$, all $p \leq$. 001) (Hypothesis 2). For all hybrid stimuli, except one (happiness), no significant bias was found (all $t(39) < 0.51$, n.s.). In contrast to our prediction, a significant LVF/RH bias was found for the hybrid condition with happy face expression, $t(39) = 3.09$, $p = .004$. Although the left bias for happy facial expression was numerically smaller for the hybrid condition (0.18 ± 0.06, *M* ± *SE*) compared to the broadband condition (0.29 ± 0.06), as predicted, the effect did not approach significance, $t(39 = 1.39$, $p =$ .17, *ns*. The results for the hybrid stimuli suggest that happiness is processed differently from other low spatial frequency content stimuli (Figure 3).

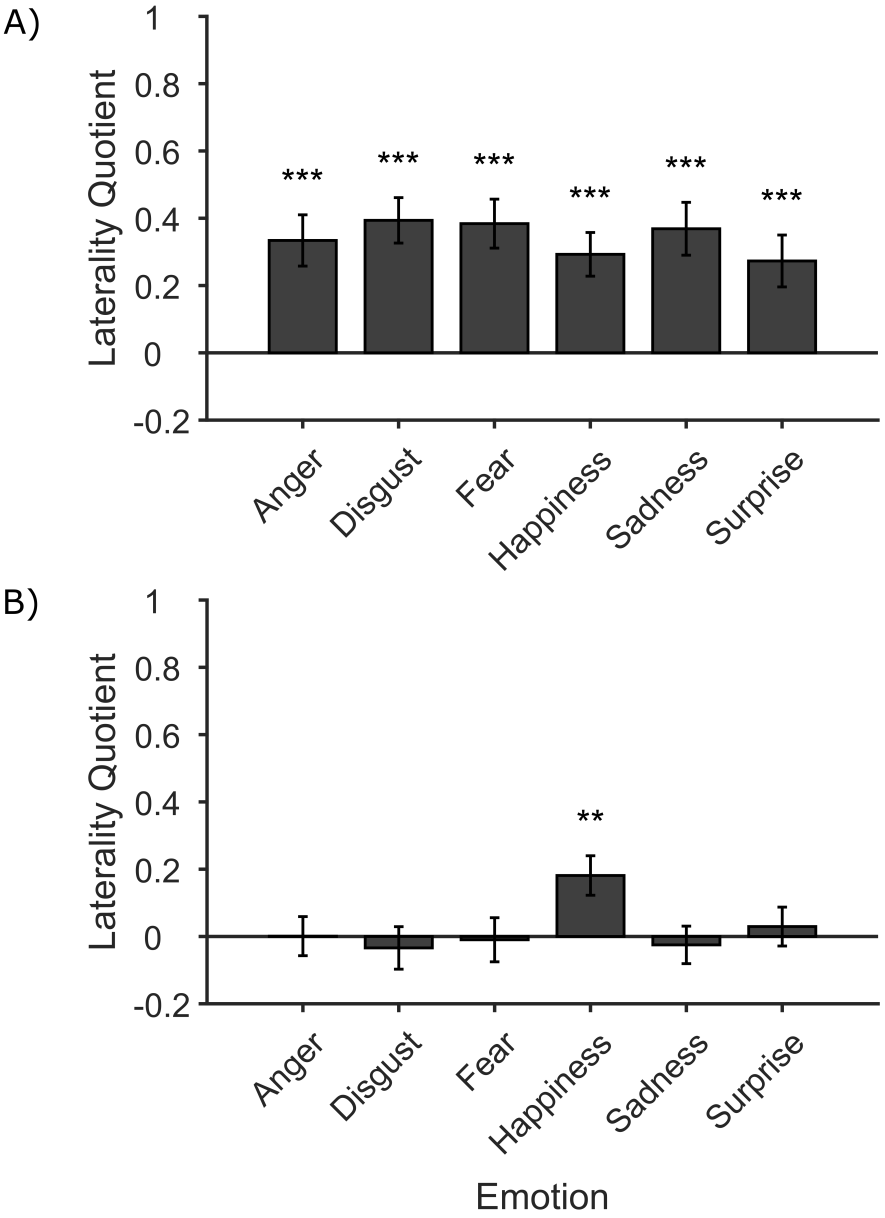

Figure 3. Mean Laterality Quotients (LQs) for each individual (A) broadband and (B) hybrid chimeric emotional face (**$p \leq .01$, ***$p \leq .001$, according to two-tailed one-sample *t*-test, Bonferroni-corrected). Positive LQs indicate a left hemiface (RH) bias.

