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THESIS

Emotion content versus feature content in faces presented under continuous flash suppression:

Spatial frequency content selectively contributes to access to awareness of emotion in faces.

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Abstract

During breaking continuous flash suppression (b-CFS), a static image of increasing contrast and a dynamic mask are presented dichoptically. It has been suggested that images of threat faces gain preferential access to awareness because of their emotional content. However, it is argued that low-level image features are behind the apparent emotion content effects. As such, studies risk attributing processing of emotion content in faces to differences in the access to awareness, when in fact this may be absent when controlled for low-level features. Here we investigate whether differences in access to awareness can be accounted for by either the emotion content or the feature content of an image. We used b-CFS to compare detection times of images with their original spatial frequency content and controlled spatial frequency content, comprising 7 emotions (Experiment 1). Our results show no main effects for spatial frequency condition. However, a main effect of emotion was found, as well as an interaction between the spatial frequency conditions and emotions. Specifically, fear, happy, sad and surprise showed differences in suppression durations between spatial frequency conditions. Moreover, in Experiment 2 images of faces without feature adjustments showed that particularly low-spatial frequencies induce differences in access to awareness. Both findings suggest that features in images, in this case spatial frequency content, could attribute to the differences in access to awareness of emotion. Though we conclude that there is not a prototypical spatial frequency content that asserts to all emotions.

Keywords: breaking continuous flash suppression, faces, features, emotion

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Introduction

Many people feel frightened by merely seeing a glimpse of a snake. The rapid detection of threat is supposedly a mechanism which prioritises certain visual events over others, provoked by the capacity restrictions of the visual system. More specifically, by directing sensory processes more efficiently towards stimuli that are evolutionary relevant for survival (Öhman & Mineka, 2001). For instance, LoBue and Deloache (2008) found that snakes were detected faster than threat irrelevant stimuli. Furthermore, they demonstrated that this bias is also apparent in young children, suggesting that faster detection of evolutionarily relevant threat stimuli is inborn. Öhman and Mineka (2001) even proposed a predisposition of threat stimuli to preferentially attract attention.

The preferential processing of threat stimuli – such as fearful faces – is even assumed to be achieved outside of awareness. Findings supporting this view come from different paradigms rendering images invisible by dissociating visual input from conscious awareness (Kim & Blake, 2005). For instance, a probe task in which a dot is located and backwards masking are often combined to investigate threat stimuli outside of awareness. Participants are asked to locate a dot after a masked fearful expression was displayed. The dot is constantly located faster when it is spatially compatible with the location of the masked fearful expression. Several studies interpreted this bias as selective orienting of attention to masked fearful faces (Carlson & Reinke, 2008; Mogg & Bradley, 1999; Mogg & Bradley, 2002; Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pourtois, Schwartz, Seghier, Lazeyras, & Vuilleumier, 2006).

Another relevant paradigm to remove awareness of visual stimuli is binocular rivalry. In binocular rivalry different images are presented to both eyes and compete to determine the percept. When one image is more salient, observers tend to mostly perceive this image, while the other image is rendered invisible (Alais & Blake, 2005). When presenting neutral and emotional pictures in binocular rivalry, emotional pictures tend to be more dominant and are more often the first percept (Alpers & Gerdes, 2007; Alpers & Pauli, 2006). Likewise, Alpers and Gerdes, (2007) found that emotional expressions, including fear, were perceived as the dominant percept for longer durations. These findings are rather surprising since binocular rivalry is associated with neuronal events occurring as early as V1 (Lee & Blake, 2002; Tong, 2001). Seeing that visual neurons in V1 are tuned to global features (Ringach, Hawken & Shapley, 2003), binocular rivalry suppression of faces could possibly be feature specific. This idea is consistent with findings indicating that binocular rivalry is sensitive to certain features. For instance, suppression depth during binocular rivalry can be modulated by orientation (Apthorp, Wenderoth, & Alais, 2009; Stuit, Cass, Paffen & Alais, 2009; Stuit, Paffen, van der Smagt, & Verstraten, 2011a, 2011b) and motion direction (Stuit et al., 2011a). Therefore, the perceived differences in the dominant percept of faces during binocular rivalry might not necessarily be caused by the emotion content, but rather by sensitivity to a certain feature. This raises an important question; how are images of faces processed outside of awareness?

A question that is now even more relevant, since studies are using a new paradigm called breaking continuous flash suppression (b-CFS). B-CFS is a variant on binocular rivalry, in which a static image of increasing intensity shown to one eye is suppressed by a dynamic visual stimulus presented to the other eye (CFS, Tsuchiya & Koch, 2005). Observers press a button when the suppressed image is detected, which is believed to be the point in time the image accesses awareness (Tsuchiya & Koch, 2004). B-CFS is capable of reliably inducing suppression from the onset of the stimulus presentation, in addition the duration lasts at least 10 times longer than presented with traditional binocular rivalry (Tsuchiya & Koch, 2005). When presented outside of awareness through b-CFS, fearful expressions consistently emerged faster into awareness compared to neutral expressions (Yang, Zald, & Blake, 2007; Gray, Adams, Hedger, Newton & Garner, 2013; Stein, Seymour, Hebart & Sterzer, 2014) or happy expressions (Yang et al., 2007; Gray et al., 2013). This suggests that fearful faces gain preferential access to awareness. However, the nature and extent to which stimuli are processed is under debate (Blake, 2005; Gayet, van der Stigchel & Paffen, 2014; Pessoa, 2005). It could be the feature content rather than the emotion content that causes differences in access to awareness of faces.

Currently, there are two competing viewpoints concerning processing of stimuli outside of awareness. One theory proposes that certain faces emerge faster into awareness through processing of the emotion content. For instance, upright faces need less time to gain dominance over suppression noise than inverted faces (Jiang, Costello & He, 2007; Stein, Hebart & Sterzer, 2011a; Stein, Peelen & Sterzer, 2011b; Zhou, Zhang, Liu, Yang & Qu, 2010). This is assumed to be caused by the greater familiarity of upright faces over inverted faces, thus by the access to high-level information. However, Stein et al., 2011b managed to greatly diminish the upright face advantage, when the contrast relations characteristic for faces were distorted. This suggest that the differences in detection times for upright and inverted faces rely on coarse visual information of a face.

This established a second theory suggesting that the observed differences in access to awareness can be explained by processing at the level of features (Yang & Blake, 2012). Crude visual processing could possibly be the explanation behind the seemingly semantic processing, as certain low-level stimulus properties have the tendency to break through suppression faster. For example, increasing the contrast of a target made suppression less reliable, resulting in faster detection times (Tsuchiya & Koch, 2005).

Furthermore, Stuit, Cass, Paffen and Alais (2009) found that suppression is stronger when the stimuli and mask are more similar in spatial frequency content. Since the mask is often kept the same throughout the experiment, the differences in detection times of emotions might be better accounted for by the similarity of the spatial frequencies to that of the suppressed grating, rather than the emotional content. In addition, Yang and Blake (2012) found that suppression can be modulated by the spatial frequency content of the suppressed image. Thus, without accounting for low-level features in stimuli, studies risk attributing variations in suppression times to a preferential processing of the emotion content in faces, when in fact this may be absent when controlled for low-level features.

