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Influence of emotional facial expressions on binocular rivalry

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Abstract

Three experiments investigated whether emotional information influences perceptual dominance during binocular rivalry. In Experiment 1, rival emotional and neutral faces in the background were coupled with grating stimuli in the foreground. Results showed that gratings paired with emotional faces dominated over those paired with neutral faces. In Experiment 2, emotional and neutral faces were presented dichoptically, without being paired with other stimuli. Dominance of emotional faces was observed. Fusion and low-level image differences were ruled out by examining dominance periods of upright and inverted emotional and neutral faces presented as face-house pairs (Experiment 3). Here, face stimuli dominated over house stimuli only for upright face conditions. In addition, upright emotional faces were perceived for significantly longer durations than upright neutral faces. The results provide further support for the influence of emotional meaning on binocular rivalry.

Keywords: binocular rivalry, emotions, facial expressions, visual awareness

Introduction

When discrepant monocular stimuli are simultaneously presented to the two eyes, they compete for perceptual dominance such that the observer perceives alternations between two distinct images each lasting for a few seconds (Tong, 2001). This is known as the phenomenon of binocular rivalry. While much is known about the psychophysical characteristics of binocular rivalry, it is only recently, after nearly two centuries of research, that the neural basis of binocular rivalry has been documented (see Blake, 2001; Blake and Logothetis, 2002; Tong, 2001). The mechanism driving the shifts in perception between the two stimuli is thought to be largely independent of voluntary control (van Ee *et al.*, 2005) and engages a number of stages along the neural visual pathways. In particular, it is claimed that the visual properties of the two rivalling stimuli are processed independently within the visual areas of the brain before the competition between them is resolved and only one of them reaches conscious awareness (Logothetis *et al.*,1996).

Several factors are known to influence the duration of the dominance and suppression phases of binocular rivalry. These include attention (Meng and Tong, 2004; van Ee, 2005), context (Fukuda and Blake, 1992; Carter *et al.*, 2004; Paffen *et al.*, 2004) and manipulating stimulus strength by increasing the contrast (Mueller and Blake, 1989), motion (Breese, 1909) and spatial frequency (Fahle, 1982) of one of the two rival stimuli. In addition to these factors, stimulus meaning can also influence perceptual dominance. Engel (1956) showed that images of upright faces, which are familiar and meaningful, dominated over images of inverted faces. Despite methodological problems of this early study (see Walker, 1978), a similar pattern of results has been reported in a subsequent study (Yu and Blake, 1992).

More recently, it has been investigated whether emotional content may also have an impact on perceptual dominance. As humans we have a limited capacity to process fully all of the perceptual information that reaches us at any one time. Therefore, it may be

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advantageous if emotionally meaningful stimuli, such as emotional facial expressions, had priority access to awareness because of their relevance to an observer's safety or well-being (Öhman and Mineka, 2001).

Preferential processing of emotional facial expressions has been investigated extensively using both the visual search paradigms (Fox *et al*., 2000; Öhman *et al*., 2001; Lundqvist and Öhman, 2005), where it has been demonstrated that negative facial expressions are detected faster among distracters than faces expressing neutral or positive expressions, and the dot-probe task, which has revealed that detection is speeded when the probe follows a negative (e.g. fearful, angry) rather than a neutral or happy face (Mogg and Bradley, 1999; Mogg *et al*., 2000; Armony and Dolan, 2002). Aside from being detected more rapidly, evidence also suggests that emotional facial expressions are more likely to enter awareness and resist failures of attention (Fox *et al*., 2005; Milders *et al*., 2006).

With regards to binocular rivalry, neuroimaging studies (e.g. Pasley *et al*., 2004; Williams *et al*., 2004) showed that pictures of emotional faces activated subcortical emotion circuits, e.g. the amygdala, not only during periods of dominance but also during rivalry suppression (Williams *et al*., 2004). Direct projections have been found which link the amygdala to areas V1 and V2 of the visual cortex (Amaral *et al*., 1992). Importantly, Alpers and colleagues suggested that this may provide a route by which emotional content could influence perceptual dominance of rival stimuli during processing in the visual cortex (Alpers and Pauli, 2006; Alpers and Gerdes, 2007) as studies have possibly indicated that rivalry is modulated by monocular neurones in V1 (Tong and Engel, 2001; Williams *et al*., 2004).

