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Unconscious processing of emotional faces

by

Katie L. H. Gray

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ABSTRACT

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Due to capacity limits, the brain must select important information for further processing. Evolutionary-based theories suggest that emotional (and specifically threat-relevant) information is prioritised in the competition for attention and awareness (e.g. Ohman & Mineka, 2001). A range of experimental paradigms have been used to investigate whether emotional visual stimuli (relative to neutral stimuli) are selectively processed without awareness, and attract visual attention (e.g. Yang et al., 2007). However, very few studies have used appropriate control conditions that help clarify the extent to which observed effects are driven by the extraction of emotional meaning from these stimuli, or their low-level visual characteristics (such as contrast, or luminance).

The experiments in this thesis investigated whether emotional faces are granted preferential access to awareness and which properties of face stimuli drive these effects. A control stimulus was developed to help dissociate between the extraction of emotional information and low-level accounts of the data. It was shown that preferential processing of emotional information is better accounted for by low-level characteristics of the stimuli, rather than the extraction of emotional meaning per se. Additionally, a robust 'face' effect was found across several experiments. Investigation of this effect suggested that it may not be driven by the meaningfulness of the stimuli as it was also apparent in an individual that finds it difficult to extract information from faces.

Together these findings suggest that high-level information can be extracted from visual stimuli outside of awareness, but the prioritisation afforded to emotional faces is driven by low-level characteristics. These results are particularly timely given continued high-profile debate surrounding the origins of emotion prioritisation (e.g. Tamettio & de Gelder, 2010; Pessoa & Adolphs, 2010).

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Declaration of Authorship

I, Katie L. H. Gray, declare that the thesis entitled Unconscious Processing of Emotional Faces, and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- This work was done wholly while in candidature for a research degree at this University;
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- Where I have consulted the published work of others, this is always clearly attributed;
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- Part of this work has been submitted for publication as:

Gray, K.L.H., Adams, W.J., & Garner, M. (under review). Unseen faces: no emotion-based processing advantage.

Signed:…………………………………………………………………………..

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Chapter 1

Is emotional information prioritised over non-emotional information?

From an evolutionary perspective, humans require defence systems that ensure survival and procreation (Ohman & Mineka, 2001). Crucial in these defence systems is the ability to locate quickly and respond flexibly to danger or threat (Ohman & Mineka, 2001; LeDoux, 2000). Due to capacity limits, the brain cannot process all information in the visual scene in parallel and therefore needs to select important information for further processing (Posner & Peterson, 1990). Adaptive behaviour would demand that selection processes filter information for further processing based on current task demands, but also that potentially dangerous stimuli are prioritised (LeDoux, 2000).

Compton (2003) suggests that there are two mechanisms involved in prioritising emotional information for further processing. The first evaluates emotional content of the scene 'automatically', and the second prioritises information deemed as emotional by the preferential allocation of attention towards that information. Operational definitions of automaticity have included a number of different characteristics; automatic processing should be fast, involuntary, independent of context, capacity free, and can operate outside of awareness (Shiffrin & Schneider, 1977, Bargh, 1992; Schneider & Chein, 2003). Attentional allocation (selective attention) towards emotional information has been investigated using a range of paradigms from experimental cognitive psychology and neuropsychology.

Automatically processing, and selectively attending to, biologically relevant emotionally significant information would have great adaptive value (Ohman & Mineka, 2001). What constitutes an emotionally significant stimulus? Many definitions of emotion are based on the concept of goal-relevance, whereby a stimulus that is "relevant to the major concerns of the organism" is considered emotional (Scherer, 2005, p. 697). These goals can be based on survival (e.g. avoiding danger), or be more complex (e.g. based on social behaviour; Compton, 2003). The *threat-superiority* hypothesis suggests that threat-related stimuli should be prioritised over other emotional information, due to the increased importance of threat-related information on survival (Ohman & Mineka, 2001; Fox et al., 2000). An opposing view is that all emotional information is prioritised over neutral information, so long as it is appraised as being sufficiently important; characterising the *emotionality* hypothesis (Martin, Williams & Clark, 1991).

One type of stimulus that has been used extensively in emotion processing research is the facial expression (see Ohman, 2002). It has been proposed that the processing of faces may be 'special'; an area in the fusiform gyrus has been reported to respond selectively to faces (Kanwisher, McDermott & Chun, 1997). There have been suggestions that the human face has evolved as a mechanism for social communication (Ohman, 2002). Indeed, emotional facial expressions display complex messages that we are expert at decoding (Ohman, 2002). Emotional faces signal an individual's motivation. That motivation may be towards harm (e.g. anger), potential danger (e.g. fear), or happiness (Ohman, 2002). The threat-superiority hypothesis would predict that only threat-relevant emotional expressions are prioritised, whereas the emotionality hypothesis would suggest that all emotions are prioritised over neutral expressions. Early research into emotional face processing suggests that there are six basic emotions: happiness, fear, anger, surprise, disgust, and sadness (Ekman, & Friesen, 1971; Ekman, 1992). Cross-cultural studies show that isolated cultures can correctly match the expression of a person in a story with a posed Western emotional face photograph (Ekman & Friesen, 1971), suggesting a universality of emotional face processing which may be due to evolution (Darwin, 1872; as cited in Ekman & Friesen, 1971).

This thesis is concerned not only with whether the prioritisation of emotional expression exists, but also which visual information is used to drive this prioritisation. In the visual system, information that loses the competition for attention may never reach consciousness (Mack & Rock, 1998). There are particular characteristics of visual information that may increase the likelihood of winning this competition; these can be based on top-down ('goal driven') and bottom-up ('stimulus-dependent') factors (Wolfe, Butcher, Lee & Hyle, 2003; Itti, Koch & Niebur, 2002). The extracted emotional meaning of a stimulus can be described as a top-down factor, as it is a characteristic of the stimulus that is informed by the observer. Bottom-up factors are those that are independent of the observers' knowledge, and can be described as low-level visual characteristics of the stimulus. Some such characteristics that are important in visual processing, and will be discussed in this thesis are: luminance (the amount of light emitted by a surface), contrast (the difference in luminance across a surface), colour (wavelength and intensity of light emitted from a surface), and spatial frequency (the spatial scale of luminance deviations).

Dissociating the visual effects that are due to top-down, high-level factors (i.e. factors due to the extracted emotional meaning), and those effects due to bottom-up, low-level factors (i.e. contrast) has attracted investigation recently (e.g. Wolfe et al., 2003). Indeed, it is impossible to show that high-level characteristics are causing variations in visual processing unless low-level characteristics are controlled for. For example, in a detection task, an emotional face may be responded to faster than a neutral face; however, whether this effect is due to high-level (the emotion of the face and its theorised evolutionary relevance; Ohman & Mineka, 2001), or low-level (differences in contrast between the emotional and neutral face) characteristics, is impossible to ascertain without adequate controls (of course, it is also possible that effects are driven by both high-level and low-level characteristics). To dissociate these possibilities within emotion processing research, it is necessary to explore apparently emotion-based effects with control stimuli. In face identity processing research, these control stimuli have generally consisted of inverted faces, as rotating a face through 180 degrees severely disrupts identity processing (Valentine, 1991). In emotion processing research, experiments that control for low-level characteristics using inverted faces will be highlighted in the upcoming review, with particular emphasis on their findings.