In the current study, we aim to determine whether the emotion content explains the differences in suppression durations of faces presented outside of awareness or whether it can be accounted for by processing at the level of features. Differences in spatial frequency content between images of faces is of a particular interest.

Methods

Participants

A total of twenty-three naive subjects participated voluntarily (age range 17-42; mean age 23.43). Furthermore, only females were allowed to participate, whereas gender differences have been found for perceiving certain emotions (Donges, Kerstling & Suslow, 2012). In addition, all participants had normal or corrected to normal vision and were provided with an informed consent at the start of Experiment 1. Participants with a history of epilepsy or eye-problems, for instance lazy-eye, colour-blindness or problems with depth perception were excluded.

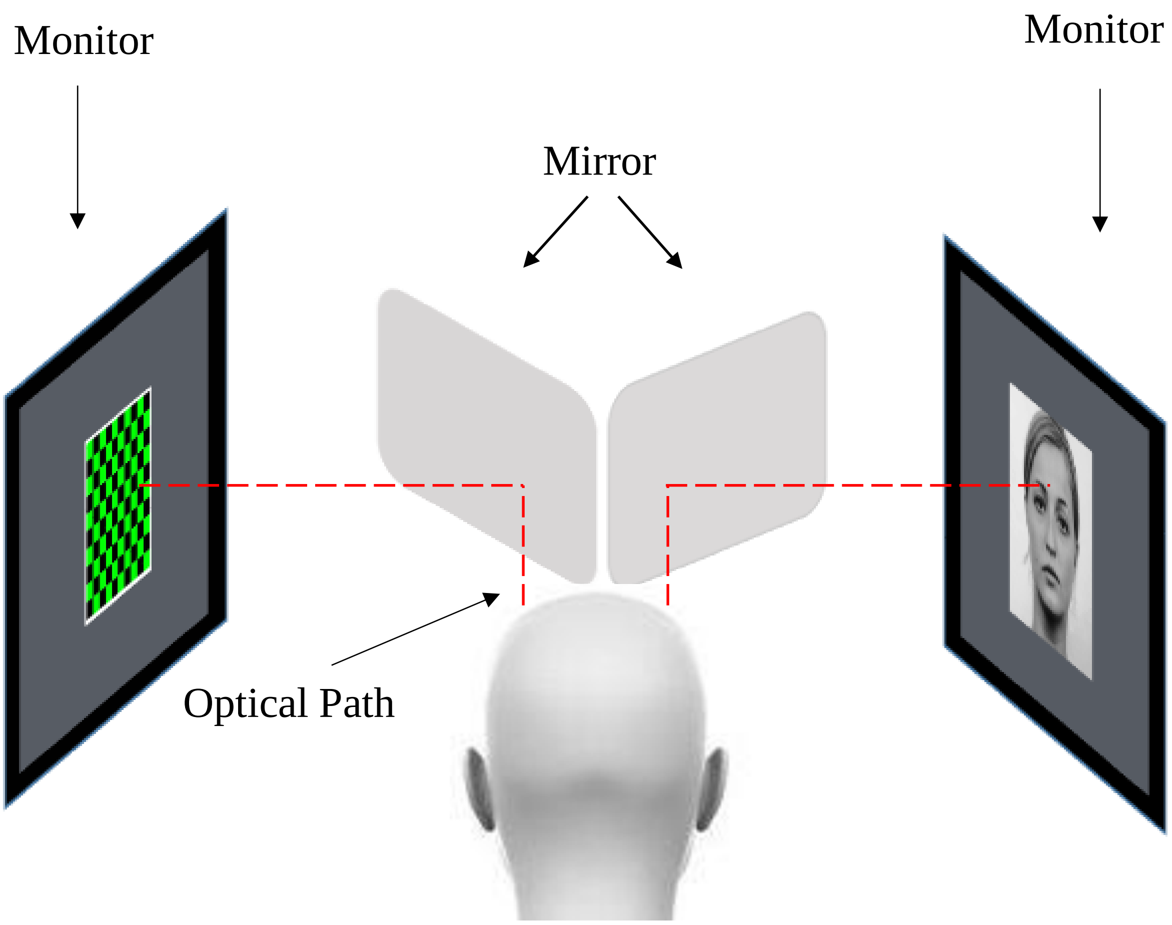

Figure 1 Schematic representation of the experiment set-up. The stimuli were viewed dichoptically on computer monitors at a 90-degree angle through a mirror stereoscope placed at the same height as a chin rest. The length of the optical path, from the eyes via the mirrors to the monitor, was 44 cm.

Apparatus

The b-CFS task was created using an Apple Mac Pro computer, operating system OS-X and Matlab software with the Psycho-physics Toolbox (Brainard, 1997; Pelli, 1997). Experiment 1 was ran using a HP z230 tower workstation, with a Windows 7 operating system, and had two linearized 60Hz monitors with a resolution of 2560 x 1440 pixels. The responses were registered with an HP keyboard model KU-115. The stimuli were viewed dichoptically at a 90 degree angle through a mirror stereoscope placed at the same height as a chin rest. The length of the optical path, from the eyes via the mirrors to the monitor, was 44 cm. Apart from the computer monitors, no light sources were present in the experiment room.

Stimuli

Stimuli consisted of images of an adult face depicting seven different emotions from the Radboud Faces Database (RaFD). More specifically, the first female Caucasian model with a frontal gaze. This identity was chosen since the agreement scores for the emotions were all above 90%. Furthermore, the emotions included angry, disgust, fear, happy, neutral, sad and surprise (Langner et al., 2010). The emotion contempt, also enclosed in the RaFD, was excluded for studies have shown that contempt has lower agreement scores than other expressions and is a lexically ambiguous emotion subject to problems with assigning expression labels (Langner et al., 2010; Rosenberg & Ekman, 1995). Moreover, all images were scaled and excised using the Vision Cascade Object Detector system. This detector is based on the Viola-Jones algorithm and is specifically configured to detect faces (Lienhart, Kuranov & Pisarevsky, 2003) Subsequently, all images were grey-scaled and adjustments were made to their image properties using the SHINE toolbox (Willenbockel et al., 2010). Specifically, the luminance and root mean square (RMS) contrast of the images were equated. The images were equated in luminance by calculating a mean luminance for all pixels within the image and in turn calculating these several means into one conformable mean. The same procedure was done to equate RMS contrast, using the standard deviation of luminance for all pixels. Moreover, we created a second group of images that, in addition to the luminance and RMS contrast matching, included equated spatial frequencies. This generated 14 stimuli, 7 images with similar luminance and RMS contrast and 7 images with the addition of equal spatial frequencies as seen in Figure 1.

