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Psychophysical evidence for distinct contributions in processing low and high spatial frequencies of fearful facial expressions in backward masking task

The present report examined the hypothesis that two distinct visual routes contribute in processing low and high spatial frequencies of fearful facial expressions. Having the participants presented with a backwardly masked task, we analyzed conscious processing of spatial frequency contents of emotional faces according to both objective and subjective task-relevant criteria. It was shown that fear perception in the presence of the low-frequency faces can be supported by stronger automaticity leading to less false positives. In contrary, the detection of high-frequency fearful faces was more likely supported by conscious awareness leading to more true positives.

Keywords: *face processing, spatial frequency, fear, awareness, backward masking, automaticity*

Introduction

Face processing and interpretation of facial emotional contents are essential in our social and communicative behavior (Critchley, 2003; Holmes, Winston, & Eimer, 2005). The fast and accurate detection of angry or fearful emotional expressions can initiate people's fight-or-flight or freeze responses when faced with danger or with threat (Blair, 2001; Öhman, & Mineka, 2001). Emotional faces are processed rapidly (Pessoa, Japee, & Ungerleider, 2005), and even very brief presentations of facial expression, lasting for 17 ms, can be consciously detected (Szczepanowski and Pessoa, 2007). Moreover, people are selectively sensitive towards higher- (HSF) and lower spatial frequency (LSF) information associated with the emotional face (Vuilleumier, Armony, & Dolan, 2003). Explicit ratings about facial emotional expressions are based mostly on the features represented by high spatial frequencies (Holmes et al., 2005; Vuilleumier et al., 2003). The LSF components of faces may be critical in terms of rapid enhancement of attention towards fearful facial expression as compared to the HSF components (Holmes, Green, & Vuilleumier, 2005). In addition, there are evidences that global face perception depends on coarse information provided by low spatial frequency components (Goffaux & Rossion, 2006). Nevertheless, both high and low spatial frequencies are needed for accurate detection of emotional expressions (Holmes et al., 2005).

Processing of spatial frequency information of emotional face in the brain

Some neuroimaging evidence already exist indicating that spatial frequency processing of emotional expressions can be supported by specialized brain regions (Johnson, 2005). An important study by Vuilleumier and colleagues (2003) indicated that two distinctive brain regions may be selectively activated when participants presented with LSF and HSF components of fearful faces while in the fMRI scanner. Apparently, it turned out that activation of the fusiform gyrus was stronger for HSF contents of the fearful faces than LSF components, in contrary, subcortical activation of the amygdala was greater for the LSF components and intact faces as compared to the HSF cues. Not surprisingly these findings were in line with brain research on face processing indicating involvement of the amygdala region in extracting information about an emotional content of the face (Adolphs, Tranel, Damasio, Damasio, 1995) as well as the fusiform gyrus region in recognition of the face identity (Kanwisher, McDermott, & Chun, 1997).

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Methodological difficulties in measuring facial sensitivity: objective vs. subjective measures

It is important to note that Vuilleumier and colleagues (2003) reported some methodological difficulties in supporting their main claim of the distinct brain routes for the LSF and HSF faces. In particular, the above-mentioned distinct spatial frequency sensitivities in processing emotional faces in the brain were found while the participants performed a gender discrimination task. The participants were shown a 200-ms presentation of fearful or neutral expressions (half each), either an intact, HSF or LSF content, and were to report whether the face was male of female, although the emotion was task-irrelevant. The objective measure ("yes-no" responses) indicated no differences between detecting the HSF and LSF faces in terms of accuracy and reaction times, therefore the brain responses were accounted for differences in spatial frequency processing. Yet, the authors admitted that distinct facial sensitivities in the brain might have been problematic, because consciously perceived LSF facial contents might have had the greater intensity than conscious perception of the HSF facial cues. Thus, to resolve this methodological puzzle, a follow-up study was carried out, outside of the scanner, by asking other group of participants to subjectively rate emotional expressions of HSF, LSF and intact faces (half fearful and half neutral) using the rating scale. Because the explicit task-relevant ratings (subjective measures) were stronger for the BSF and HSF faces as compared to the LSF cues, and on the other hand the brain responses were stronger for the LSF components, it was claimed that activation of the amygdala was more likely driven by the LSF components.