This review is concerned with the prioritisation of emotional face processing. Firstly, anatomical evidence for the prioritisation of emotional information will be reviewed. Evidence will then be reviewed regarding whether attention is allocated preferentially to emotional stimuli over neutral stimuli. A discussion of studies that have examined automatic and pre-attentive processing of emotion will follow. This will include discussions of the visual characteristics that may be responsible for the effects, and an indication of whether they are driven by emotional content or low-level visual properties. A detailed conceptual review of differences between varied operational definitions of automaticity used to date (and related terms often used interchangeably e.g. preattentive processing) is beyond the scope of this thesis. However evidence from paradigms that have examined whether emotion processing occurs rapidly, without drawing on attentional resources, and outside of awareness (Shiffrin & Schneider, 1977; Bargh, 1992) will be reviewed. These characteristics, if found for emotional and not neutral stimuli, would suggest that emotional information incurs privileged processing, and is prioritised over neutral information. Dysfunction in the emotion processing system is central to models of emotional disorders, including individual differences in anxiety (Mogg & Bradley, 1998; Bishop, 2007), and so the effect of anxiety on these processes will then be introduced.

1.1. Anatomical evidence for prioritised processing of emotional information

Over the last 20 years, neural mechanisms that might underlie adaptive emotion processing have been delineated through functional and structural imaging and evidence from lesion studies in animals and brain injury in humans. The amygdala has been purported to be a hub of fear learning and expression (LeDoux, 2000). The amygdala is situated in the medial temporal lobe with widespread connections to many other brain regions (LeDoux, 2000). There is evidence that it receives information through two distinct pathways: one cortically, the other subcortically mediated (LeDoux, 2000). The cortical pathway consists of projections from the retina to the lateral geniculate nucleus of the thalamus (LGN), then on to the primary visual cortex (V1), and through extrastriate visual areas (Polyak, 1957). In primates, the amygdala has rich connections with extrastriate visual processing regions (Amaral, Price, Pitkanen & Carmichael, 1992). The alternative, subcortical pathway may carry visual information from the visual thalamus directly to the amygdala (via the superior colliculus and pulvinar nucleus), bypassing the visual cortex (LeDoux, 2000). Animal lesion research has indicated the existence of such a subcortical processing pathway for auditory and visual information in rats (Doron & LeDoux, 1999). However, conclusive evidence for a retinal-collicular-pulvinar-amygdala pathway for visual information in primates has not yet been found (Pessoa, 2005).

Due to the rich connections between the amygdala and visual processing regions (Amaral et al., 1992) it has been suggested that the amygdala may modulate perceptual processing of emotional stimuli (Vuilleumier, 2005). Evidence for this modulation comes from correlations between amygdala activation and enhanced responses to emotional stimuli in visual cortex (Vuilleumier, Armony & Dolan, 2003). Additionally, amygdala lesions abolish the enhanced processing of fearful faces in cortical visual processing regions (Vuilleumier, Richardson, Armony, Driver & Dolan, 2004), impair enhanced perception of emotionally salient events (e.g. Anderson & Phelps, 2001), and impair recognition of emotional facial expressions (Adolphs, Tranel, Damasio, 2001). Therefore, the enhanced perceptual processing of emotional information may result from direct feedback from the amygdala to visual regions such as the fusiform and extrastriate cortices (Vuillemier et al., 2004).

Input to the amygdala is dominated by magno cells (Miller, Pasik & Pasik, 1980), which are fast responding cells with large receptive fields (De Valois & De Valois, 1980; Shapley & Lennie, 1985). The large receptive fields of the magnocellular pathway allow only coarse, or low-spatial frequency, visual information to be processed, such as global information about shape (Livingston & Hubel, 1988). In contrast, parvocellular channels project along the cortical pathway (Livingston & Hubel, 1988), with slow responses over small receptive fields, and tend to process high spatial frequency information (that represents abrupt spatial changes in the image, such as detail). Therefore, neurobiological models of emotion processing predict that low spatial frequency information drives the prioritisation of emotional information (Vuilleumier, Armony, Driver & Dolan, 2003) through the proposed subcortical pathway (LeDoux, 2000).

1.2. To what extent is emotional information preferentially attended?

As the visual system is capacity limited, information has to be selected for further processing. Generally, the fate of unattended stimuli is poor; they are perceived less accurately than stimuli that are attended (Mack & Rock, 1998; Rock & Guttman, 1981). A large body of neuroimaging research suggests that attention mechanisms can modulate sensory processing by boosting the neural representation of attended information, at the expense of unattended information (see Driver, 2001). Allocating attention to a stimulus suggests that it has been prioritised at the expense of other information in the visual scene. The dot-probe task and exogenous cueing task have been used to investigate the extent to which attention is allocated to emotional information. Additionally, observations from brain-damaged patients have provided evidence regarding the extent to which attention is allocated to emotional information.[1]

Models have highlighted the distinction between different components of attention, such as shifting, engagement and disengagement (Posner & Peterson, 1990). When an individual attends to a stimulus, attention must first be *shifted* to the stimulus. For the time

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[1] The emotional Stroop task may also address the question of whether attention is preferentially allocated to emotion (McLeod, 1991). The emotional Stroop task consists of presenting a word (either emotional or neutral) and recording RTs to name the colour of the word (the lexical content of the word is always irrelevant; for a review, see McLeod, 1991). The emotional stroop task does not provide an unambiguous measure of attention, e.g. it is unclear whether colour-naming interference reflects competition at attentional (input), or at the response selection (output) stage (Macleod, 1991). Therefore, the emotional Stroop literature will not be reviewed here.

that that stimulus is attended, attention is *engaged* on the stimulus. Before attention can be allocated elsewhere, it must be *disengaged* from its current focus (Posner & Peterson, 1990). The specific attentional component that is measured is thus very important. Evolutionary theory suggests that attention will be preferentially drawn towards threatening stimuli, as fast and accurate orienting to potential danger is important for survival (Ohman & Mineka, 2001). However, biases can occur without threatening information drawing attention, i.e. by delayed disengagement (Fox, Russo & Dutton, 2002).

1.2.1. Evidence from the visual-probe task. Originally configured by Posner, Snyder and Davidson (1980), the visual-probe task is based on the reasoning that quicker responses will be produced to a probe presented in a currently attended location, relative to a currently unattended location. On emotional visual-probe tasks, critical trials consist of an emotional stimulus presented in one location, and a neutral stimulus in another (Armony & Dolan, 2002). Prioritisation of emotional information would be indexed by faster reaction times to subsequent probes presented in the same spatial location as emotional stimuli. Faster reaction times have been found when probes are preceded by fearful faces (Pourtois, Grandjean, Sander, & Vuilleumier, 2004; Pourtois, Schwartz, Seighier, Lazeyras & Vuilleumier, 2006), and angry faces (Cooper & Langton, 2006; Holmes, Bradley, Nielsen & Mogg, 2009), relative to probes preceded by neutral stimuli. However, none of these visual-probe studies controlled for low-level stimulus differences between the different emotional expressions (i.e. they did not use inverted faces as a control). Instead, two of the studies compared low-level differences between the stimuli (including average pixel luminance, luminance contrast, face size, and central spatial frequency), and suggest that there are no measurable low-level differences between them (Pourtois et al., 2004; Pourtois et al., 2006). Although the global low-level properties between emotional faces were not statistically different (e.g. Pourtois et al., 2004), it is possible that local differences between stimuli could be driving the emotion effects.