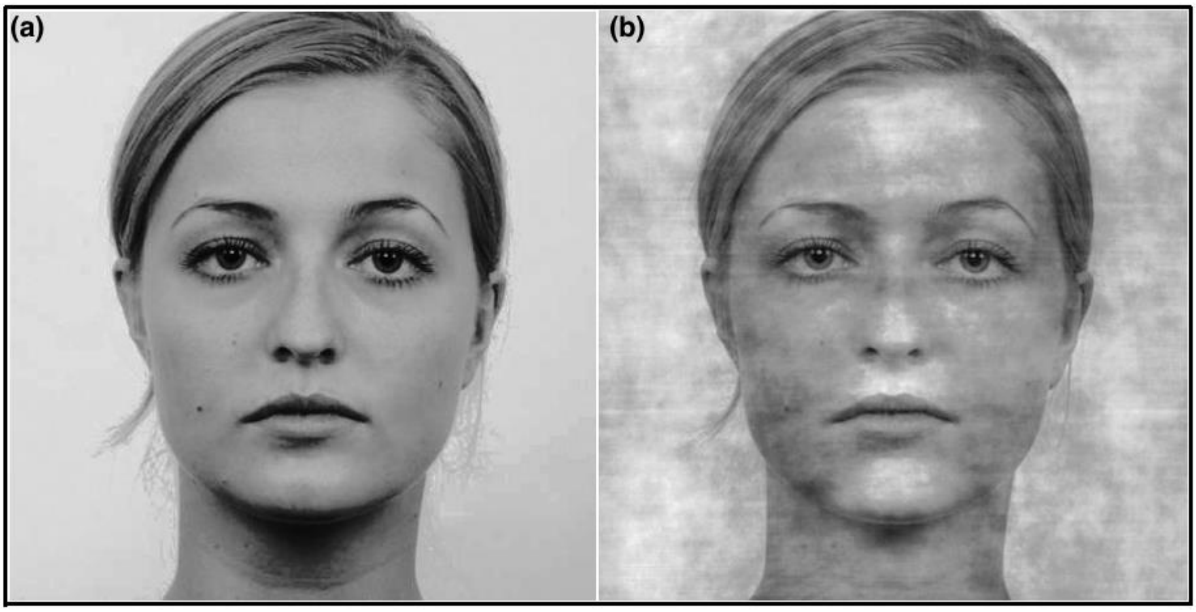

Figure 2 Examples of target stimuli used in Experiment 1. All images were scaled and excised using the Vision Cascade Object Detector. Thereafter, the images were grey-scaled and adjustments were made to their image properties using the SHINE toolbox. a) First, all images were matched in luminance and root mean square (RMS) contrast. b) Furthermore, a second group was created that in addition were equated in spatial frequency content.

The logic behind the manipulation is that if the processing of emotion content is the cause of the differences in suppression for faces, one might expect that equating the spatial frequency content has no effect on suppression durations, since the emotion content can still be extracted. On the contrary, if spatial frequency content were the cause of the variation in suppression times, equating the spatial frequency content would disrupt this, making suppression times equal for all the seven emotions. All stimuli were shown 30 times resulting in a total of 420 trials. For the practice trials different images were used. More specifically, images of a female Caucasian child, model number eleven, with a frontal gaze from the RaFD. Likewise, only one identity was chosen and they comprised the same emotions as the adult images. Furthermore, the same method was used to equate the luminance and RMS contrasts of all images and to create an additional group with matched spatial frequency content. In de practise trials all 14 stimuli were displayed five times and hence included 70 trials.

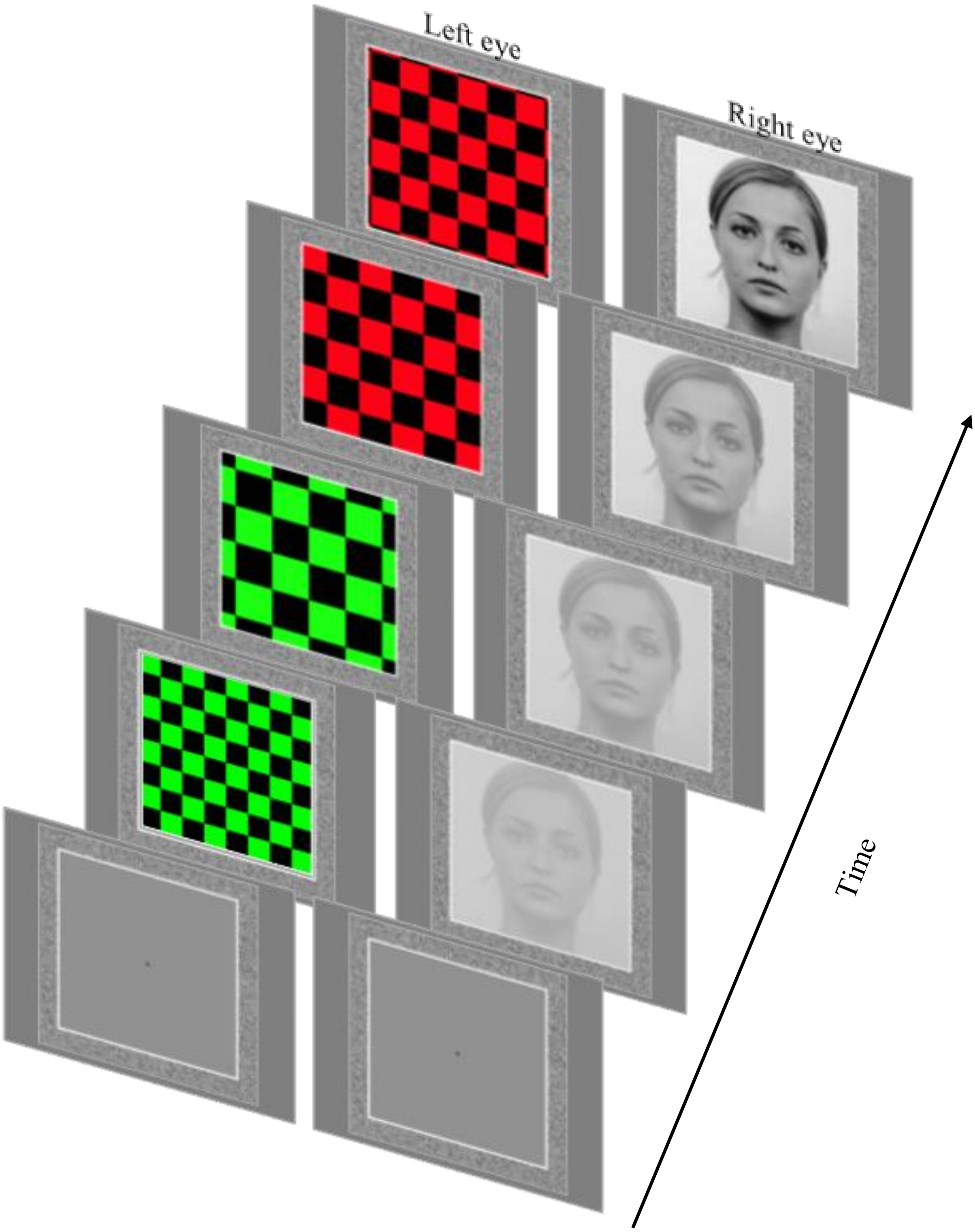

Figure 3 Schematic representation of the stimulus task presented separately on two monitors.. In a dichoptic viewing condition, a central fixation cross was presented to each eye. Subsequently, observers viewed a dynamic mask presented to the left eye, while an image of a face was presented to the right eye. The contrast of the stimulus increased linearly from 0 to 100% from the beginning of the trial and remained constant until either a response was made or the trial was automatically terminated after 15 seconds.