It is worth noting that both objective and subjective measures have been employed in studying the role of conscious awareness in processing emotional faces (Pessoa, 2005; Szczepanowski and Pessoa, 2007). Both measures can establish different constraints on visual mechanisms and their neural network mechanisms that underlie these processes (Pessoa, 2005). For instance, activation of the amygdala as a function of objective and subjective measures can be differentially activated (Pessoa, 2005). In fact, objective and subjective measures are inherently linked with the notion of weak and strong automaticity that is connected with involuntary processing when emotional items perceived. The use of two different methods for measuring awareness may rise a question of the feasibility of these two brain networks for spatial frequency processing in the brain. The additional concerns to this study, yet not reported, is that behavioral responses in the discrimination task were sensitive to a response bias. For instance, the gender discrimination task did not consider the participant's tilt to his of her willigness to say "yes" to fearful or non-fearful faces. Thus, differences in the ratings design could also reflect some tendency to respond to some other basis than merit of the main task.

The present sudy

Here, we addressed these methodological concerns by behaviorally examining the hypothesis of distinct spatial facial sensitivity under a backward masking task with ratings. Within this paradigm, conscious processing is limited by degrading visibility of the prime by its time duration and the subsequent mask stimulus (Szczepanowski, 2011). The masking with confidence ratings allowed us to analyze the spatial frequency content of the emotional face according to both the objective ("yes-no" responses) and subjective (confidence ratings) task-relevant criteria. Thus, under the reported hypothesis of neural mechanisms for the different spatial frequency sensitivities, we expected that spatial frequency processing of fearful face should be enhanced (e.g., faster responses, more efficient automaticity) with the LSF content than HSF content even though the level of detecting the HSF is higher than for LSF cues. In addition, because it was likely that gender discrimination was inherently biased, our masking study attempted to mitigate the response bias problem by employing a bias-free sensitivity measure.

Experiment

Participants

Thirty one undergraduates (4 males and 27 females) of Warsaw School of Social Sciences and Humanities, aged 20-35 (mean of 23.4, SD = 4.2), participated in this study in exchange for course credit points. Participants had normal or corrected-to-normal vision. The study was approved by Ethics Committee of the School. The datasets indicating any chance behavior were excluded (6), and one more dataset was removed due to a participant's failure to use confidence ratings. The data are reported here from a total of 24 participants.

Materials and apparatus

Six face pictures of three different identities that expressed two emotions (fearful, neutral) each were chosen from the Picture of Facial Affect set (Ekman & Friesen, 1976) and the set elaborated by Öhman and colleagues (KDF, Lundqvist, Flykt, & Öhman, 1998) as target stimuli. Each face picture was trimmed by the black-background oval to remove the hair and non-facial contours. Ovals containing only faces (without hair, background or other personal non-emotional features) were cut from the face pictures. The face stimuli subtended 4 x 5° of visual angle. A viewing distance was of about 60 cm. The face pictures underwent a filtering procedure to get high- and low-spatial frequencies. Given existing literature data on face processing (Costen, Parker, Craw, 1996; Schwaninger, Lobmaier, Wallraven, & Collishaw, 2009), the relevant parameters of filters by Adobe Photoshop 6.0 were chosen. In particular, a high-pass filter of the 2.5 pixel radius per face and a low-pass filter (Gaussian Blur) of the 1.0 radius per face were applied to the pictures (see Fig.1). The filtering