One previous study (Bourne, 2005) reported sex/gender effects in ECFT in a sample of 276 participants, showing larger LVF/RH biases in men than women. However, the present study did not include sex/gender because (a) sex/gender effects were not in the focus of the present study, and (b) this analysis would require a larger sample size. If sex/gender had been included in the ANOVA, however, no main effect or interaction with sex/gender would have approached significance (all $F < 2.80$, *ns*).

Experiment 2

The present study was based on the assumption that emotional facial expressions are largely invisible when presented in the low spatial frequency range, whereas emotions are easily detectable when presented as broadband stimuli. To test this assumption directly, we added a control experiment in which a small sample of 20 different participants (10 men, 10 women) was tested. Mean age was 28.30 years (*SD* = 4.14) and mean handedness LI was 70.92 (*SD* = 40.27, range: -73.30 - 100). In this control experiment, participants saw broadband and hybrid emotional chimeric faces presented centrally on the screen (one single stimulus per trial). Participants were asked to indicate by button press whether the left or right hemiface of the chimeric stimuli displayed the emotion. Stimulus size, timing of presentation and number of trials (8 trials for each emotion) were identical to the main experiment. Broadband and hybrid stimuli were again presented in separate blocks. Percentages of correct responses for each emotion/hemiface combination were tested against chance level with one-sample t-tests (test score: 50%). Significance level for one-sample *t*-tests was set to 1% due to multiple testing.

For broadband stimuli, mean percentage of correct responses averaged across all emotion/hemiface combinations was 93.44% (*SD* = 6.67). One-sample *t*-tests revealed performances for each emotion/hemiface combination significantly above chance level, all $t(19) \geq 4.35$, all $p < .0001$. For hybrid faces, mean percentage of correct responses averaged across all emotion/hemiface combinations was significantly lower, 58.33% (*SD* = 13.04), $t(19) = 11.22$, $p < .0001$. One-sample *t*-tests revealed performances above chance level only for happy right (75.00%, SD = 32.44, $t(19) = 3.45$, $p = .003$) and fearful right hemifaces (73.75%, SD = 23.61, *t*(19) = 4.50, *p* = .002). For all other emotions, and in line with our assumption, performances did not differ from chance level, all *t*(19) ≤ 2.48, *ns*, suggesting that the emotion in hybrid stimuli was largely invisible.

Data are publicly available in SPSS format (v22) at https://www.dropbox.com/sh/mqv5w1t3r7ms48d/AACho3OmUd619D3aORngmu4wa?dl=0

Discussion

The present study sought to investigate whether low spatial frequency components in images of emotional facial expressions induce a RH bias across all basic emotions. We tested this under free-viewing with ECFT. For broadband stimuli, the results replicated numerous previous studies showing a consistent LVF/RH bias in ECFT (Hypothesis 1), and regardless of the emotional facial expression (Hypothesis 2) (Bourne, 2010, 2011; Innes et al., 2016; Workman et al., 2000). In addition, and in line with our Hypothesis 3, we found significant differences between broadband and hybrid stimuli, suggesting that low spatial frequency components alone are not carrying emotional information disproportionately to one hemifield over another. The exception was the emotional facial expression of happiness. This may indicate that happiness unlike other basic emotional facial expressions has specific low level visual characteristics in low spatial frequency components of the image. This interpretation is supported by the control experiment which revealed for hybrid faces an above-chance discrimination only for happy (and fearful) right hemifaces. The fact that these two emotions were detected only when the emotion was shown in *right* hemifaces suggests a LH-dominant feature-detection strategy based on low level visual characteristics (e.g., Rhodes, 1985). However, this interpretation should be considered with caution because the results of broadband stimuli in the control experiment did not reveal any laterality bias, if single emotional chimeric faces were presented foveally and for several seconds. Overall, the results may suggest that, in order to show a consistent LVF/RH bias in emotion lateralization using facial expressions, we require conscious access to the percept. This is in contrast to a previous studies (Prete et al., 2014) suggesting that emotion lateralization can be driven by low spatial frequencies even when this information is effectively ‘invisible’ to participants.