Armony and Dolan (2002) circumvented the issue of potentially confounding low-level visual characteristics by presenting conditioned angry faces in a visual-probe paradigm. It has been argued that threat processing, and the acquisition of fear through conditioning, share a common brain circuitry (Bishop, 2007). In fear conditioning, a conditioned stimulus (CS) generates a conditioned fear response (CR) due to repeated association with an aversive unconditioned stimulus (US). Armony and Dolan presented a different angry face on each side of a screen, one of which (the CS) was conditioned to a loud burst of white noise (US) to elicit a CR. It was found that when the probe was presented on the same side as the CS, responses were faster, indicating a prioritisation of the fear-conditioned angry face.

In a recent study, Holmes, Green and Vuilleumier (2005) attempted to elucidate the visual characteristics that drive the prioritisation of emotional faces in the visual-probe task. They presented neutral and fear faces that contained either high or low spatial frequency information (HSF and LSF respectively). Responses to probes replacing LSF fearful faces were faster than to LSF neutral faces. However, there was no difference between responses to probes replacing HSF fearful compared to HSF neutral faces. There was no difference between responses to probes replacing LSF fear compared to LSF neutral faces when they were inverted. These results suggest that attentional prioritisation is driven by the LSF content of faces.

Overall, there is some inconsistency in whether threatening stimuli are preferentially attended in the visual-probe task (for example see Bradley, Mogg, Falla & Hamilton, 1998). This could be attributed to the visual-probe task only sampling attention when the probe is presented and thus not profiling attention allocation throughout stimulus processing (Fox, Russo, Bowles & Dutton, 2001). However, by manipulating the duration between onset of the emotional stimulus and the probe, specific attentional mechanisms (i.e. shifting vs. engagement) can be tapped (Cooper & Langton, 2006). For example, Cooper and Langton (2006) found a trend for threatening faces to elicit quicker responding than neutral faces when probed at 100ms, a pattern that was reversed when probed at 500ms. These results suggest that threatening stimuli elicit faster shifting, but attention may not be maintained to threatening relative to neutral stimuli.

A more sensitive version of the visual-probe task has also been used, where instead of responding to the location of the probe, observers to respond to its visual characteristics. Phelps, Ling and Carrasco (2006) presented a brief fearful or neutral face followed by a probe. Observers were required to indicate whether the probe was tilted clockwise or anti-clockwise, and the contrast of the probe was varied across trials, so that sometimes it was easy to perform the tilt task (i.e. the probe had high contrast), whereas at other times, it was far more difficult (i.e. the probe had low-contrast). Participants were better at the tilt discrimination when the task followed a fearful face, than when it followed a neutral face (i.e. they were more accurate at the tilt task at a lower contrast following fearful compared to neutral faces). There was no difference in task performance between the fear and neutral faces when they were inverted, thus suggesting that it is the emotional content of the fearful faces that enhances contrast sensitivity.

In a recent study, Bocanegra and Zeelenberg (2009) explored the visual characteristics of the probe even further, by varying its spatial frequency content. When a fearful face preceded a low spatial frequency visual-probe, it facilitated perception, so participants were better at the tilt discrimination task compared to when the visual-probe was preceded by a neutral face. On the other hand, when the fearful face preceded a high spatial frequency visual-probe, it impaired perception, so participants were worse at the tilt discrimination task compared to when the visual-probe was preceded by a neutral face. This suggests that fearful faces selectively facilitate low spatial frequency information, and they impede high spatial frequency information compared to neutral faces.

1.2.2. Evidence from the exogenous cueing task. The exogenous cueing task is similar to the visual-probe task, but only one stimulus is presented per trial. This means it does not measure selection between competing stimuli directly, as emotional and neutral stimuli are never competing for attention. Rather it examines the extent to which stimulus content (emotion) modulates shift and disengage components of attention.

In the original exogenous cueing paradigm, the participants' task was to detect a target presented on the left or right of fixation (Posner, 1980). On most trials (e.g. 80%), a stimulus precedes the target at the same spatial location, thus acting as a valid cue. On the remaining trials (e.g. 20%), the cue is presented in an alternative spatial location to the target, and therefore acts as an invalid cue. Generally, valid cueing results in shorter reaction times to the target (Posner, 1980), particularly when the temporal separation between the cue and target is less than approximately 200ms (if separation is longer, responses are slower at valid locations due to inhibited re-processing of a previously attended location; known as inhibition of return, Posner & Peterson, 1990). The allocation of attention to the cued location tends to occur regardless of cue validity consistent with peripheral stimuli exogenously cueing attention to their spatial location (Jonides, 1981).

In the modified emotion task, the emotional content of the cue varies, and thus allows investigation of attentional shift and disengage components of attention as a function of cue validity. A bias in the initial shift component of attention allocation to threat would be indicated with *faster* RTs to the target when the cue is threat-related on *valid* trials. In contrast, delayed disengagement of attention to threat would be indicated by *slower* RTs to the target when the cue is threat-related (relative to neutral) on *invalid* trials. Several studies using this method have found no evidence for a bias in the shift component (i.e. initial orienting of attention; Fox et al., 2001; Yiend & Mathews, 2001). Indeed, a recent study reported the opposite effect, as attention was directed to the valid target faster following a neutral face than an emotional face (Koster, Verschuere, Burssens, Custers & Crombez, 2007). Additional evidence has shown greater maintenance/delayed disengagement for threatening compared to neutral stimuli (Fox et al., 2001; Yiend & Mathews, 2001; for contrary findings using aversively conditioned cues see, Koster, Crombez, Van Damme, Verschuere & De Houwer, 2004). However, in these studies, RTs were generally very fast towards targets that were validly cued, therefore the lack of an attentional shift towards threat may be due to a ceiling effect (Fox et al., 2001).

1.2.3. Evidence from observations with brain-damaged patients. Neuropsychological observations of brain-damaged patients have also provided evidence that attention is preferentially allocated to emotional information. Brain damage, particularly to the inferior parietal lobe in the right hemisphere, can cause hemispheric neglect (Driver & Vuilleumier, 2001). Neglect is defined by a lack of awareness of the contralateral space (e.g. on the left side following a right lesion), which may be the result of a deficiency in directing attention towards stimuli presented on that side (Driver & Vuilleumier, 2001). For example, although neglect patients rarely fail to perceive a single light when it is presented anywhere in the visual field, when two lights are presented it is common for them to only report perceiving the light located in the ipsilesional space (e.g. following a right lesion, only reporting the stimulus furthest right; Bender & Tueber, 1946). This phenomenon is called extinction, as the additional source of information has 'extinguished' the source in the contralesional space (Driver & Vuilleumier, 2001).

Extinction is less likely to occur for schematic faces compared to scrambled faces and geometric shapes (Vuilleumier, 2000). Schematic faces are cartoonised facial stimuli consisting of eyes, mouths and eyebrows (occasionally omitted). They are simplified versions of facial expressions, differing from each other in the orientation and curvature of feature lines. Schematic faces are easier to match on their low-level visual properties than photographs of faces. Vuilleumier and Schwartz (2001) used happy, angry and neutral schematic faces to probe residual emotion processing in neglect patients. They found that when compared to neutral faces, both happy and angry schematic faces are less prone to extinction (Vuilleumier & Schwartz, 2001).