In terms of behavioural data, Coren and Russell (1992) presented images of different facial expressions stereoscopically and found that faces displaying particularly pleasant or unpleasant emotions had dominance over less valenced faces. However, percepts were reported after the binocular presentation ended. It is therefore possible that the reporting of the perceived stimuli was influenced by memory. More recently, Alpers and Pauli (2006) investigated dominance of emotional stimuli using pictures from the International Affective Picture System (IAPS). Here, emotional pictures (pleasant and unpleasant) dominated over neutral pictures, both with regards to the initial percept and total viewing time across each trial. However, as they point out, participants verbalised their percept which may have resulted in a response bias favouring the emotional stimulus. Moreover, simple physical differences (such as luminance and contrast) between the stimuli, which may have accounted for the differences in perceptual dominance, were not controlled for.

Attempting to address this latter issue, Alpers *et al*. (2005) used rival stimuli consisting of simple geometric patterns (horizontal or vertical lines) and employed fear conditioning to induce emotional significance in one of the stimuli. Aversive conditioned patterns dominated over the non-conditioned, although the observed dominance was weaker compared with other experiments (Coren and Russell, 1992; Alpers and Pauli, 2006), possibly because the stimuli lacked evolutionary relevance (Alpers *et al*., 2005). Nonetheless, Alpers and Gerdes (2007) later used emotional facial expressions, which were ecologically meaningful, and controlled for physical characteristics. Stereoscopically presenting (a) emotional and neutral expressions of the same actor, and (b) schematic emotional and neutral expressions, led to dominance of the emotional percept. Moreover, a probe-detection task provided preliminary evidence suggesting that dominance of emotional expressions was not merely because of a response bias (Alpers and Gerdes, 2007).

In this study, we sought to confirm the previously reported influence of emotion upon binocular rivalry using emotional facial expressions and extend the findings using two experimental manipulations. Different from previous research, we have used an implicit measure where participants were not explicitly asked to focus on the emotional content: instead emotional facial expressions were presented in the background and paired with central rivalry stimuli (Experiment 1). Previous research has shown that emotional facial stimuli may still be processed and influence cognitive performance even when they lie outside the focus of attention (e.g. Vuilleumier *et al*., 2001; Fenske and Eastwood, 2003). Here, it was investigated whether this is also the case within a binocular rivalry paradigm. In other words, would emotion impact upon binocular rivalry not only when specific facial expressions need to be explicitly identified but also when emotion processing is implicit and task irrelevant?

Similar to Alpers and Gerdes (2007) we dichoptically presented emotional and neutral facial expressions, of the same actor, and investigated whether emotional faces would dominate over neutral faces in two separate studies where we investigated the effect of stimulus size on the duration of perceived emotional expression (Experiment 2A and 2B).

Low-level image differences such as contrast may influence dominance in binocular rivalry. This issue has been controlled for previously by presenting schematic facial expressions (Alpers and Gerdes, 2007). However, it is well known that inversion disrupts facial processing (Tanaka and Farah, 1993) and the recognition of emotional expressions (Searcy and Bartlett, 1996; de Gelder *et al*., 1997), while retaining feature differences. Thus, we used inverted presentation (Experiment 3) to further investigate whether emotion is the driving force behind dominance in binocular rivalry or whether simple low-level image differences are the accountable factors.

Experiment 1

Experiment 1 was designed to investigate whether the dominance duration of centrally positioned orthogonal gratings was affected by the presence of emotional facial expressions in the background. During the experimental conditions, the background consisted of rival emotional (happy or fearful) and neutral facial expressions, whereas during the control condition, it consisted of neutral facial expressions only. This allowed us to investigate whether the emotional stimuli affected the dominance of the grating stimulus they were paired with. This implicit task was akin to the probe-detection task used by Alpers and Gerdes (2007). However, task difficulty was lower as participants only needed to code rivalry of the gratings, and not perform a 'dual task' as in Alpers and Gerdes (2007).

Participants

Twenty-seven participants (21 female; mean age: 22.9 years, range: 17–47 years) took part. All had normal or corrected to normal visual acuity, were naïve to the purpose of the experiment and had no prior knowledge of binocular rivalry.

Stimuli and apparatus

Stimuli consisted of orthogonal gratings and face photographs of three male individuals (JJ, PE and WF) taken from a standard set of facial expression pictures (Ekman and Friesen, 1976). Each individual showed three different expressions: fearful, happy or neutral. All face pictures were in grey scale and subtended $9.8° \times 13.2°$. Luminance levels of the face stimuli ranged between 5.2 and 7.8 cd m^2 and there were no differences in terms of average luminance levels among the three facial expressions. The orthogonal grating stimuli consisted of four slanted lines that had perpendicular orientations in the two eyes. The grating stimuli had a frequency of 1 cycle per degree, subtended $2.7° \times 2.7°$ and were suprathreshold; they were oriented diagonally to the left and right in the two eyes.