Mask

In order to present the stimuli outside of awareness, a coloured high contrast broadband checkerboard pattern was simultaneously presented. Specifically, every frame the polarity of the masks was reversed, while every two frames the colour changed (displayed in Figure 4). The colours of the masks included, red, green blue, and white, with the colour black used for reversing polarity. In addition, the block size of every new mask was randomly changed, ranging from a minimum of 0.39 x 0.39 degrees of visual angle to a maximum of 0.64 x 0.64 degrees of visual angle.

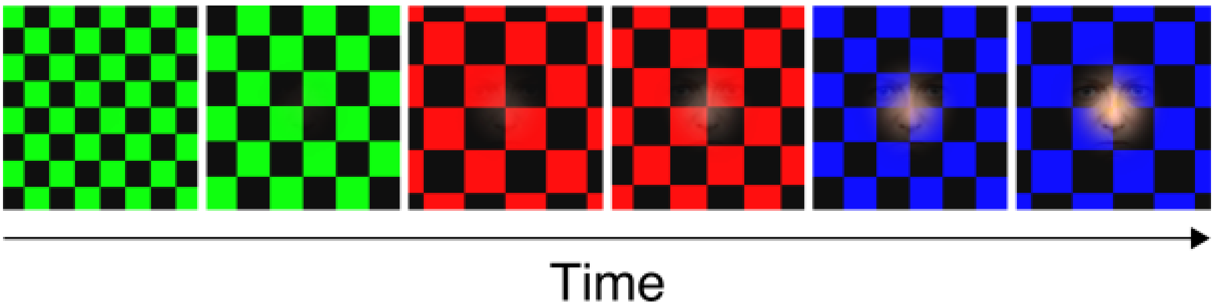

Figure 4 Schematic representation of the percept of a stimulus presented outside of awareness through b-CFS. In b-CFS a coloured high contrast broadband checkerboard pattern is presented to one eye, which suppresses an image presented to the other eye. Specifically, every frame the polarity of the masks was reversed, while every two frames the colour changed Participants are asked to respond when the suppressed image is detected. This is believed to be the point in time the image access awareness.

Control trials

Lastly, to test for possible misconduct, we included two different types of control trials enclosing the same images used in the practise trials. The first type consisted of 21 trials in which no images were present, thus expecting participants to have longer reaction times. In the second type, 22 trials containing images of children's faces from the same database were presented under pseudo rivalry. Under pseudo rivalry, participants should immediately be aware of the image, since the face is superimposed on the dynamic mask (image weight = .75). Therefore, faster reaction times are to be expected. Data-sets not meeting the expectations will be excluded for analysis.

Procedure

Instructions were given verbally by the experimenter without reference to faces or emotions. Participants were told to press the spacebar as quickly as possible, if they saw 'something' different than the dynamic mask. First, participants became familiar with the task by completing approximately 10 practice trials, at this time the experimenter was still in de room to answer questions and to verify that the task was carried out correctly. After, the experimenter left the room and the practice trials were started again, now running the full 70 trials. This was then followed by the experimental trials containing the images of adult faces.

Every trial started with a white fixation cross presented in the middle of the screen. After pressing the spacebar, the fixation cross disappeared and was followed by the stimulus and mask appearing simultaneously. The contrast of the stimulus increased linearly from 0 to 100% within a period of 2 seconds from the beginning of the trial and remained constant until either a response was made or the trial was automatically terminated after 15 seconds. Participants pressed the spacebar when they detected the stimulus, which terminated the screen and again displayed a white fixation cross. After every block, containing 50 trials, a mandatory break was programmed lasting at least 10 seconds. A schematic representation of one trial is depicted in Figure 3.

All stimuli were presented at 7.56 x 7.56 degrees of visual angle against a uniform grey background and were surrounded by a black frame to facilitate binocular rivalry. Furthermore, the stimuli were presented pseudo-randomly, meaning that all images were shown in a random sequence, except within 50 trials all emotions were equally distributed. In addition, the stimuli and masks were counterbalanced between eyes in both the practice- and experimental trials, as well as the control trials.

Results and Discussion

The distribution of the reaction times followed the expected gamma shape, therefore median reaction times were used in the data analysis. To test whether observers carried out the task properly, two control types were included. In the first control type the image was not present, hence longer reaction times are to be expected. In contrast, in the second control type faster reaction times are expected, since images were presented under pseudo rivalry and observers should be instantly aware of the image. For each observer an independent sample t-test was used to test whether the different control types had significantly different reaction times. One t-test was found to be non-significant, with the type 1 control (M = 14.16, SD = 2.57) reporting no difference from the type 2 control (M = 1.99, SD = 3.61), t (54) = 14.51, p = .316. This was not according to the expectations and for that reason this participant has been excluded from the analysis. The datasets of the remainder participants showed overall that control type 1 had significantly longer reaction times (M = 11.47, SD = 5.26) compared to control type 2 (M = 1.41, SD = .89), t (1230) = 46.76, p < .001. As a result, a total of twenty-two participants were included in the analysis based on performance on the control trials.

Main analysis

The aim of Experiment 1 was to determine whether the emotion content of the image can account for differences in access to awareness under b-CFS or whether it can be accounted for by differences in spatial frequency content. The reaction times to images of emotions with either their original spatial frequency content or matched spatial frequency content were compared using a 2 x 7 (spatial frequency condition by emotion condition) repeated measures Anova. The results show no main effects for spatial frequency condition (original spatial frequency content compared to matched spatial frequency content; F (1, 21) = .97, p = .34) (Figure 5). If spatial frequency content were the cause of the variation in suppression times, we would expect that equating the spatial frequency content would disrupt this. However, the absence of a main effect of spatial frequency condition indicates that equating the spatial frequency content had no effect on suppression durations. Since, the emotion content could still be extracted from the equated spatial frequency condition, differences in emotion content could therefore be behind differences suppression durations of faces. Particularly, since a significant main effect of emotion has been found (F (6, 126) = 2.60, $p < .05$) (Figure 6), as well as an interaction between the spatial frequency conditions and emotions (F (6, 126) = 3.35, $p < .01$). These findings suggest that emotion content induces differences in reaction times of faces presented outside of awareness, though the interaction indicated that spatial frequency could still have contributed to these differences.