1.2.4. Summary. Investigating attentional allocation to emotional stimuli has been problematic; paradigms such as the visual-probe and exogenous cueing paradigm cannot completely differentiate between different attentional mechanisms. It is possible that inconsistencies using the visual-probe task (Fox et al., 2001; Koster et al., 2004) arise from stimulus and methodological differences across studies. However, both the visual-probe and the exogenous cueing task do provide some evidence that emotional (specifically threat-related) information is prioritised over neutral information in some circumstances (Koster et al., 2004; Pourtois et al., 2004). Additionally, there is some suggestion that these effects may be due to the LSF content of the faces (Holmes et al., 2005).

Evidence from the attention tasks in normal participants supports the threat-superiority hypothesis of emotion processing (Ohman & Mineka, 2001). Observations from brain-damaged patients suggest that emotional (including both positive and negative) faces are preferentially allocated attention compared to neutral faces (Vuilleumier & Schwartz, 2001). These observations from patients support the emotionality hypothesis of emotion processing (Martin, Williams & Clark, 1991): that all emotional information is prioritised over neutral information.

Very little of the research investigating attentional prioritisation of emotional faces has adequately controlled for low-level visual differences between the stimuli (with exception of Armony & Dolan, 2002; Holmes et al., 2005; Phelps et al., 2006; and Bocanegra & Zeelenberg, 2009). Thus making it difficult to tell whether effects are due to the emotional content of the faces, or low-level visual properties.

1.3. Does emotional face processing demand attentional resources?

If emotion processing demands no attentional resources, it should experience no disruption from competing stimuli. Visual search tasks have been used extensively to discover the extent to which emotion processing is independent of attentional resources (i.e. unaffected by the number of distractor stimuli). Monitoring neurological activation to stimuli when they are unattended has also been used to test whether emotional face processing demands attention.

1.3.1. Evidence from the visual search task. The visual search task has been used to explore the extent to which visual information can be processed without attentional resources, or preattentively (i.e. whether aspects of the scene can be rapidly evaluated before attention is deployed; for a review, see Wolfe, 1998).

Typically a target stimulus is presented within a field of distractors, and the participant is asked to find the target as quickly and accurately as possible. If the target has a perceptual feature that can be detected before attentional processing has been initiated, target identification is independent of the number of distractors in the display (set size); this is labelled ‘pop-out’. On the other hand, if target detection is impaired by increasing set size, then it is assumed that the stimuli are processed serially. Whether a target ‘pops-out’ is based on its top-down (goal directed) and/or bottom-up (stimulus-driven) saliency. ‘Pop-out’ has been found for stimulus characteristics including colour, size, orientation and spatial frequency (Wolfe, 1998). Even if a stimulus does not pop-out (i.e. target identification is dependent on set size), it may be processed more efficiently compared to other stimuli. The search efficiency of a stimulus can be calculated by computing the slope of the linear relationship between set size and latency.

In an initial study with faces, Hansen and Hansen (1988) displayed matrices of individual faces and asked participants to detect whether the faces all had the same emotional expression, or whether one facial expression (target) differed from the others. Angry faces were found significantly faster than happy faces, and the speed at which the angry faces were found did not depend on set size (as it did for happy faces), consistent with them ‘popping-out’. However, it has since been noted that in this original experiment a low-level visual confound made the angry faces easier to detect (Purcell, Stewart & Skov, 1996). To find whether the effects of emotion are due to low-level characteristics, some experimenters have investigated visual search with inverted emotional faces (Williams & Mattingley, 2006; Calvo & Nummenmaa, 2008). However, results have been mixed, with some finding the emotion effect disappears with inversion (Williams & Mattingley, 2006), and others finding a reduction, but not elimination of the effect (Calvo & Nummenmaa, 2008), thus it is impossible to conclude whether results are due to the extraction of emotional meaning from the faces, or low-level characteristics.

Although some visual search experiments suggest that angry faces are detected faster than other expressions, and are therefore consistent with a threat-prioritisation account of visual processing (Williams & Mattingley, 2006), a large number of experiments have found that happy faces are prioritised in search (Calvo & Marrero, 2009; Juth, Lundqvist, Karlsson

& Ohman, 2005; Calvo & Nummenmaa, 2008). Calvo and Marrero (2009) presented all 6 basic expressions as targets (in an array of neutral distractors), and found that happy expressions were detected fastest, followed by surprise, disgust, fear, then angry, and finally sad faces. They were particularly interested in the visual characteristics responsible for these effects, and therefore computed average low-level visual properties (including luminance, RMS contrast, energy, colour and texture) for each of the emotions and covaried them in the analysis. The covaried results suggested that speeded responses to happy targets were not caused by global low-level visual properties. However, they also conducted an image analysis by rating regions (or features) of change between emotional and neutral faces. When these ratings were covaried with the search performance, the effect of emotion disappeared. In particular, the feature with the greatest contribution to search performance was the visibility of the upper teeth, which was consistently and only associated with the happy expression. This suggests that the visual search advantage for some expressions is caused by the presence of particular features that are consistently associated with them. What this study does not address is whether the difference in features that is driving the effect of facilitated search involves emotional processing or simply low-level visual processing.

Another approach to try to counteract the low-level explanation for prioritisation in search has been to simplify the emotional face stimuli by using schematics (Fox et al., 2000; Ohman, Lundqvist & Esteves, 2001; Calvo, Avero & Lundqist, 2006).

Fox et al., (2000) presented an angry or happy target with neutral distractors in an imaginary circle around a fixation point. They found that schematic angry faces were detected more efficiently than happy faces when paired with neutral distractors. Using a different set of schematic stimuli, and a different stimulus arrangement (in a 3 x 3 matrix), Ohman, Lundqvist and Esteves (2001) constructed a similar visual search experiment. Although, again, no ‘pop-out’ effect was found, they reported consistently faster search times for angry versus happy faces.[2] Recently, the schematic emotional face studies above have been replicated; Horstmann (2007) used the same stimuli as in three original experiments (Ohman, et al., 2001; White, 1995; Fox et al., 2000) but used the same method across all three experiments. Overall, Horstmann (2007) found no evidence of ‘pop-out’ for

[2] Similar results have also been found with other biologically relevant stimuli when compared to neutral objects, including snakes and spiders (Ohman, Flykt & Esteves, 2001).

angry faces, but there was an indication of more efficient search for angry faces compared to happy faces in all studies (although to different degrees depending on the stimuli).

Although low-level differences between emotions in schematic stimuli are more controlled than their photographic counterparts, differences do still exist. Therefore, to show that effects of emotion in schematic visual search are due to the emotional content, as opposed to low-level properties of the stimuli, control stimuli are still required. Fox et al., (2000) presented both upright and inverted face stimuli, and found that the emotion effect found in the upright schematic faces (faster detection of angry) disappeared when they were inverted. However, some studies using schematics have reported the same angry effect in both upright and inverted faces (Ohman et al., 2001; White, 1995).

In a recent study, Coelho, Cloete and Wallis (2010) investigated the visual characteristics that were responsible for the angry prioritisation in visual search with schematic faces. They used oriented lines contained within a circle (which were rated as non-emotional), and found the same effect: the abstract shape that had the same orientation of lines as the angry face was detected faster than that of the abstract shape with the same orientation of lines as the happy face. Over three experiments, Coelho et al. showed that the orientation of the internal lines relative to the edge of the surrounding circle is crucial to detection times, and can account for all of the variance between happy and angry schematic faces in visual search. Thus, their paper suggests that emotion is not driving the angry prioritisation found with schematic stimuli, but the effects are due to low-level characteristics of the stimuli.