Stimuli were presented centrally on a Sony 21″ Trinitron monitor using a Super Video Graphics Array (SVGA) graphics card (Cambridge Research Systems, Rochester, Kent, UK). The monitor was enclosed in a cubicle with a forehead and chin rest mounted at the edge of the cubicle, at a viewing distance of 64 cm from the screen. The inside of the cubicle was covered in a non-reflective black-matt felt material. Testing was carried out in a dimly lit room (10 lux) to reduce the likelihood of combined perceptions of the two rival stimuli (cf. O'Shea *et al*., 1994).

A black and white fixation circle was presented in the centre of the screen. The two grating stimuli (left orientated and right orientated) were overlaid within this circle. The background consisted of two overlapping facial stimuli presented dichoptically (*Figure 1*). To induce binocular rivalry participants wore goggles equipped with ferroelectric liquid crystal shutters (VSG125; Cambridge Research Systems) which alternately occluded the two eyes at the same frequency as the frame-rate of the monitor (100 Hz). Locking of screen refresh rate and shutter times was ensured by the dedicated graphics card which automatically synchronises the two. This resulted in the two overlaid gratings and facial stimuli being presented to separate eyes. To avoid selective biasing for a particular stimulus in half of the trials within each block of trials, participants were presented with the right-orientated grating to their right eye and the left-orientated grating to their left eye, whereas in the other half of trials, they were presented with the left-orientated grating to their right eye and right-orientated grating to their left eye. A response box was employed to record participant's responses (see *Procedure* section).

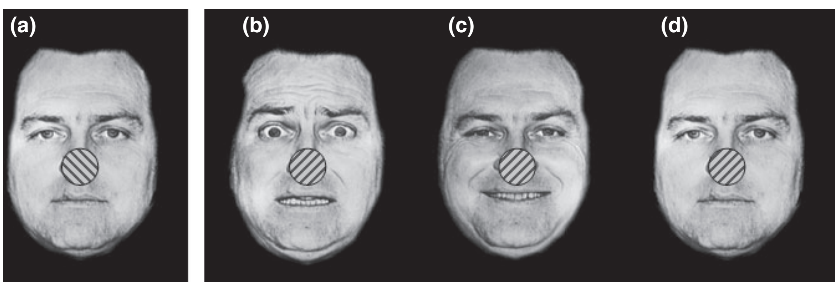

Figure 1. Example of stimuli in Experiment 1. Stimulus (a) was presented to one eye while at the same time stimulus (b), (c) or (d) was presented to the other eye for the fearful, happy and neutral conditions, respectively.

Experimental conditions

Three different stimulus conditions were employed; a 'control condition' where participants were presented with the same neutral face to both eyes (identical neutral faces were used as piloting with two different identities demonstrated that participants attributed negative valence to the stimulus); a 'fearful condition' with a fearful face to one eye and a neutral face to the other eye; and a 'happy condition' with a happy face to one eye and a neutral face to the other eye. There were three blocks of 12 trials, each consisting of four fearful–neutral pairs, four happy–neutral pairs and four neutral–neutral pairs. Each trial lasted 60 s and was separated from the preceeding trial by a 5-s rest period (blank screen). Trials were randomised within the blocks. Note that irrespective of conditions, participants were always simultaneously presented with two facial stimuli in the background and two grating stimuli in the centre of the screen (*Figure 1*). Also, for half of the participants, the emotional face stimuli were always paired with the right-orientated grating (i.e. they were presented to the same eye), whereas for the remaining half of the participants, the emotional face stimuli were paired with the left-orientated grating.

Procedure

Before the experiment, the participants took the TNO-test for stereoscopic vision (Okuda and Wanters, 1977) to establish that they had normal stereoscopic vision. All had adequate stereo acuity (30 s arc). Participants were instructed to focus only on the gratings appearing in the white circle and to indicate the orientation of the gratings they perceived as dominant throughout the trial via a response box. They were told not to be concerned with the facial stimuli in the background. Participants were given six practice trials to familiarise themselves with the coding procedure.