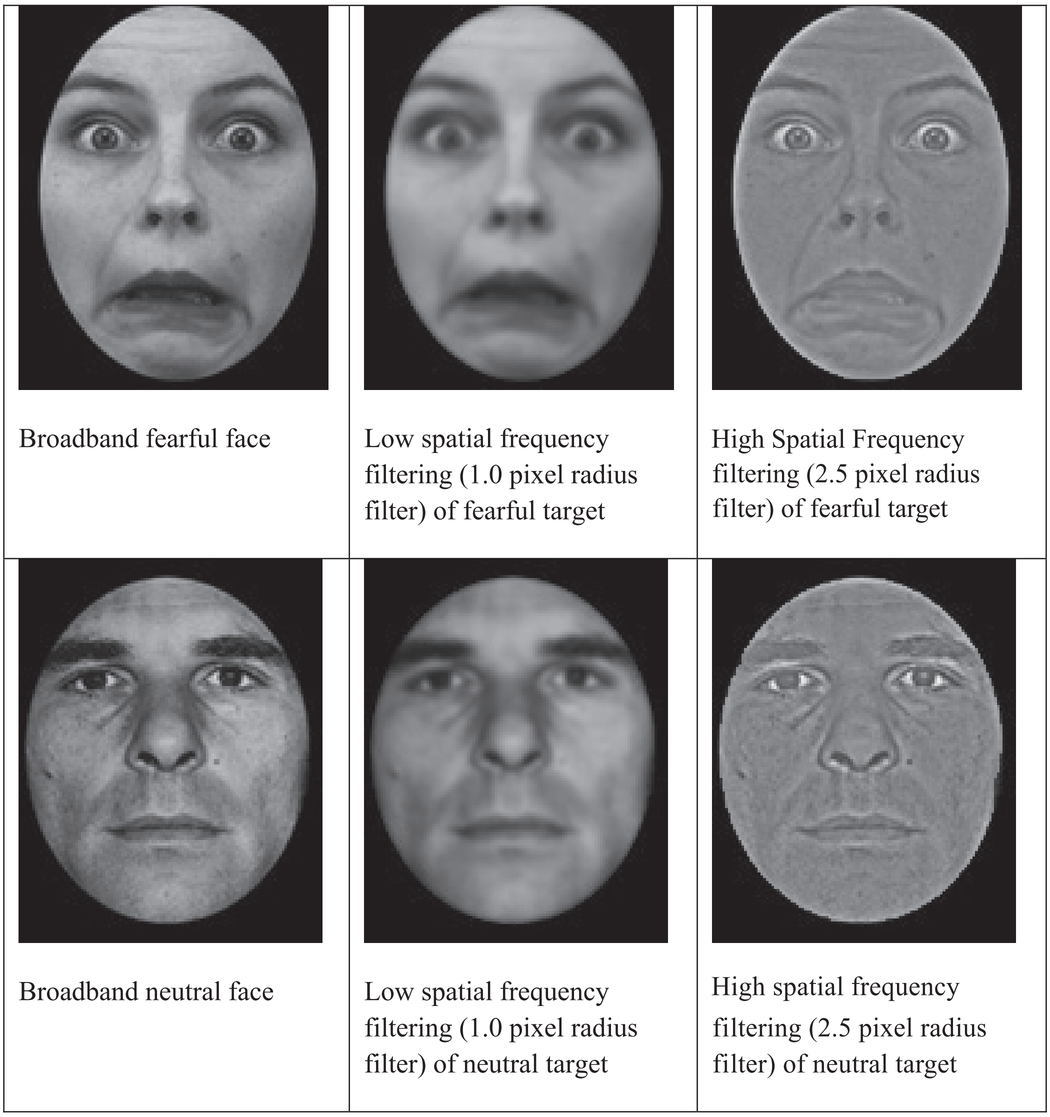

Figure 1. Sample of target stimuli with intact, low- and high filtering used in the study

procedure of face pictures resulted in 18 target stimuli: 3 identities x 2 emotional expressions (Fearful, Neutral) x 3 spatial frequencies (high spatial frequency, low spatial frequency, broadband spatial frequency). We also used 96 non-filtered, neutral faces chosen from the same face picture sets as masks. The face stimuli were presented on the Iiyama MA203DT Vision Master Pro 513 monitor with a refresh rate of 120 Hz. Participants were seated in a dim light room in front of the monitor, with their heads fixed by a chin rest.

Procedure

Each trial started with a white fixation cross that was displayed for 300 ms on a black screen, it was followed by a 50 ms blank screen, followed by a fearful or neutral face target for a 25 ms duration, which was immediately followed by a neutral face mask. After the presentation of each target-mask pair, within 2 sec the participants was requested to ask whether or not the emotional face was present using the button press on the numerical keyboard. Then, the participants had 2.5 sec to rate their confidence of their “yes or no” responses using a 1-to-6 scale (from low to high confidence). There were six blocks of trials involved in the study, each consisting of 96 trials. The target faces were randomized and counterbalanced across blocks. Participants did not receive any feedback on their performance. The experiment involved a total number of 576 trials, lasting approximately one hour.