The visual search paradigm has been criticised on several grounds, including its inability to separate the attentional effects of the targets from the distractors (Koster et al., 2004), or to disassociate different aspects of attention (Fox, 2007). Schematic faces have been used frequently in the visual search paradigm to reduce low-level visual confounds (e.g. Ohman et al., 2001; Horstmann, 2007). However, the use of schematics has been questioned due to their low ecological validity (Horstmann & Bauland, 2006). Also, facial expressions represented by schematics have been limited to angry, happy, sad and neutral expressions (e.g. Ohman et al., 2001). This could be because it is difficult to represent additional emotions with good validity and reliability using schematics. This is particularly important, given that the threat-superiority hypothesis would suggest that fearful faces should also induce preattentive processing (Ohman & Mineka, 2001).

1.3.2. Evidence from neurological activation to emotional faces without attention. It is well documented that unattended stimuli are perceived less accurately than stimuli that are attended (Mack & Rock, 1998; Rock & Guttman, 1981). Neurological data indicate that information that is unattended evokes reduced activation compared to attended stimuli in relevant processing areas (Corbetta, Miezin, Dobmeyer, Shulman & Peterson, 1990). The processing of emotional information outside the current focus of attention would suggest that emotion processing does not demand attentional resources.

Vuilleumier, Armony, Driver, and Dolan (2001), presented two faces and two houses arranged in vertical and horizontal pairs whilst measuring local cerebral blood volume and flow using functional Magnetic Resonance Imaging (fMRI). On 50% of trials, the houses were identical, and on the other half of trials they were different. The faces were manipulated in the same way, with either the same, or different identities being presented. Crucially, the emotional expression of the faces was also manipulated; the two faces either both had fearful expressions, or both had happy expressions. Participants were instructed to make same/different judgements on either the faces (based on identity) or the houses after 250ms stimulus presentation. The expression of the faces was entirely irrelevant, as participants were not asked to perform any emotion-related task. The fMRI data showed that faces produced a marked increase in activation of the fusiform gyri when they were at the attended locations compared to unattended locations. However, critically, amygdala activation towards fearful faces was not modulated by spatial attention. This suggests that the subcortical processing of fearful faces does not demand attentional resources.

Anderson, Christoff, Panitz, De Rosa, and Gabrieli (2003) also investigated amygdala activation to unattended emotional (fear, disgust and neutral) faces using fMRI. Instead of a spatial location manipulation, Anderson et al., (2003) superimposed a face and a scene by creating semi-transparent images and overlaying them. Object-based attention was manipulated by asking participants to make a gender judgement (attend to the faces), or a location judgement (attend to the place). On each trial, the face and scene were coloured, one was tinted red, the other green. During the condition in which faces were attended, fear faces evoked significantly greater amygdala activation than the neutral and disgust expressions. When faces were unattended, amygdala activation did not significantly change to fear faces, but did significantly increase to disgust faces. These findings show that without attention, the amygdala response to fear is maintained, and in addition, the amygdala loses specificity to fearful faces and seems to respond more generally to any potential threat-relevant stimulus (e.g. disgust).

Pessoa, McKenna, Gutierrez and Ungerlieder (2002) also explored the extent to which emotional faces can be processed without attention. A fearful, happy or neutral face was presented at fixation for 200ms, whilst one bar was presented in the left, and another in the right periphery (at 5.7° eccentricity). On attend trials, participants were asked to judge the gender of the face. On unattended trials, participants had to discriminate the orientation of the two peripheral bars, where they were either similar (both horizontal or vertical), or dissimilar (one horizontal, one vertical). Using fMRI, Pessoa et al., (2002) found that amygdala activation was eliminated when participants were not attending to the emotional faces. This is in direct opposition to the studies presented above (Vuilleumier et al., 2001; Anderson et al., 2003). How can Pessoa et al.'s findings be reconciled with the evidence above? Pessoa et al.'s task was harder than Vuilleumier et al., and Anderson et al.'s tasks (accuracy: 64% compared to 86% and 87%, respectively). Arguably, Vuilleumier et al.'s, and Anderson et al.'s results were caused by the distractor task not exhausting perceptual load demands (Lavie, 2005), therefore allowing attention to 'spill' over on to the emotional faces (Pessoa et al., 2004).

Perceptual load is related to the number of different-identity items in the scene that are required to be perceived (Lavie, 2005). The load theory of attention suggests that perceptual processing is automatic, but it is limited by perceptual capacity (Lavie, 1995). Under conditions of low perceptual load (e.g. when the target task is perceptually undemanding), spare capacity will spill over to distractors. However, under conditions of high perceptual load, there are no spare resources with which to process distractors, and therefore they go unprocessed. Empirical support for this theory has been found with a number of different paradigms and stimuli; as perceptual load increases, the extent to which distractors are also processed (and therefore interfere with current goals) is reduced (see Lavie, 2005 for a review). Therefore, the processing of 'unattended' stimuli is not necessarily all-or-none. By diverting attention somewhat, it is still possible that distractor items are processed to some degree. To eliminate all processing, the distractor task must be sufficiently demanding on attentional resources.

1.3.3. Summary. Results from visual search using emotional faces suggest that threat-related faces are not entirely processed without attention; emotional targets have not been found to 'pop-out'. However, threat-related faces are processed more efficiently than neutral or positive faces (Ohman, Lundqvist & Esteves, 2001; Hortsmann, 2007). Recent studies investigating visual search with both phototographic and schematic stimuli have suggested that effects are due to low-level visual characteristics (Calvo & Marrero, 2009; Coelho et al., 2010).

Sustained neural activation to unattended fear and disgust faces in emotion processing regions suggest that threat-related faces can be processed without complete attention (Vuilleumier et al., 2001; Anderson et al., 2003). However, when attention is fully distracted, threat-related faces are no longer processed (Pessoa et al., 2004). This suggests that although emotional face processing may depend on fewer resources than neutral face processing, it is not capacity free. Overall, research from both behavioural and neuroimaging paradigms, suggests that emotional information can be detected more efficiently, and can be processed with less attention than neutral information. However, it is unclear whether these results are due to the extracted emotional meaning of the faces, or low-level visual properties.

1.4. Can emotional faces be processed unconsciously?

Unconscious processing is defined as the stimuli not being perceived, despite being physically presented on the retina in a non-degraded state. Various methods have been used to manipulate conscious awareness of visual stimuli, including backward masking, crowding, bistable figures, motion-induced blindness, inattentional/change blindness, attentional blink, and binocular rivalry (for a review see Kim & Blake, 2005). These methods vary in the extent to which they successfully render a stimulus outside of awareness, and the generality of stimuli they are able to render outside of awareness. In emotion processing research, backward masking procedures, and binocular rivalry have been exploited due to their effective suppression of emotional stimuli.

1.4.1. Evidence from backward masking. Backward masking consists of presenting a brief ‘target’ stimulus followed by a ‘mask’. Observers characteristically report never having seen the target, as long as its presentation is sufficiently brief (<40ms; Esteves & Ohman, 1993). Investigators have used backward masking and measured the effects of the (unreported) stimulus on physiological responses, neurological events, or behavioural tasks.