Results and discussion

For each trial, the duration of gratings paired with the emotional faces (fearful or happy) and those paired with the neutral faces were summed. Emotional dominance was then indexed as a ratio following Levelt's (1965) approach which makes use of summed time for each stimulus [T(s)]; T (emotional)−T (neutral)/T (emotional) + T (neutral). One-sample *t*-tests were employed to test if the ratios differed significantly from zero meaning that gratings coupled with emotional faces were perceived longer than those coupled with neutral faces. For the fearful condition, the mean cumulative (summed) time during which participants reported seeing the gratings paired with the fearful faces was longer (31.6 s) than the time during which the gratings paired with neutral faces were seen (25.6 s). The average emotional dominance (ratio of perceptual dominance of the gratings paired with fearful faces compared with neutral faces) was significantly different from zero (mean ratio = 0.11; S.D. = 0.08; t(26) = 6.883; $p < 0.001$). Likewise for the happy condition, gratings paired with the happy faces were perceived longer (31.1 s) than those paired with neutral faces (25.7 s). The average emotional dominance ratio for the happy condition was also significantly different from zero (mean ratio = 0.10; S.D. = 0.08; t(26) = 5.987; $p < 0.001$). Thus, the emotional faces affected the dominance of the rival stimulus they were coupled with (*Figure 2*). However, when two neutral faces were presented the average cumulative time of the two grating stimuli were approximately equal (29.1 s vs. 28.9 s) and the dominance ratio was non-significant (mean ratio = 0.003; S.D. = 0.02; t(26) = 0.846; $p = 0.405$).

The significant influence of emotional content of the background on binocular rivalry confirms and extends previous studies by Alpers *et al.* (2005), Alpers and Pauli (2006) and Alpers and Gerdes (2007) which demonstrated significant dominance of emotional IAPS pictures, fear-conditioned grating stimuli and emotional facial expressions, respectively. However, it should be noted that in Experiment 1 emotional conditions differed from the neutral condition in that whereas the neutral condition consisted of a central rivalry display with two compatible, non-rivalling neutral faces in the background, both fearful and happy conditions had additional stimulus competition in the background because of two rivalling expressions. It is possible that the observed dominance of the grating stimuli in the emotional conditions may be due to the incompatibility of the background stimuli, which was not present in the neutral control

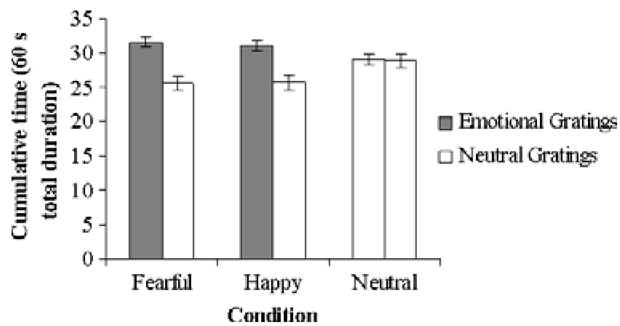

Figure 2. Results of Experiment 1. Mean cumulative time of grating-face stimuli for the fearful, happy and neutral conditions. Mean duration in seconds (of 60 s total duration of one trial) are represented. Error bars represent standard errors of the mean (S.E.M.).

condition, and may not be influenced by the features of an emotional face *per se*. Yet, after the experiment, a number of participants commented that during the emotional conditions they always perceived a stationary emotional facial expression rather than actual rivalry between the neutral and emotional faces. Consequently, in Experiment 2, we investigated what participants perceived in the background during the emotional conditions. Here, the gratings were removed and the effect of emotional meaning on face stimuli in binocular rivalry was measured directly.

Experiment 2A

Participants

Thirty-two participants (26 female; mean age: 22.9 years; range: 17–47 years) took part: none had participated in Experiment 1. All participants had normal or corrected to normal visual acuity and normal stereo acuity. None of the participants had any prior knowledge of binocular rivalry.

Stimuli and apparatus

The experimental set-up and stimuli were identical to those used in Experiment 1, except that the facial stimuli were not paired with gratings of differing orientation. Two different stimulus conditions were employed; a 'fearful' condition and a 'happy' condition in which fearful and neutral or happy and neutral faces were presented dichoptically. There were two blocks of 12 trials, each consisting of six fearful–neutral pairs and six happy–neutral pairs. Each trial lasted 60 s and was separated from the preceeding trial by a 5-s rest period (blank screen). Trials were randomised within the blocks. As previously in order to avoid selective biasing for a particular eye, in half of the trials, participants were presented with the emotional faces to their right eye and the neutral faces to their left eye, whereas in the other half of trials, they were presented with emotional faces to their left eye and neutral faces to their right eye. Left/right eye presentation was randomised across trials.