In order to understand the inconsistencies between the present and previous studies using hybrid faces, it is important to consider the methodological differences arising from the different paradigms (ECFTs versus visual half-field stimulation) used in these studies. The key differences that might explain these inconsistencies are in (1) presentation times, (2) the range of emotional facial expressions tested, and (3) the specific instructions given to participants.

In contrast to the long presentation times used in the present study, Prete et al. (2014) used brief presentation times in the visual half-field paradigm. Specifically, Prete et al. (2014) presented hybrid happy, hybrid angry and neutral faces for 250 ms and shorter foveally or in the LVF or RVF to control for saccadic eye movements, suggesting that the effects of the low spatial frequency components of images on emotion lateralization only becomes apparent at such short presentation times. Presentation times of 250 ms were also used in ECFT paradigm by Prete, D’Ascenzo, Laeng, Fabri, Foschi, and Tommasi (2015) in which chimeric faces consisted of two identical or different emotional (happy and angry) and neutral hybrid hemifaces (e.g., happy/happy, happy/angry, happy/neutral, angry/happy, etc.), and participants were asked to rate ‘friendliness’ of single chimeric faces, assuming that happy facial expressions were judged as more friendly than angry looking faces, especially when happy face expressions were displayed on the left of the chimeric face. However, in contrast to broadband face stimuli which showed significant modulation in friendliness ratings, depending on the face expression being happy, neutral or angry, Prete, D’Ascenzo et al. (2015) found no modulation in friendliness ratings for hybrid stimuli. All friendliness ratings for hybrid stimuli were numerically slightly below the score of 3 (“neutrality point”), suggesting that participants were unable to detect the emotion in hybrid stimuli. This might also explain why no laterality biases (i.e., no differences between happy/neutral and neutral/happy, and angry/neutral and neutral/angry) were found for hybrid stimuli, which is in line with the results of the present study. The results are partly in line with Prete, Laeng, Fabri, Foschi, and Tommasi (2015, Experiment 2) which used the same ECFT as Prete, D’Ascenzo et al. (2015) but with shorter presentation times of 128 ms. Significant increases in friendliness ratings were particularly found for hybrid stimuli carrying happy expressions in the left hemiface or in both hemifaces. Unfortunately, however, Prete, Laeng et al. (2015, Experiment 2) did not compare hybrid versus broadband stimuli directly, because broadband stimuli were not included in a control condition. However, other findings such as those of Laeng and colleagues (Laeng et al., 2010, 2013; Leknes et al., 2013) suggest that participants were affected by the low spatial frequency content in a hybrid face presented for several seconds when tested in paradigms that did not probe lateralization. The present study was the first investigating the LVF/RH bias in emotional facial expression processing with hybrid stimuli under free-viewing.

It is important to acknowledge that emotional facial expressions differ in their basic visual properties. Some facial expressions, particularly positive expressions, like happiness, have single features, such as changes in the mouth, which are utilized for recognition in addition to the configural information which usually defines negative expressions like sadness (Bombari et al., 2013). Therefore, it may be that for hybrid stimuli, the laterality bias for happy facial expressions differs from other basic emotional facial expressions because of some salient features. Featural face processing is thought to be left lateralized and configural processing right lateralized (Bourne, Vladeanu, & Hole, 2009). This suggests that emotion lateralization could potentially be explained by asymmetries in processing featural and configural information. Featural changes can particularly affect the spatial frequency composition of the face (Goffaux & Rossion, 2006; Keenan, Whitman, & Pepe, 1989). The characteristic changes in the mouth region associated with expressions, such as happiness, produce significant changes in the low spatial frequency content of the image of the face (Smith & Schyns, 2009). It is well known that low spatial frequency information carried by the magnocellular channel of the visual system is processed more rapidly than high spatial frequency components carried in the parvocellular system (e.g., Nowak, Munk, Girard, Bullier, 1995). As a consequence, it is plausible that rapid tachistoscopic presentation of emotional facial expressions dominated by low spatial frequency characteristics is more likely to produce a RH bias in visual half-field studies. However, the results of the present ECFT study suggest that a RH bias for happy facial expressions can still persist with longer presentations.