Early research using emotional backward masking investigated skin conductance responses (SCRs) to masked threatening stimuli (Esteves, Dimberg & Ohman, 1994). SCRs are a measure of physiological arousal and are often used to index arousal-based emotion processing (Lang, Greenwald, Bradley & Hamm, 1993; Bauer, 1998). Autonomic arousal causes increased moisture levels of the skin and the resultant changes in the electrical conductance of the skin (Wallin, 1981) can be measured using electrodes. Esteves et al. (1994) aversively conditioned SCRs to nonmasked presentations of angry or happy faces. During the conditioning phase, one emotional face was repeatedly paired with aversive electric shocks, which resulted in elevated SCRs to that emotional face. The test trials consisted of masked emotional faces. In these test trials, conditioned SCRs were maintained when they were paired with the angry face, but were abolished when paired with the happy face. Therefore elevated SCRs to conditioned stimuli are maintained when those stimuli are fear relevant (e.g. angry faces), but are not maintained if they are fear irrelevant (happy faces). This suggests that the conditioned threat had been analysed outside of awareness.[3]

Morris, Ohman and Dolan (1998) studied the neural mechanisms underlying the maintenance of physiological arousal to aversively conditioned masked stimuli. They measured neural activity using positron emission tomography (PET) to backward masked angry faces, one of which had been previously classically conditioned to an aversive burst of white noise. Replicating Esteves et al.'s findings, elevated SCRs were found to the presentation of the conditioned angry expression, both when it was unmasked and masked. Additionally, PET results showed significant amygdala activation in response to the masked conditioned angry face (Morris, Ohman & Dolan, 1998).

In the same year, a different group also investigated neurological activation in response to backward masked emotional faces (Whalen, Rauch, Etcoff et al., 1998). Whalen et al. (1998) presented happy or fearful target faces for 33 msec, subsequently replacing them with a neutral mask (presented for 167 msec). Out of the 10 participants tested, eight subjectively reported not having seen an emotional face on any of the trials, and were therefore included in the analysis. Amygdala activation was increased in response to masked fearful faces compared to masked happy faces. Other brain regions that were active with unmasked emotional faces, such as the fusiform gyrus, were not found to be active with masked versions of the same expressions.

The majority of studies investigating unconscious emotional face processing using a backward masking paradigm paired with neuroimaging techniques have focussed on fearful faces (e.g. Whalen et al., 1998; Liddell, Brown, Kemp, et al., 2005; Williams, Liddell, Rathjen et al., 2004; Williams, Das, Liddell, et al., 2006; although see Critchely, Mathias & Dolan, 2002, for further evidence that conditioned angry faces elicit amygdala activation

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[3] The same pattern of results with SCRs has been found with flowers as fear irrelevant, and snakes as fear relevant stimuli (Ohman & Soares, 1993).

when presented unconsciously, and Killgore & Yurgelun-Todd, 2004, for evidence that masked happy faces also do).

In an attempt to discover which visual characteristics of an unconsciously presented fearful face are responsible for the sustained amygdala activation towards them, Whalen, Kagan, Cook, et al. (2004) conducted a study using only the eye region of emotional faces. They removed all information from the fearful and happy face stimuli, except for the visible part of the eye-ball (eye whites). These stimuli were then presented for 17ms, before being masked with a whole neutral face. In a control condition, the luminance contrast of the eye region for each expression was reversed, so that the pupil was white, and the scleral field was black. The results showed greater amygdala activation in response to masked fearful compared to masked happy eye whites; there was no difference between the expressions in the control condition. These results suggest that the amygdala activation associated with unconscious processing of fearful faces may be due to the large size of the white scleral field in this emotion. The lack of an emotion effect in amygdala activation for the negative luminance eye region indicates that this is not simply a contrast effect, or due to the outline of the eye.

Some researchers have paired the backward masking procedure with tasks that probe attention, therefore measuring potential behavioural biases towards unconsciously presented threat (Mogg & Bradley, 1999; Carlson & Reinke, 2008; Carlson, Reinke & Habib, 2009). Mogg & Bradley (1999) used a masked version of the visual-probe task to investigate attentional biases to emotion outside of awareness. In this paradigm, a briefly presented (e.g. 14 ms) emotional face was presented outside of awareness by immediately masking it with a jumbled face. RTs were measured to probes presented in the same location as the masked emotional face, compared to a masked neutral face on the other side of fixation. It was found that probes replacing masked threat faces were responded to significantly faster than those replacing masked neutral or masked happy faces.

Carlson and Reinke (2008) also used a masked visual-probe technique, and found that RTs were significantly faster when the probe was preceded by a masked fearful face compared to when it was preceded by a masked neutral, or happy face. In this experiment, a phase-scrambled face was used as a control. Phase scrambling means the resultant image has the same amplitude spectrum as the original image, but without recognisable structure and clear contours (Thomson, Foster, & Summers, 2000). Although recent research has shown that observers are biased in orienting towards phase-scrambled images containing faces rather than cars (Honey, Kirchner, & VanRullen, 2008), the effect of phase-scrambling on emotional face processing is unknown. In Carlson and Reinke's study, participants responded to probes following masked fearful faces faster than when they followed masked phase-scrambled faces.

Recently it has been suggested that there are individual differences in the extent to which backward masking renders the target face invisible (Pessoa, Japee, & Ungerlieder, 2005). As a result, investigation has turned to the criterion that is set to evaluate visual awareness (Pessoa, et al., 2005). Subjective awareness is measured by asking participants whether they saw the target face; if their response is negative, it is taken to indicate that they were unaware of the target. This subjective criterion assesses the conscious experience of the participant, however, it may be influenced by differences in response criteria. On the other hand, objective awareness is measured by an alternative forced choice paradigm, where at the end of each trial participants are required to indicate the expression of the target. With the objective criteria, signal detection theory (SDT) can be used to provide a measure of sensitivity that is independent of possible response biases (MacMillan & Creelman, 1991). Whilst measuring awareness using a forced choice design and analysed with SDT, Pessoa et al. (2005) found large individual differences in the extent to which the target emotion of the masked face could be reliably detected. Using the objective criterion, they found that approximately 60% of participants could reliably detect a target emotion when it was presented for 33ms before it was masked. This finding is particularly important because targets have been presented for 33msec in backward masking experiments that have not used awareness checks (e.g. Carlson & Reinke, 2008), as this duration has been linked with unconscious perception in the past (Esteves & Ohman, 1993).

The importance of an objective awareness criterion has been demonstrated by Pessoa, Japee, Sturman and Ungerlieder (2006). They measured amygdala activation using fMRI to masked emotional faces. Those people that were objectively unaware (measured by forced choice and analysed using SDT) did not show significant amygdala activation to masked fearful faces. However, those that were subjectively unaware (reported not having seen a fearful face), but performed above chance on the objective awareness check, did show significant amygdala activation to masked fearful faces. This suggests that when participants are subjectively unaware of the target expression, amygdala activation to masked fearful faces depends on objective awareness.