Procedure

Participants were instructed to focus upon the central fixation point. They were informed that throughout the experiment they would be presented with a series of faces and that their task was to indicate which face (emotional or neutral) they perceived as dominant at any given moment of time throughout the trial via a response box. Prior to the main experiment, participants were given six practice trials.

Results and discussion

For each trial, the duration for which participants perceived the emotional faces (fearful or happy) and neutral faces as dominant were summed. This revealed very strong dominance of emotional stimuli. All participants perceived the emotional faces as dominant for the entire 60 s trial duration. At no point during any of the 768 trials (32 participants × 24 trials each) did participants perceive the neutral face. No rivalry between the different facial expressions (emotional vs. neutral) occurred; emotional faces (fearful and happy) were seen continuously. This runs counter to Alpers and Gerdes (2007) who found evidence of rivalry using emotional and neutral faces. The findings from Experiment 2A possibly imply that in Experiment 1 participants may have perceived a single fearful or happy facial expression in the background. Thus, it is unlikely that the reported emotional dominance in Experiment 1 was merely because of differences in compatibility of the background stimuli between emotional and neutral conditions as possibly no background rivalry was present. The findings of Experiment 2 showing that the emotional expression dominates over the neutral expression, is entirely consistent with those of Experiment 1. In Experiment 1, gratings are treated as an object superimposed in a face stimulus. Should the implicit processing of a facial expression lead to dominance of that image (as in Experiment 1), then it would be expected that the line orientation is superimposed on the dominant facial expression and should also be seen for significantly longer durations than that of the orientation superimposed in a neutral face.

The finding that no rivalry occurs when emotional and neutral faces are presented to the two eyes is of interest. While this may reflect the powerful effect of emotional facial expressions within perception, the results may also be explained in terms of simple fusion. For instance, the stimuli presented dichoptically were faces of the same identity displaying different facial expressions. Thus, the rivalling stimuli were identical in terms of features, shape and differed only in their expression. Levelt (1965) already demonstrated that when stimuli are of the same shape and contrast, they are not sensitive to conflict and will not rival. Rather the similarity of the rivalling stimuli results in the two images being fused together to create a single image in experience. Thus, it is possible that emotional and neutral faces were fused together with eyes and mouth of the emotional face overlapping the neutral so that participants perceived a single emotional face. Such fusion may have occurred because the rival stimuli were large (9.8° × 13.2°). Presenting stimuli at a much smaller visual angle is thought to make fusion less likely (Blake *et al.*, 1992; Blake, 2001). Thus, we ran a short replication of Experiment 2 where we reduced the size of the face stimuli.

Experiment 2B

Ten participants (eight female; mean age: 23.8 years, range: 20–25 years) took part. The set-up and procedure was identical to Experiment 2A except that the face stimuli subtended 3.6° × 2.9°.

Results showed that all 10 participants experienced no rivalry when the competing faces were fearful and neutral, always seeing the fearful face as dominant. When the rival stimuli consisted of happy and neutral faces, half (5) of the participants experienced no rivalry, seeing the happy face as always dominant. For the remaining five participants, who did experience rivalry between happy and neutral faces, happy faces persisted longer (51.1 s) than neutral faces (5.2 s) and the average emotional dominance ratio was significantly different from zero (mean ratio = 0.82; S.D. = 0.07; $t(4) = 25.816$; $p < 0.001$). It would appear therefore that when using small images, rivalry between emotional and neutral faces can occur (supporting the findings of Alpers and Gerdes (2007)), providing that the emotional face is happy. However, even when using small images thought to make 'piecemeal rivalry' less likely, fusion can still occur, possibly because the similarity of features between rival faces of the same identity, especially when the competing faces are fearful and neutral.

This concern of the similarity of the rivalling stimuli was addressed in Experiment 3. In Experiment 3, a further class of rival stimuli was selected that differed in terms of features from the emotional faces to make fusion of stimuli less likely, namely house stimuli. In recent years, several binocular rivalry studies have presented images of faces and houses dichoptically. These studies have focused upon the pattern of brain activity when these images were consciously perceived, versus when they were suppressed (Tong *et al.*, 1998; Williams *et al.*, 2004). No behavioural study has examined how face-house rivalry affects binocular rivalry when the face carries emotional significance. If the enhanced dominance of emotional faces in Experiment 2 is caused by their emotional meaning rather than simple fusion then dominance of fearful and happy over neutral faces should be found when these faces are presented as face-house pairs. This was explored in Experiment 3. Experiment 3 also addressed another factor that may have been driving the results, namely low-level image differences. For instance, for both fearful and happy expressions, the mouth is open leading to the exposure of teeth. This may lead to a salient, high contrast region of the image. This region is not present in neutral faces where the mouth is closed. Thus, it is possible that these low-level image differences may also be responsible for the differences in perceptual dominance found in the first two experiments. To examine this possibility, we presented both upright and inverted stimuli in Experiment 3. It is well known that inversion of faces interferes with holistic processing of faces (Tanaka and Farah, 1993). Psychophysical studies show that the rating of valence of emotional stimuli is reduced with inversion (Fallshore and Bartholow, 2003; Prkachin, 2003). Therefore, if emotional expressions are the critical factor in producing the stronger dominance of emotional stimuli then the dominance observed should be greatly reduced when the faces are inverted. On the contrary, if low-level information is responsible for the pattern of results then similar results should be found for both upright and inverted presentations because all of the same features are present in both images.