Behavioral measures of sensitivity

The accuracy of the face detection was assessed with a bias-free sensitivity measure, so called A’. To do so, receiver-operating characteristics (ROC) were generated for which points were cumulative data (the pairs of hit and false alarm rates) represented by the sums of proportions over confidence ratings ranging in order from high confidence for targets to high confidence in non-targets (Macmillan & Creelman, 2005). The hit rate represents the probability of reporting fear, given that a fearful face was the target (p[„fear“ | fear]), while the false alarm rate is the probability of reporting fear given that a non-fearful face was the target (p[„fear“ | no fear]). Since our paradigm followed the 6-point confidence ratings design, the 12 pairs of hit and false alarm rates were used to generate ROC curves. The A' sensitivity measure of the subject's ability to detect fearful target was evaluated by computing the areas under the ROC curve. Thus, emotion perception was deemed aware when the sensitivity measures were significantly greater than 0.5 (the baseline level).

Results and discussion

Objective measures of fear

Initially, we investigated fear detection ability for the BSF, LSH and HSF faces by looking at the A' values. The sensitivity measures were entered into the repeated-measures ANOVA with one within-subject factor (spatial frequency content). The ANOVA revealed the main effect for facial spatial frequency in terms of detecting fear, $F(2, 46) = 25.39$, $p < .001$, $\eta_p^2 = .53$, where the highest detection level of .86 was for the intact faces, the middle level of .80 for the HSF cues, and the lowest level of .77 for the LSF faces. The post-hoc comparisons with the Tukey's adjustments ($p < .05$) showed the significant differences in detection ability among all spatial frequencies. Thus, our results demonstrated that the participants were aware of detecting fear no matter the spatial content perceived. In fact, the greater accuracy of consciously perceived fear was found in the presence of the HSF than in the LSF contents.

In addition, we investigated emotional processing of presented masked facial expressions by running the ANOVA with two-within factors (type of response, spatial frequency) on signal detection components of yes-no responses associated with hits and false-alarms. The analysis of the hit rates showed the main effect of spatial frequency on emotional processing, $F(2,46)=41.78$, $p<.001$, $\eta_p^2=.65$. The multiple comparisons with the Bonferroni correction ($p<.05$) revealed that the intact facial content received more hits (.80) than the HSF contents (.70), and the LSF content (.60). On the other hand, the ANOVA conducted on the false-alarm rates showed the main effect of spatial frequency, $F(2,46)=12.18$, $p<.001$, $\eta_p^2=.35$. Strikingly, the post-hoc comparisons with the Bonferroni adjustments ($p<.05$) indicated that only the LSF cues received substantially less false-alarms (.18) as compared to the BSF (.24) and HSF cues (.25). Although the sensitivity measures could suggest that consciously perceived LSF facial contents might have had the lesser intensity than conscious perception of the HSF facial cues, the low level of false positives contradicted this claim at some point. Thus, given the lowest level of awareness for detecting the LSF cue, the reduced false-alarm ratio of LSF could be indicative of stronger automaticity in the analysis of coarse scale visual cues of fear. On the other hand, emotional processing of the HSF content could be to some extent underlined by weak automaticity where more accurate responses were modulated by conscious awareness.