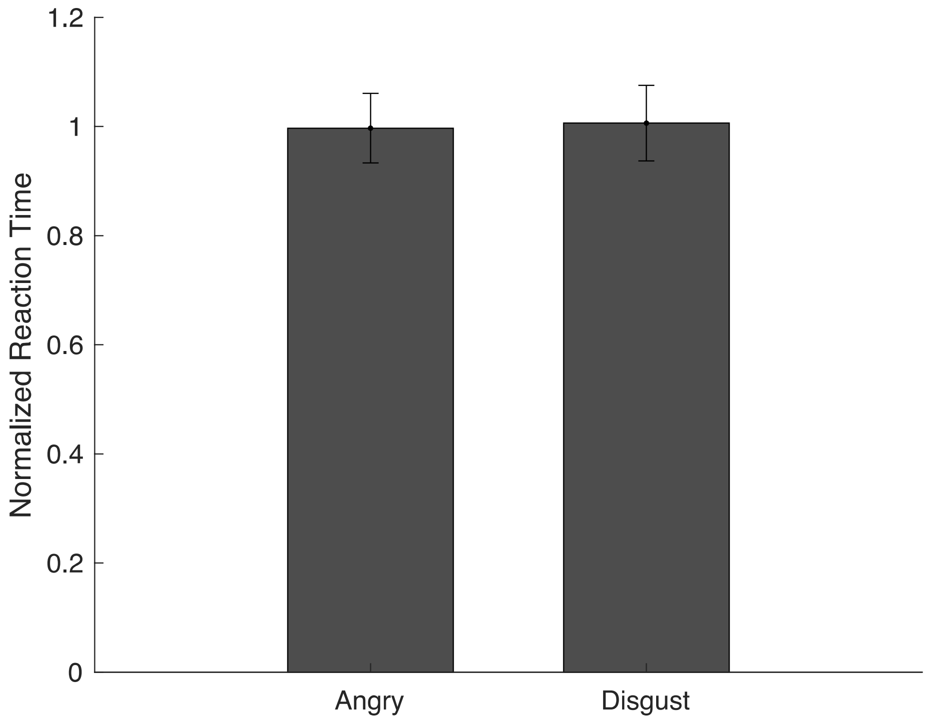

Figure 5 Results of the main effect of spatial frequency content of Experiment 1. The bars indicate the normalised reaction times to the images in the original spatial frequency condition and in the equated spatial frequency condition. We did not find a significant difference between the two spatial frequency conditions.

Next we independently compared the suppression durations of the emotions to the original and the equated spatial frequency condition. First, the reaction times for all 7 emotions were compared using a repeated measures Anova, with all images containing their original spatial frequency content. There was a significant difference in the reaction times per emotion for the images with their original spatial frequency condition (F (6, 126) = 2.60, $p < .05$). Similarly, reaction times have been compared for the 7 emotions in the equated spatial frequency condition. A significant difference in the reaction times per emotion has been found for the images with matched spatial frequencies (F (6, 126) = 3.19, $p < .01$). Matching the spatial frequency content of the images did not disrupt the emotion perception of faces presented under b-CFS. These results suggest that the difference in reaction times depends on the difference between the emotions of the images under both the original- and matched spatial frequency condition. This effect of emotion content seems particularly robust, since the magnitude of the emotion effect was fairly similar between the spatial frequency conditions, partial $\eta 2$ = .111 and partial $\eta 2$ = .132. As a result, there can be concluded that differences in

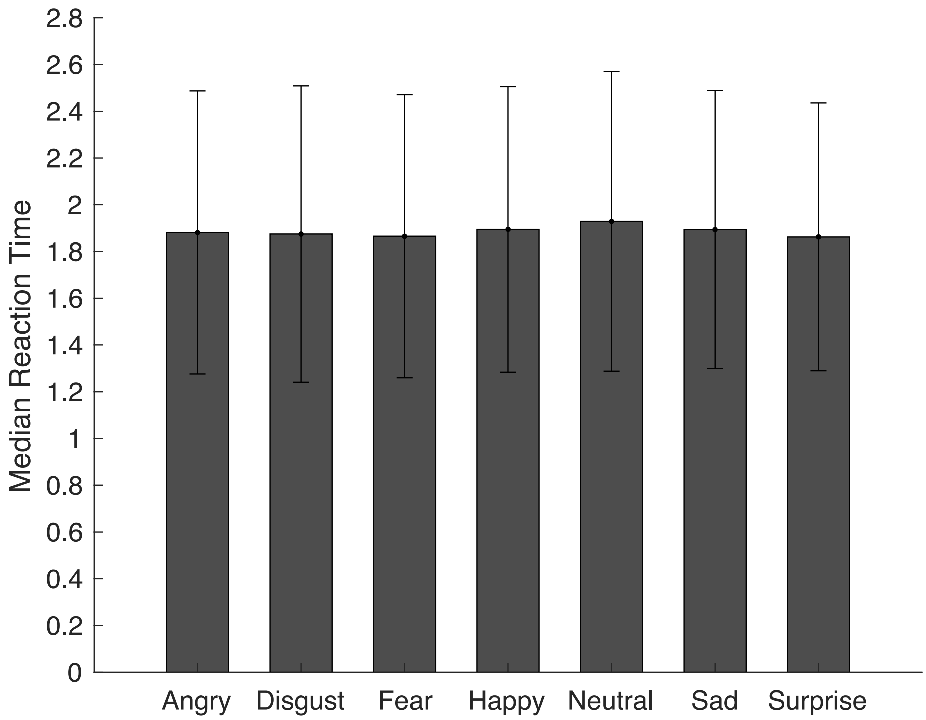

Figure 6 Results of the main effect of emotion content of Experiment 1. Each bar represents the median reaction time of an emotion. The emotions comprised angry, disgust, fear, happy, neutral, sad and surprise. Note that, although the amplitudes do not seem differ much, a significant difference was found between the reaction times of the emotions.

access to awareness of emotion in faces mostly depends on the emotion content of the images, rather than their spatial frequency content. However, it is important to note that spatial frequency content could still have contributed to the differences in access to awareness, since an interaction effect has been found as well.

Table 1 Results of the paired samples t-test comparing the median reaction times between the spatial frequency conditions per emotion for Experiment 1. The p-values indicate that the original spatial frequency condition of the emotions fear, happy, sad and surprise significantly differed relative to the equated spatial frequency condition.

Emotion	Mean	t-values	p-values
Angry	-.017	-.786	.441
Disgust	-.014	-.484	.634
Fear	-.038	-2.155	.043*
Happy	.044	2.114	.047*
Neutral	.001	.468	.644
Sad	.045	3.434	.002**
Surprise	.036	2.876	.009**

*Significant at $p < .05$
** Significant at $p < .01$

It is of particular interest to discover how spatial frequency content contributes to the differences in access to awareness and if the spatial frequency conditions have different influences on specific emotions. In order to find out how the differences in access to awareness extend to spatial frequency content, difference scores were calculated for each emotion per spatial frequency condition (Figure 7). These scores were calculated by subtracting normalised median reaction times to emotions in the original spatial frequency condition from the normalised median reaction times to emotions in the matched spatial frequency condition. The differences scores were then compared using a repeated measures Anova. The analysis revealed that the differences scores between emotions differed significantly (F (6, 126) = 3.32, $p < .01$) (Figure 8). To further understand which emotions are affected by the different spatial frequency conditions a paired samples t-test was conducted. In the paired sample t-test, median reaction times between the spatial frequency conditions per emotion were compared.