Experiment 3

Participants

Twenty participants (13 female; mean age: 26. 5 years, range: 19–49 years) took part. All had normal or corrected to normal visual acuity and normal stereo acuity. None of the participants had participated in the previous experiments and none had any prior knowledge of binocular rivalry.

Stimuli and apparatus

Stimuli consisted of face photographs of six individuals from Ekman and Friesen (1976), three male (JJ, PE, WF) and three female (MF, PF, SW), each displaying a neutral, fearful or happy facial expression. All face pictures were in grey scale and subtended 9.8° × 13.2°. Luminance levels of the face stimuli ranged between 5.2 and 8.2 cd m^2 and there were no differences in terms of average luminance levels among the three facial expressions. Six photographs of houses (luminance levels ranging between 2.8 and 5.7 cd m^2) were chosen to closely match the area of the faces. Inverted versions of the stimuli were made by taking each stimulus and inverting it through 180°.

Experimental conditions

A trial consisted of a rival face–house pair presented for 60 s (*Figure 3*). Each trial was separated from the preceding trial by a 5-s rest period (blank screen). There were four blocks of 18 trials. Each block contained six fearful face–house pairs (three upright, three inverted), six happy face–house pairs (three upright, three

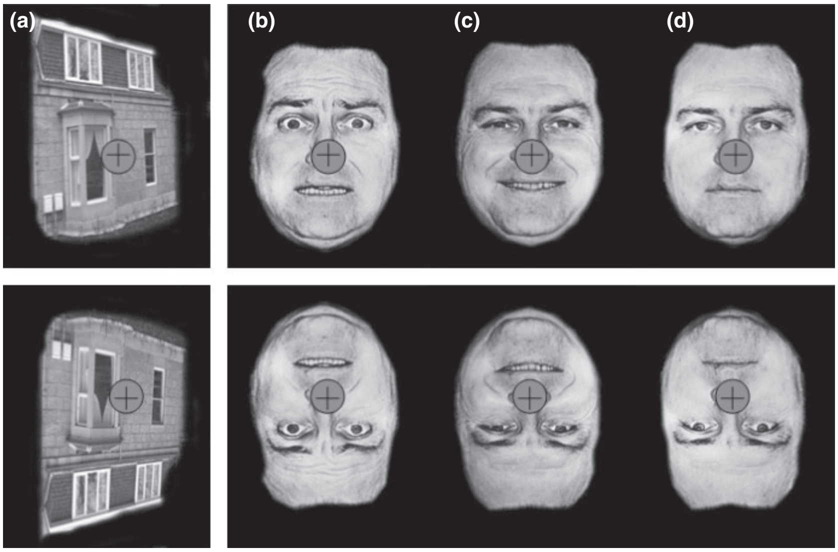

Figure 3. Example of stimuli in Experiment 2. Stimulus (a) was presented to one eye while at the same time stimulus (b), (c) or (d) was presented to the other eye for the upright and inverted fearful, happy and neutral conditions, respectively.

inverted) and six neutral face–house pairs (three upright, three inverted). Trials were randomised within the blocks. Two blocks comprised solely of male faces, the other two of female. The order of the blocks was counterbalanced between participants. As in the previous experiments, selective biasing for a particular eye was controlled for by counterbalancing the presentation of stimuli in both eyes.

Procedure

Participants were instructed that they would be presented with two images simultaneously (one face and one house). They were asked to fixate on the centre of the screen and report whether their dominant percept altered to that of a house or a face via a response box. Prior to the main experiment participants were given six practice trials.