One study that used backward masking to present stimuli unconsciously used a stringent, objective awareness check, and thus provides evidence that not all emotion effects are eliminated when such checks are used (Whalen et al., 2004; this study was described in detail above). Additional studies (e.g. Williams et al., 2006; Liddell et al., 2005) have presented masked stimuli for a duration lower than has previously been found to support unconscious presentation measured by an objective awareness check (Williams et al., 2004). However, as individual differences have been found in the detection of masked emotion (Pessoa et al., 2005), the only way to ascertain whether the masked expression does not reach awareness for each participant tested is to examine emotion classification using an objective awareness check after each experimental trial.

1.4.2. Evidence from observations with brain-damaged patients. Neuropsychological observations with brain-damaged patients have also provided evidence suggesting that emotional stimuli are processed outside of awareness (de Gelder, Vroomen & Pourtois, 2001). The primary visual cortex is organised according to a retinotopic map of the visual field, lesions to this area cause blindness to corresponding parts of the visual field (Driver & Vuilleumier, 2001). However, under some conditions, stimuli presented to the blind field can be accurately identified or located, despite not being consciously perceived (Barbur, et al., 1980); this has been termed ‘blindsight’. The phenomenon of blindsight may be mediated by subcortical processing via the visual thalamus and superior colliculus (Barbur, Ruddock, & Waterfield, 1980), and has been found to occur with simple geometric patterns (Weiskrantz, 1996).

Recent experiments have shown that a patient with occipital lobe damage can correctly discriminate (by ‘guessing’) different emotional expressions presented in his blind field (de Gelder, Vroomen, & Pourtois, 2001)[4]. The subcortical amygdala pathway has been implicated in the residual processing of emotional information in blindsight (Morris, DeGelder, Weiskrantz & Dolan, 2001). In this experiment, Morris et al., (2001) found that faces presented to a patient’s blind field do not evoke the striate, fusiform, or dorsolateral prefrontal responses that were found when they were presented to the undamaged hemifield. Nevertheless, there was increased amygdala activation in response to fearful compared to happy expressions when the faces were presented to the patient’s blind field. Similar amygdala activation was also recorded to perceived fearful faces presented in the undamaged hemifield. This pattern of activation shows considerable resemblance to findings with normal individuals to backward masked emotional faces (e.g. Whalen et al., 1998).

[4] Successful fear conditioning to simple visual stimuli (schematic objects) has also been found in an individual with complete cortical blindness (Hamm, Weike, Schupp et al., 2003).

Taking advantage of the finding that humans mimic others' facial expressions (Hatfield, Cacioppo & Rapson, 1994), Tamietto, Castelli, Vighetti et al. (2009) presented emotional faces to the blind field of patients with unilateral occipital lobe damage whilst measuring their facial reactions. Facial movements were measured using electromyography (EMG), to record muscle activity. It was found that patients showed significant patterns of synchronised facial movement even when faces were presented in the blind field. Additionally, these facial EMG responses were faster when the stimuli were presented in the blind field compared to the undamaged hemifield. This suggests that unconsciously processed emotional faces can cause physical variations in muscle activity associated with emotional perception.

1.4.3. Evidence from binocular rivalry. First empirically explored in 1838 (Wheatstone), binocular rivalry is a perceptual phenomenon in which different stimuli are presented to each eye; and conscious perception switches between the stimuli, despite unchanging retinal input (see Blake, 1989). Early theories of binocular rivalry proposed that competition for dominance occurs between the two eyes, and is resolved by inhibitory connections in monocular processing channels early in the visual system where eye of origin information is available (Blake, 1989). Low-level characteristics of the stimuli, such as contrast, motion and colour impact significantly on dominance proportions in binocular rivalry (Alais & Blake, 2005). However, evidence now suggests that both images are processed beyond the site of binocular interactions before dominance is resolved (Kovacs, Papathomas, Yang & Feher, 1996; Logothetis, Leopold & Sheinberg, 1996). Some higher-level characteristics of the stimuli can influence dominance in binocular rivalry, including coherent organisation (Yu & Blake, 1992) and spatial context (Graf & Adams, 2008). Such effects may well be mediated via feedback to early visual areas (e.g. V1; Watson, Pearson & Clifford, 2004), suggesting that competition between representations may be occurring at early visual areas. Binocular rivalry has been employed in different ways to explore unconscious emotion processing; it has been has been coupled with neuroimaging techniques to measure brain activity to suppressed emotional stimuli, and used as a behavioural tool.

Binocular rivalry has been used and modified in various ways: 1) Classic binocular rivalry paradigm, When a different image is presented to each eye, instead of a fusion of the two images, observers perceive alternations between them. The time that each stimulus is dominant is recorded, and a dominance proportion is calculated. Increased salience of one image due to low-level properties (e.g. luminance, contrast) is associated with higher dominance proportions (Mamassian & Goutcher, 2005); 2) Initial percept paradigm, where one stimulus is presented to one eye and a different stimulus is presented to the other. The observer indicates the stimulus initially dominant and the trial ends. An initial dominance proportion can then be calculated from the number of trials that each stimulus was perceived first. Previous research (Mamassian & Goutcher, 2005) has found that increased salience of one image due to low-level properties is also associated with higher probability of initial dominance. Initial dominance measures allow the study of unconscious processing without contamination from subsequent evaluation of the stimuli during dominance periods; 3) Continuous flash suppression (CFS), CFS is a variant of binocular rivalry used to render stimuli invisible for extended periods of time (Tsuchiya & Koch, 2005). A stimulus is presented to one eye, and in the other, random, highly salient, dynamic noise is continuously flashed at approximately 10 Hz (Tsuchiya & Koch, 2005). The random dynamic noise renders the stimulus invisible for long periods of time, typically a couple of minutes (Tsuchiya, Koch, Gilroy & Blake, 2006). It also provides stronger suppression than conventional rivalry (Tsuchiya et al., 2006), making it an optimal technique to use whilst investigating unconscious processing mechanisms.

Neurological Evidence. Two of the first experiments that combined the binocular rivalry paradigm with measures of brain activation were conducted in 2004. Williams et al. presented fearful, happy or neutral faces to one eye whilst presenting a house to the other eye for 500ms. They found that differential activation to faces (compared to houses) in the fusiform gyrus was dependent on seeing the face. However, activation in the amygdala was larger for fearful than neutral faces, and this was true whether or not the faces were suppressed in rivalry. Additionally, when happy faces were presented, there was no difference in amygdala activation (compared to neutral faces) when they were consciously viewed, but there was an increase in amygdala activation to happy faces when they were suppressed. Pasley et al. presented either a fearful face, or a chair in one eye, and a house in the other. In a paradigm similar to CFS, they ramped in the contrast of the face/chair whilst ‘jittering’ the position of the house. This caused the house to be dominant for the length of the trial (approximately 1.5 seconds). They found increased activation in the amygdala in response to the suppressed fearful faces compared to the suppressed chairs.

Jiang and He (2006) used fMRI to measure activation in response to fearful and neutral faces presented consciously and unconsciously using CFS. They constructed an objective awareness check; participants were at chance in this control task. Consistent with backward masking studies (Morris et al., 1998; Whalen et al., 1998), Jiang and He found equally strong amygdala activation in response to fearful faces irrespective of whether or not they were consciously perceived. In contrast, amygdala activation in response to neutral expressions was reduced when they were not consciously perceived. The main conclusion from these neurological studies is that amygdala activation in response to fearful faces occurs independently of visual awareness (Williams et al., 2004; Pasley et al., 2004, Jiang & He, 2006). In contrast, activation of high-level visual processing regions, such as the fusiform gyrus, are modulated by visual awareness, and therefore reflect conscious perception (Williams et al., 2004).