Subjective measures of fear

Further evaluation of differential responses to facial expressions as function of spatial frequencies included explicit ratings. The repeated-measures ANOVA with two-within factors (expression, spatial frequency) was applied to confidence responses. The subjective measured showed the main effect of expression (mean, 4.3 for fearful and 4.0 for neutral facial expression), $F(1,23)=5.10$, $p<.05$, $\eta_p^2=.18$, the main effect for spatial frequency content, $F(2,46)=12.00$, $p<.001$, $\eta_p^2=.34$, and the interaction between both factors, $F(2,46)=18.33$, $p<.001$, $\eta_p^2=.44$. The analysis of the simple effects for fearful faces indicated the main effect of spatial frequency on explicit ratings (4.6 for the BSF, 4.3 for the HSF, and 4.1 for the LSF contents), $F(2,46)= 19.53$, $p<.001$, $\eta_p^2=.46$. The follow-up comparisons ($p<.05$, Tukey's corrected t-tests) showed the significant differences in explicit ratings among all spatial frequencies. In addition, for neutral faces there was no simple effect of spatial frequency on the confidence judgments, $F(2,46)=1.06$, $p>.05$. Thus, the subjective measures of participants' explicit knowledge of emotion their experienced were in concert with the objective indices suggesting that fear increased for the presence of the HSF as compared to the LSF emotional faces.

Reaction times

To investigate whether the spatial frequency content of the emotional face was driven by different types of processing, we went to the analysis of temporal characteristics of responses. The reaction times were entered into the ANOVA that yielded the main effect of spatial frequencies (mean, 862 ms for the intact faces, 882 ms for the HSF faces, and 888 ms for the LSF faces), $F(2,46)= 5.31$, $p<.01$, $\eta_p^2=.19$. The Tukey's post-hoc multiple comparisons ($p<.05$) indicated the faster reactions in detecting fear for the intact faces as compared to the HSF and LSF cues; there was no difference between detecting the HSF and LSF cues. To further explore temporal characteristics of emotional processing, we collapsed the reaction times into the hit and false-alarm datasets, accordingly. The analysis of the "hit" reaction times indicated the main effect of spatial frequency, $F(2, 46) = 16.49$, $p < .001$, $\eta_p^2=.42$. As indicated by the Tukey's multiple comparisons ($p<.05$), the faster hits were made in detecting fear in the presence of intact faces (802 ms), as compared to the HSF cues (848 ms), and the LSF cues (876 ms); all differences were significant.

This implied that conscious awareness was a possible modulating factor in enhancing emotional responses toward threat-related cues for the HSF content. The ANOVA of the "false alarm" reaction times showed also some moderate effect of spatial frequency, $F(2, 46)=2.80$, $p<.01$, $\eta_p^2=.11$. Not surprisingly, the faster false-alarms were produced for the LSF faces (1006 ms) as compared to the HSF faces (1081 ms) as indicated by the multiple comparisons with the Tukey's test ($p<.05$). This suggested that under aware perception stronger automaticity was possibly involved in enhancing responses towards the LSF faces while error-monitoring activity.

General discussion

The present study was aimed at finding psychophysical evidence for dissociation in processing low- and high-spatial frequency contents of emotional faces. The task-relevant objective and subjective measures of fear showed that the effect of presenting emotional faces was greater for the intact or HSF faces than for the LSF faces. In fact, successful fear detection of LSF faces was supported by the relatively small number of false-alarms. Evidence for similar dissociation between the HSF and LSF contents was also found in temporal characteristics of fear detecting. The emotional reactions were faster for the LSF cues, however, only when false-positives made. The effects were opposite in generating true positives, because the faster reaction times were observed when the intact or HSF faces perceived. Thus, our study suggests that detecting fear in the presence of the LSF cues can be supported by stronger automaticity leading to less false positives. In the contrary, processing of fear in high-frequency faces can be enhanced by conscious awareness subsequently increasing number of true positive responses. Thus, our study provides evidence supporting the claim that qualitative differences in processing the HSF and LSF contents of the emotional faces can be supported by the different visual routes.

In fact, we found the similar dissociations in terms of processing spatial contents as that Vuilleumier and colleagues (2003) reported in their explicit ratings measures. That is, the explicit ratings for the fearful HSF cues were elevated in our study. Hence, our subjective measures, as indicative of explicit conscious knowledge of emotion, suggest a greater role of the HSF cues in conscious interpretation of processing outputs under the backward masking condition. This specific pattern in detecting the HSF faces was in accordance with weak automaticity for these spatial frequency cues shown by the objective measures of yes-no responses. Thus, as opposed to the gender task used by Vuilleumier and colleagues (2003), the present report shows when fear is task-relevant, and consciously processed, objective measures of fear are in accordance with the subjective measures.

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