Results and discussion

For each trial, the duration for which participants perceived face and house percepts was summed. Using the same approach as in Experiment 1, facial dominance ratios were calculated for each of the three conditions (fearful, happy and neutral) in the two orientations (upright and inverted); facial dominance ratio = T (face)−T (house)/T (face) + T (house). One sample *t*-tests revealed that for upright presentation average facial dominance ratios were significantly different from zero for both fearful (mean ratio = 0.26; S.D. = 0.12; $t(19) = 9.484$; $p < 0.001$) and happy (mean ratio = 0.22; S.D. = 0.14; $t(19) = 6.990$; $p < 0.001$) as well as neutral conditions (mean ratio = 0.12; S.D. = 0.07; $t(19) = 7.580$; $p < 0.001$) (see *Figure 4a*). However, perception of inverted face stimuli did not persist significantly longer than inverted house stimuli (see *Figure 4b*). Average facial dominance ratios did not differ from zero across inverted fearful (mean ratio = 0.02; S.D. = 0.07; $t(19) = 1.120$; $p = .277$), happy (mean ratio = 0.02; S.D. = 0.07; $t(19) = 1.482$;

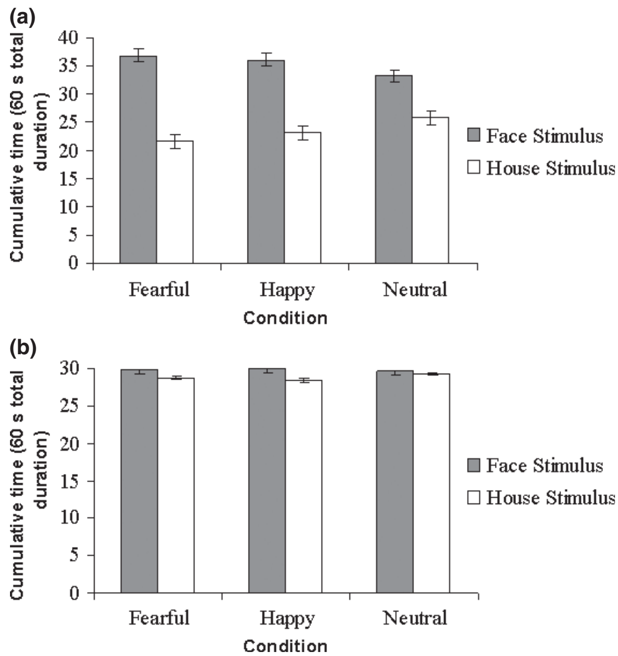

Figure 4. Results of Experiment 3. Mean cumulative time that the face and house stimuli were perceived as dominant for fearful, happy and neutral conditions in both upright (a) and inverted orientations (b). Mean duration in seconds (of 60 sec total duration of one trial) is represented. Error bars represent S.E.M.

$p = 0.155$) or neutral conditions (mean ratio = 0.01; S.D. = 0.06; $t(19) = 0.430$; $p = 0.672$).

To investigate the importance of the emotional significance of the face stimuli, facial dominance ratios were analysed using a 2 (orientation: upright vs. inverted face) × 3 (facial expression: fearful, happy and neutral) repeated measures analysis of variance (ANOVA). A significant orientation × facial expression interaction, $F(2, 38) = 6.246$; $p < 0.01$, $\eta_p^2 = 0.247$, revealed that the expression conveyed by the face influenced perceptual dominance only for upright displays. Subsequent analysis with pairwise Bonferroni comparisons showed that for upright presentation facial dominance ratios for fearful (0.26) and happy (0.22) were significantly larger than those for neutral faces (0.12) ($p < 0.001$ and $p < 0.01$, respectively). Emotional faces persisted longer than neutral faces. However, there were no significant differences between the two emotional conditions (fearful and happy) ($p = 0.531$). For inverted presentation, no significant differences in dominance emerged between any of the conditions (fearful, happy and neutral); all $p > 0.05$.

The results from Experiment 3 show that faces persist longer in the observer's percept than houses only when the stimuli were presented in an upright orientation. The differences in perceptual duration of upright emotional face and house stimuli were significantly larger than that for upright neutral face or house stimuli. However, there were no differences between the perceived duration of any inverted stimulus conditions. The findings reiterate the role of emotional stimuli in binocular rivalry.