The results show that the difference in the spatial frequency conditions particularly have an effect on the emotions fear, happy sad and surprise. More specifically, the emotions happy, sad and surprise were found to induce shorter suppression durations for images containing their original spatial frequencies relative to their equated counterpart (Table 1). In contrast, the original spatial frequency content of the emotion fear was found to induce longer suppression durations relative to the equated spatial frequency condition. This suggest that spatial frequency content contributes to the differences in access to awareness of emotion. Though there is not a prototypical spatial frequency content that asserts to all emotions.

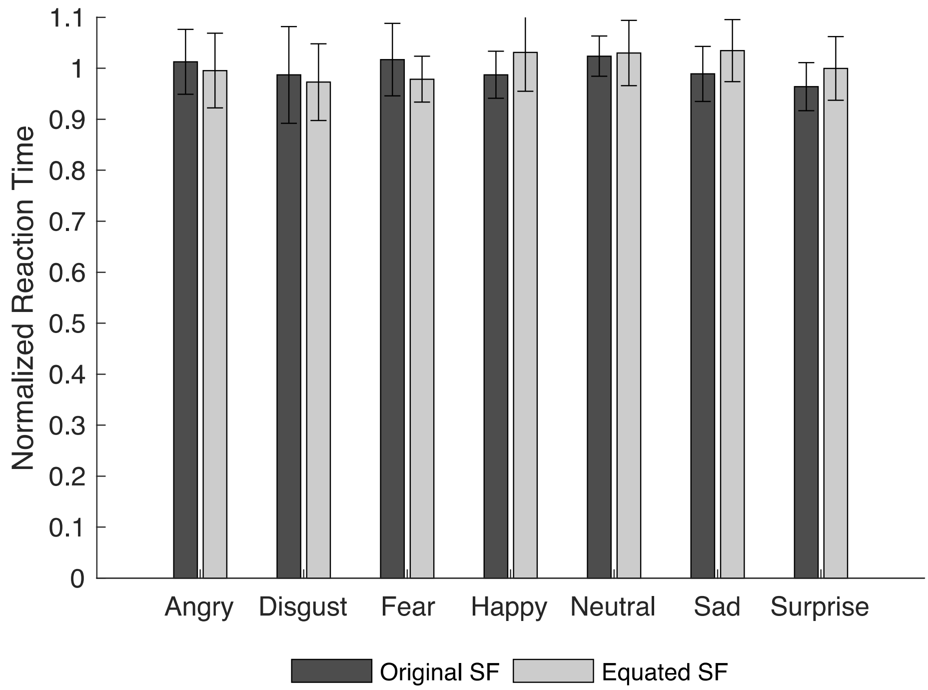

Figure 7 Results of the interaction effect between emotion content and the spatial frequency conditions of Experiment 1. The dark grey bars represent the normalized reaction time per emotion in the original spatial frequency condition. The light grey bars represent the normalized reaction times per emotion in the equated spatial frequency condition. Note that for fear the reaction times in the original spatial frequency condition were longer, relative to the equated spatial frequency condition. Whereas happy, sad and surprise induced faster reaction times in the original spatial frequency condition, relative to the equated spatial frequency condition.

In conclusion, our results show that emotion content induces differences in suppression durations of faces presented outside of awareness. Spatial frequency content contributes to this effect, though only for selective emotions. However, the question remains; is it the high or low spatial frequencies that account for this contribution? In addition, we intent to contrive other features that could be important in access to awareness of emotion.

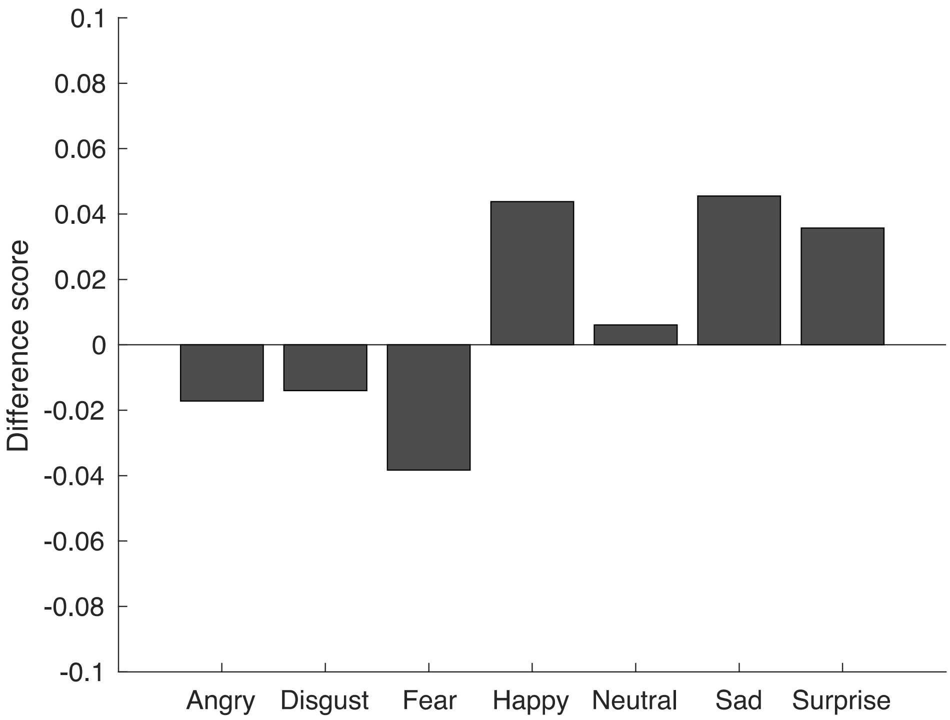

Figure 8 Results of the interaction effect between emotion content and the spatial frequency conditions of Experiment 1. The bars represent the difference scores from the conditions per emotion, which were calculated by subtracting the normalised scores in the original spatial frequency content normalised scores in the equated spatial frequency condition. Note that the differences between the conditions for the emotions fear, happy, sad and surprise were significantly different.

Experiment 2

The goal of Experiment 1 was to determine whether the emotion content of the images accounted for differences in access to awareness under b-CFS or whether it can be accounted for by differences in spatial frequency content. First of all, we did not encounter a main effect of spatial frequency content on access to awareness. A possible explanation could be the lack of variation in the spatial frequencies of the images, since only one identity has been used. However, we did observe a main effect of emotion, as well as an interaction effect between the emotion content and the spatial frequency condition. Although this suggests that emotion content is behind the differences in access to awareness, the interaction effect indicates that spatial frequency content could have contributed to this effect. Moreover, in Experiment 1 the luminance and RMS contrast were equated across all images, while both these features could be important in the access to awareness.