Prete et al. (2014, Prete, D'Ascenzo et al., 2015; Prete, Laeng et al., 2015) only included facial expressions of happiness and anger as stimuli, whereas the present study included all six basic emotions. Surprisingly, the inclusion of all six basic emotions has not commonly been the practice in studies on emotion lateralization (e.g., Najt et al., 2013). This leads us to consider further whether emotional facial expressions of happiness or anger differ from the other four basic emotions in the laterality biases they elicit.

In line with the broadband results of the present study, the few ECFT studies that have used all six basic emotions (e.g., Bourne, 2010, 2011; Innes et al., 2016; Workman et al., 2000) revealed rather consistent LVF/RH biases across all emotions, supporting the RH Hypothesis (Borod et al., 1998), rather than the Valence model of emotion lateralization (e.g., Silberman & Weingartner, 1986; Stafford & Brandaro, 2010) and corroborating other studies which have used less than six emotions (e.g., Christman & Hackworth, 1993). Support for the RH hypothesis from visual half-field studies is less consistent. For example, Najt et al. (2013) reported consistent LVF/RH biases only for a subset of negative emotions, including anger, fear and sadness, rather suggesting a "negative (only) valence model".

For the hybrid chimeric faces, however, no overall hemiface bias emerged. This is inconsistent with the assumption that biases within the chimeric face task rely on the same mechanisms as for VHF tasks, and demonstrates that the processing of spatial frequency differs between paradigms. This might be expected given that higher spatial frequencies processing increases with exposure duration (Goffaux et al., 2011).

Sergent's (1982; 1987) Spatial Frequency Hypothesis predicts that low-pass filtered faces would be better categorized as emotional in the RH, maybe promoting an LVF bias for emotion lateralization. However, we only find evidence for this with the expression of happiness in the hybrid condition. In fact, the laterality bias for hybrid faces with masked happy facial expressions revealed an LVF/RH bias in both Prete et al. (2014) and the present study. This suggests that low spatial frequencies components are important, and sufficient, for identifying happy facial expressions. This finding is also in line with recent observations suggesting that low spatial frequencies appear to be more useful for identifying happiness compared to other emotions (Kumar & Srinivasan, 2011; Smith & Schyns, 2009).

Related to the issue with differences in the range of emotional facial expressions tested, the present study differed from previous ones in the instructions given to participants. As noted earlier, Prete et al. (2014, Prete, D'Ascenzo et al., 2015; Prete, Laeng et al., 2015) did not ask participants to make decisions about the emotional content of hybrids, but rather asked them to rate their 'friendliness', assuming that happy facial expressions were judged as more friendly than angry looking faces. In contrast, in the present study participants were asked about which of two (identical, but mirror reversed) chimeric faces appears more emotional. In the present study the response required is less specific in terms of emotions than that required by Prete et al. (2014, Prete, D'Ascenzo et al., 2015; Prete, Laeng et al., 2015). It would be hard to argue that the task used in the present study is more demanding of discrimination abilities than that of Prete et al. In addition, of course, the much more relaxed timing demands of the present study are also likely to make the task easier. This makes it unlikely that the consistent laterality bias in our experiment was missing because ECFT was too demanding or more demanding than the visual half-field task by Prete et al. (2014) or the ECFTs by Prete, D'Ascenzo et al. (2015) and Prete, Laeng et al. (2015).

The present study is one of the very few that examined effects of spatial frequencies on the laterality of emotional face perception using hybrid faces. It also appears to be the only study to include all six basic emotions, and thus provided an opportunity to assess the generality of hypotheses concerning the lateralization of processing emotions in the context of spatial frequencies. The results presented here are generally consistent with the idea that emotional face perception is RH lateralized. However, the results of the present hybrid faces experiment showed that emotion lateralization is not entirely driven by low spatial frequency content in the ECFT. It is clear, therefore, that these two tasks should not be regarded as equivalent measures of emotion lateralization, and selection of either task should take into account differences in the sensitivity to spatial frequency content. Finally, the present study suggests that consistent lateralization effects for unconsciously processed emotional facial expressions may only become evident in paradigms which use short presentation times. These findings have important implications for our understanding of the relationship between consciousness and the perception of emotion and the extent to which these processes show hemispheric specialization.

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