General discussion

The present study was aimed to confirm and extend the previously reported effect of emotional facial expression on binocular rivalry (Alpers and Gerdes, 2007). Here we have (i) investigated whether emotional influence is also observed in a binocular rivalry task where emotion processing is implicit and task irrelevant and (ii) used inverted presentation to further eliminate low-level differences as possible contributing factors to emotional dominance. When an emotional facial expression was presented to one eye, and a neutral expression to the other, emotional faces dominated to the extent that neutral faces were not seen. This may have been the result of fusion because of large stimuli size. Reducing the size of the face stimuli, to make fusion less likely, led to rivalry and emotional dominance consistent with Alpers and Gerdes (2007). However, this rivalry was only present when the competing faces were happy and neutral, suggesting that the features of a fearful face, which signal a potential danger in the environment, at least under this experimental condition, resist rivalry. We also showed that an emotional facial expression in the background is sufficient to modulate the dominance of the rival stimulus it is coupled with. This may indicate that, consistent with the literature (Vuilleumier *et al.*, 2001; Fenske and Eastwood, 2003), the emotion conveyed by a face can be perceived outside the focus of attention and influence task performance even though it is irrelevant to the task in hand. Moreover, when emotional and neutral faces in the observer's percept were presented as face–house pairs, emotional faces persisted longer than neutral faces only when presented upright. This suggests that emotion is the crucial factor in influencing dominance durations, not low-level image properties. Taken together the results confirm and extend the previous finding that emotional meaning can modulate binocular rivalry both when expressions need to be explicitly identified (Experiment 2) and also when expression is implicit in a binocular rivalry task (Experiments 1 and 3). The dominance of emotional facial expressions in the current study is consistent with other studies which have shown that emotional IAPS pictures (Alpers and Pauli, 2006), fear-conditioned visual patterns (Alpers *et al.*, 2005) and emotional faces (Alpers and Gerdes, 2007) dominate over neutral stimuli.

It is well known that emotional facial expressions, especially threat-related, are effective at capturing attention and influencing task performance. One major explanation for this finding may be that it is vital for an organism to attend to information which is of high importance for behavioural goals, because this information will assist in guiding both actions and thoughts (Fenske and Eastwood, 2003). Thus, emotional facial expressions, which are known to convey a high adaptive value in signalling crucial social information, undergo preferential processing and play an important part in the allocation of attentional resources (Fenske and Eastwood, 2003). Therefore, in the present study, the emotional expressions may have affected dominance durations by biasing the allocation of attentional resources. However, it is also possible that emotional faces, especially threat-related, may have influenced rivalry by decreasing the ability to disengage attention from these faces (Fox *et al.*, 2002).

Despite the fact that previous studies (e.g. using a visual search, dot-probe paradigm) have found an advantage for negative facial stimuli compared with positive or neutral faces (Mogg and Bradley, 1999; Fox *et al.*, 2000; Mogg *et al.*, 2000; Öhman *et al.*, 2001; Armony and Dolan, 2002; Lundqvist and Öhman, 2005), we found dominance for both fearful and happy facial expressions. Although binocular rivalry is likely to engage several stages along the visual pathways of the brain including both cortical and subcortical areas, these data further support the hypothesis that the mechanism underlying the observed emotional dominance reported here, may reflect automatic activation of emotion circuits such as the amygdala (see Alpers and Pauli, 2006; Alpers and Gerdes, 2007). This may be made possible by the direct neural link between the amygdala and the sensory pathways of the thalamus, and the fact that the amygdala responds to emotional stimuli even during periods of rivalry suppression (Williams *et al.*, 2004).

However, it is necessary to consider the possible limitations of this study. First, participants were not required to indicate if they perceived mixed gratings (Experiment 1), mixed faces (Experiment 2) or blends of faces and houses (Experiment 3). Although we have no reason to expect that the experimental conditions led to the overestimation of emotional percepts, this possibility cannot be fully ruled out. Second, across all three experiments, eye movements were not monitored. Although participants were instructed not to move their eyes, occasional fixation losses cannot be ruled out. van Dam and van Ee (2006) have previously reported a positive correlation between saccades and perceptual alternations, which in turn may emphasise the persistence of emotional expression.

In conclusion, the results reported further support the role of emotion in binocular rivalry. This has important implications for the driving force behind binocular rivalry. Previously, it was thought that rivalry was a low-level process, concerned only with stimulus strengths (including brightness, contrast and spatial frequency) of the two rival images (Levelt, 1965; Carter *et al.*, 2004). However, the observed modulation of rivalry by emotional meaning in this study suggests that rivalry may reflect a higher-level process. The view that rivalry is a high-level process has been prominent in recent literature, with attention (Meng and Tong, 2004; van Ee, 2005) and interocular grouping (Alais and Blake, 1999; Sobel and Blake, 2002) effects being documented in support of this viewpoint. This study confirms that the meaning of percepts may be another factor that supports this high-level process view.

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