In Experiment 2, we aim to extend the findings of Experiment 1 and test for possible other important features that could account for differences in access to awareness of emotion in faces, as well as obtaining more clarity on how this is affected by spatial frequency content. In Experiment 2, images comprising the same emotions are once again presented under b-CFS. However, we enlarge the variation in our data by using images of different identities. Moreover, no adjustments will be made to the features of the images, in order to secure all their original features. Instead, we include all features and take them into account in the analysis.

Methods

Participants

A total of twenty naive subjects participated voluntarily (12 females and 8 males; age range 21-51, mean age 25.05), including 6 participants from Experiment 1. It is important to note that in contrary to Experiment 1, both males and females were allowed to participate, since we wanted to establish more variation in our data. Furthermore, all participants had normal or corrected to normal vision and were provided with an informed consent at the start of Experiment 2. Participants with a history of epilepsy or eye-problems, for instance lazy-eye, colour-blindness or problems with depth perception were excluded.

Apparatus

All apparatus specifications were identical to those in Experiment 1.

Stimuli

As in Experiment 1, stimuli included images of adult faces from the Radboud Faces Database (RaFD), portraying the same 7 emotions as in Experiment 1 (Langner et al., 2010). However, with the difference that instead of using one identity now 57 different identities were included to facilitate more variation in image properties. All 57 identities were presented once per emotion, thus resulting in a total of 399 trials.
Furthermore, for the practice trials another 7 images of child faces were selected from the RaFD. More specifically, the images of a female Caucasian child, model number eleven with a frontal gaze. Only one identity was chosen and they comprised the same emotions as the adult images. In de practise trials all 7 stimuli were displayed 10 times and hence included 70 trials.

Once again, all images were scaled and excised using the Vision Cascade Object Detector system. However, contrary to Experiment 1 all images were kept the original colours and no adjustments were made to their image properties. The mask and control trials were consistent with those used in Experiment 1.

Procedure

The procedure described in Experiment 1 is identical to the procedure executed in Experiment 2.

Results and Discussion

Once again median reaction times were computed and used in our data analysis. In order to test for possible misconduct, an independent t-test was conducted to compare the reaction times of the two types of control trials. In the first control type the image was absent and in the second control type images were presented under pseudo rivalry. Longer reaction times were expected for control trial 1 and faster reaction times were expected for control trial 2. The independent t-test revealed that control type 1 had significantly longer reaction times (M = 11.46, SD = 5.22) compared to control type 2 (M =2.65, SD = 2.92), t (815) = 29.53, $p < .000$, thus meeting our expectations. Therefore, no participants were excluded based on performance on the control trials. Regardless, one participant was excluded from analysis due to colour-blindness. This resulted in a total of 19 datasets that were used in the analysis.

Main analysis

The aim of Experiment 2 was to replicate the main effect of emotion content on the access to awareness of faces, that we found in Experiment 1, using images of different identities containing all their original feature contents. Moreover, we wanted to determine whether low or high spatial frequencies contribute to the access to awareness of emotion, as well as contrive other features that possibly affect awareness. The reaction times to images of 7 different emotions were compared using a repeated measures Anova. The results show that the emotion content induced significant differences between the access to awareness of faces (F (6, 114) = 3.14, $p < .01$). This main effect indicates that differences in the access to awareness depend on the emotion content of the images of faces. The effect of emotion content on suppression durations of faces presented outside awareness is particularly robust, since it replicates the finding from Experiment 1.

Furthermore, we evaluated if specific emotions have different influences on the access to awareness of faces by conducting a post-hoc test using the Bonferroni adjustment for multiple comparisons. The post-hoc test (using an α of .05) revealed significant differences between the emotion *disgust* and *sad*, as well as between *disgust* and *surprise*. More specifically, the emotion disgust (M = 1.86, SD = .449) had significantly faster access to awareness than the emotions sad (M = 1.99, SD = .477) and surprise (M = 2.02, SD = .57). For the remainder emotions, no significant differences were found. This suggest that the effect of emotion content on suppression durations of faces presented outside awareness, depends on the differences between the emotions disgust, sad and surprise (Figure 9).

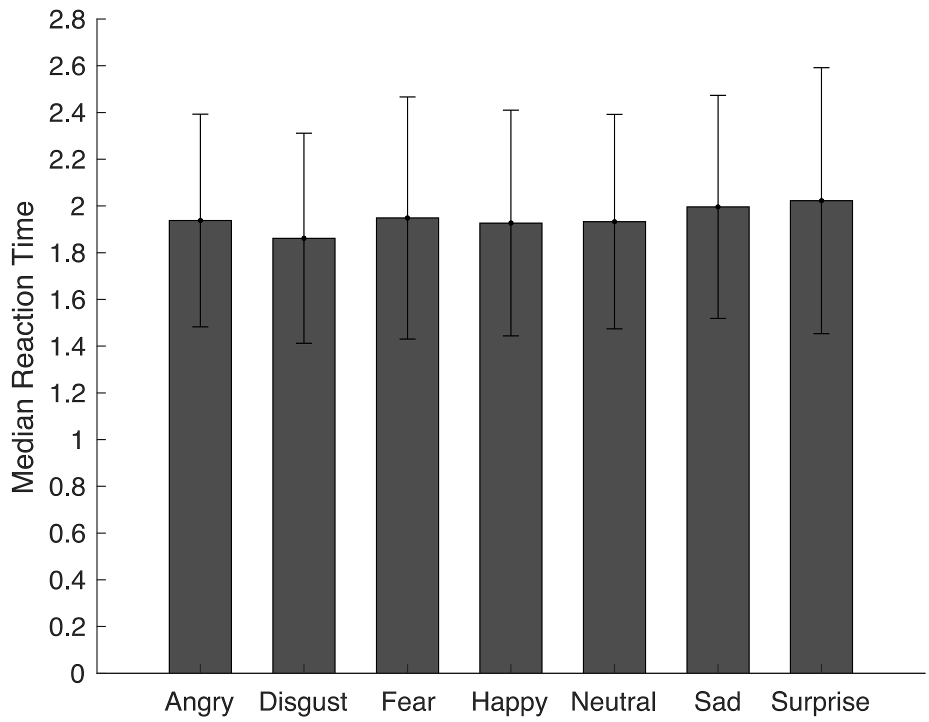

Figure 9 Results of the repeated measures Anova of Experiment 2. The bars represent the median reaction time per emotion. Note that the emotion disgust was found to be significantly different from the emotions sad and surprise

Next, we tested for emotion invariant image statistic effects on the reaction times. We wanted to assess the differences between low and high spatial frequencies in access to awareness of emotion, as well as establish if there are other features that affect awareness. Therefore, a total of fourteen image statistics were included in the analysis. The first image statistics comprised root mean square (RMS) contrasts, which is based on the standard deviation of luminance levels in the stimulus (Moulden, Kingdom & Gatley, 1990). More specifically, we used three different RMS contrasts, by calculating the standard deviation between the distribution of black/white-, blue/yellow- and red/green- contrast. Furthermore, ten groups of different spatial frequencies were included, ranging from low to high, as well as a predictor including the difference in feature content between the suppressed image and the dynamic mask. To assess the size and the direction of the linear relationship between the above mentioned image statistics and the reaction times, bivariate Pearson correlation coefficients were calculated for the reaction times of each participant separately. Thereafter, for each predictor a one sample t-test was used to compare the correlation coefficients against zero. If an image statistic induces differences in reaction times, then the correlation coefficients should be significantly different from zero. The results show the correlation coefficients of the lowest spatial frequencies in the images (M = -.02, SD = .04) were significantly different from zero (t (18) = -2.24, $p < .05$). This suggest that low spatial frequencies in the images induce differences in access to awareness. For the remainder predictors, no significant differences were found between the correlation coefficient and zero.

General discussion

In this study, we investigated whether emotion content explains the differences in suppression durations of emotion presented outside awareness, or whether it can be accounted for by processing of features. In Experiment 1, reaction times were compared to images of emotions, with either their original spatial frequency content or matched spatial frequency content, to assert the effect of spatial frequency condition on emotion perception under b-CFS. The results show that access to awareness of images is affected by the emotion content of the image. Moreover, this emotion effect has been found in both the original and the matched spatial frequency condition. This indicates that matching the spatial frequency content did not disrupt the differences in the suppression of emotion under b-CFS. The differences in access to awareness therefore depended more on the emotion content of the images, rather than their spatial frequency content. The effect of emotion content on the access to awareness of faces seems particular robust, since the findings of Experiment 2 show an emotion effect with a similar effect size, when using images without adjustments to their feature content. Both these findings are consistent with claims that attribute access to awareness to the emotion content in faces (Jiang et al., 2007; Stein et al., 2011a; Stein et al., 2011b; Zhou et al., 2010). However, it is important to note that Experiment 1 also found an interaction effect between emotion content and spatial frequency condition. Therefore, spatial frequency content could still have contributed to the differences in access to awareness of the emotions. Our results show that the difference in the spatial frequency conditions particularly have an effect on the emotions fear, happy sad and surprise. More specifically, the emotions happy, sad and surprise were found to induce shorter suppression durations for images containing their original spatial frequencies relative to their equated counterpart. In contrast, the original spatial frequency content of the emotion fear was found to induce longer suppression durations relative to its equated spatial frequency condition. This suggests that spatial frequency content contributes to the differences in access to awareness of emotion. Though there is not a prototypical spatial frequency content that asserts to all emotions.

As mentioned before, Experiment 2 also showed a main effect of emotion content on access to awareness of faces. Particularly, disgust was found to emerge faster into awareness than the emotions sad and surprise. This indicates that the effect of emotion content on suppression durations of faces, mainly depended on the differences between these emotions. This is incongruent to studies suggesting a threat advantage, causing fearful faces to gain preferential access to awareness. For instance, fearful expressions presented under b-CFS were found to consistently emerge faster into awareness compared to neutral expressions (Yang, Zald, & Blake, 2007; Gray, Adams, Hedger, Newton & Garner, 2013; Stein, Seymour, Hebart & Sterzer, 2014) or happy expressions (Yang et al., 2007; Gray et al., 2013). The absence of an effect of fearful faces on access to awareness was therefore not anticipated. Interestingly, disgust is also considered to be threat related and has been found to induce an attention bias (e.g. towards disgust-words; Charash & Mckay, 2002). The literature on threat-related processing under b-CFS has an almost exclusive focus on the emotion fear and many studies do not include disgust (e.g. Yang, Zald, & Blake, 2007; Gray, Adams, Hedger, Newton & Garner, 2013). We therefore reason that it would be beneficial to compare access to awareness of disgust versus other emotions.

Next, we assessed whether emotion invariant image statistic have an effect on the access to awareness of faces (Experiment 2). From the results became evident that in particular low spatial frequencies can induce differences in the suppression durations of images. Nevertheless, it is yet unclear how exactly faces are affected by low spatial frequencies. Our findings are consistent with Hedger et al., (2015b) who found that contrast sensitivity is greater for low spatial frequencies, which related to enhanced access to awareness. However, it is in contrast with Stein et al. (2014) claiming that differences in high rather than low spatial frequency content modulates suppression durations across emotional expressions. There are important differences between our study and Stein et al. (2001) that could explain the different results. For instance, their study used grey-scaled images variating in spatial frequency band pass-filters, whereas in Experiment 2 of our study no adjustments were made to the spatial frequency content of the images and they were kept in the original colours. These methodological differences could be behind the different effects of spatial frequency and it is unclear whether the study from Stein et al., (2001) can unequivocally support that high spatial frequencies in images of faces modulate suppression.

In Experiment 2, we did not find an effect of RMS contrast on suppression durations. This is surprising, as Hedger et al., (2015b) demonstrated that awareness of facial expressions could be predicted by effective contrast. A possible explanation might be that the images were at a high contrast when they accessed awareness. Reynolds, Pasternak and Desimone, (2000) demonstrated that attention causes an increase of a neuron's sensitivity and that this effect was diminished at high contrasts. Moreover, they found that the effect of attention reached a minimum for stimuli that were above the saturation point on the neuron's contrast–response function. Therefore, is it possible that the RMS contrasts did not have an effect on suppression durations, because at the time the images accessed awareness they were already above the saturation point on the neuron's contrast–response function.

In conclusion, our results show that the emotion content in faces induces differences in access to awareness under b-CFS. Spatial frequency content did contribute to the differences in suppression durations of emotion in faces, though there is not a prototypical spatial frequency content that asserts to all emotions. In addition, our results show that particularly low spatial frequencies can be related to differences in suppression durations. Therefore, when interpreting emotion differences in the access to awareness of faces the feature content of the images should be taken into account.

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Appendix

Informed Consent

Hartelijk dank voor je deelname aan dit onderzoek! Dit onderzoek vindt plaats in opdracht van de Universiteit Utrecht, naar aanleiding van de Master scriptie. Het experiment maakt gebruikt van flikkerende beelden. Als je in het verleden epileptische aanvallen hebt gekregen van lichtflitsen of patronen, dan kan je niet meedoen aan het onderzoek. Het is belangrijk dat je dit meldt bij de proefleider.

Daarnaast is het van belang aan de proefleider te melden of er sprake is geweest van:

- Kleurenblindheid
- Lui oog
- Problemen met dieptewaarneming
- Overige medische oogproblemen

De taak zal ongeveer 45 minuten duren. Deelname is geheel vrijwillig en je kunt het onderzoek op elk moment afbreken. De resultaten van dit onderzoek zullen volledig vertrouwelijk en anoniem worden behandeld. Privacy zal te allen tijde worden gewaarborgd en gegevens zullen nooit aan derden worden verstrekt.

Met vriendelijke groeten,

-Sascha van Huis

Door te ondertekenen geef ik aan de informatie goed te hebben gelezen en ga ik akkoord met de deelname en het gebruik van mijn gegevens voor dit onderzoek.

Naam	Datum	Handtekening
……………………	……………………..	……………………

Onderzoeker	Handtekening
……………………	……………………