Behavioural Evidence. Using the classic binocular rivalry paradigm, several studies have reported higher dominance proportions for emotional compared to neutral faces (Alpers & Gerdes, 2007; Bannerman, Milders, De Gelder & Sahraie, 2008; Yoon, Hong, Joormann & Kang, 2009)[5]. Alpers and Gerdes investigated the dominance of photographic emotional faces in rivalry (Alpers & Gerdes, 2007, Experiment 1). Happy and angry faces were found to dominate perception significantly more than neutral expressions. However, several methodological issues with this experiment call the interpretation of the results in terms of unconscious biases towards emotional information into question. Firstly, the stimuli were large (8.6° x 9.5° of visual angle; where optimal presentation size for binocular rivalry is under 1°; Blake, O'Shea & Mueller, 1992). Having large stimuli increases the probability of piecemeal rivalry (not seeing one image exclusively; Blake, O'Shea & Mueller, 1992). Piecemeal rivalry may have caused biased responses in Alpers and Gerdes (2007) experiment, as participants may have responded 'emotional' when one emotional feature was dominant, but the rest of the dominant features were neutral. Secondly, it is possible that the faces were not rivalling at all. This is because binocular rivalry only occurs between dissimilar images; fusion of the two eyes' input is always preferred over rivalry when possible (Blake, 1989). As the only difference between the faces presented to each eye was the emotional expression of the face, there was unlikely to be enough dissimilarity between the faces to cause rivalry. Any rivalry that did occur is likely to have been between local

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[5] A limited number of studies have also looked at the predominance of emotional pictures (Alpers & Pauli, 2006), and aversively conditioned gratings in binocular rivalry (Alpers, Ruhleder, Walz, Muhlberger & Pauli, 2005). Emotional scenes were found to dominate perception more than neutral scenes (Alpers & Pauli, 2006). However, as low-level stimulus characteristics were not controlled in this experiment, it is impossible to tell whether the results are due to the emotional content of the pictures or systematic differences in these low-level properties between emotional and neutral images. In a subsequent study, Alpers and colleagues (2005) controlled for the low-level characteristics of the stimuli by aversively conditioning participants to a vertical or horizontal grating. Results showed a tendency for the aversively conditioned grating to dominate perception, although the findings were not conclusive (results were marginally significant).

regions of the face, where information differs across emotion (e.g. mouth; eyes). Therefore the results may be the outcome of participants perceiving a composite of the emotional and neutral features, with this composite appearing emotional. And lastly, there was no control for the low-level visual characteristics of the stimuli, suggesting that results could be due to the emotional faces having more salient low-level properties than neutral faces.

In a second experiment, Alpers and Gerdes (2007; Experiment 2) attempted to address the issue of confounding low-level stimulus properties by presenting schematic faces. Both angry and happy schematic faces were found to dominate over neutral schematic faces. However, this experiment did not address the issues regarding piecemeal rivalry or fusion, which are arguably more likely to be responsible for effects when schematic faces are used.

Another recent publication has explored the extent to which emotional faces predominate over neutral faces in binocular rivalry. Bannerman et al. (2008) aimed to study the effects of emotion on binocular rivalry by instructing observers to report the dominance of centrally presented oblique gratings, whilst emotional faces were presented in the background of the display. Results showed that a grating presented to the same eye as the fearful and happy faces tended to dominate over the grating presented to the same eye as the neutral face. While the authors interpreted this as evidence of a significant influence of the emotional background on perception, again, methodological issues raise questions about the mechanisms that are responsible for this effect. These issues are largely the same as directed to Alpers and Gerdes (2007). Firstly, the face stimuli were large (9.8° x 13.2° of visual angle) which may have led to piecemeal rivalry. Secondly, the only difference between the faces presented to each eye was the emotional content, therefore it is highly probable that all but a few local regions of the face were fused. And lastly, there was no control for the low-level characteristics of the stimuli. The impact of these issues is discussed above. To address the second (fusion) and third (confounding low-level characteristics) issues raised here, Bannerman et al. (2008; Experiment 3) presented fear, happy and neutral faces paired with houses, with an upright and an inverted condition. They recorded dominance of the faces over the houses, and then compared the different emotional expressions, both when upright and inverted. A main effect of emotion (fear and happy dominating over neutral) was present when the faces were presented upright, but eliminated when the stimuli were presented upside-down. This suggests that it is not the low-level characteristics of the stimuli driving this effect. As large stimuli were used it is improbable that exclusive rivalry was obtained, although this is less of an issue as a non-face, neutral object (a house) was presented to the other eye.

As both stimuli alternate in awareness in a classic rivalry trial, is it impossible to tell if these emotion effects are due to unconscious processing of the stimuli, or contamination from subsequent evaluation of the stimuli during dominance periods. One way to control for this is to use the initial percept paradigm, where only the initial percept is recorded for many short trials. Gray, Adams, and Garner (2009) recorded initial dominance of emotional faces that were equalised for some low-level visual characteristics (matched for mean luminance and root mean square (RMS) contrast), with an additional inverted face condition to ascertain if results were due to visual properties, rather than emotional content. Faces (fear, happy, angry and neutral) were oriented ±30° from 0° in the upright condition, and ±30° from 180° in the inverted condition. Tilting the faces induced clear rivalry (eliminating fusion) by disrupting the featural alignment across the two faces. Observers responded as soon as one of the faces became dominant. To eliminate potential response biases, participants indicated the orientation of this initial dominant face (left vs. right tilt) via a key press.

Gray et al. (2009) found that happy and fearful expressions were initially dominant more frequently than angry and neutral expressions. It is unclear whether the comparative dominance proportion between the expressions was driven by low-level characteristics of the stimuli, or emotion processing, as the main effect of emotional expression was reduced when the faces were inverted, but the reduction was not statistically significant. This may suggest that emotion continued to modulate selection, even when the faces were presented upside-down. This may reflect residual effects of emotion processing (even fully inverted faces do retain some emotional energy; Prkachin, 2003) particularly as the images were rotated ±150° (as opposed to a full 180° inversion).

When random, highly salient, dynamic noise is presented to one eye, and another stimulus (e.g. a face) is presented to the other eye, the time it takes for the stimulus to overcome suppression is indicative of its salience (Jiang, Costello & He, 2007; Tsuchiya & Koch, 2004). Similarly to initial dominance paradigms, CFS also has the advantage of being uncontaminated by prior evaluation of the conscious stimulus that might influence overall dominance in the classic rivalry paradigm.

In a recent study, CFS was used to investigate emotional face processing outside of awareness by analysing the latencies for different expressions to overcome CFS suppression. Yang, Zald and Blake (2007) presented fearful, happy or neutral faces to one eye, and random dynamic noise to the other. To control for low-level stimulus characteristics, inverted faces were also presented. In the first experiment, participants were instructed to respond when they had detected a face, and on 30% of trials (‘catch trials’) no face was presented. The second experiment used an alternative forced-choice procedure, where participants were required to respond to the location of the face (out of 4 possible locations). In both experiments, there was an effect of emotion, whereby fearful expressions overcame suppression faster than happy or neutral expressions. However, the same pattern of results occurred in both the upright and inverted tasks. In addition to the emotion effect, RTs to upright faces were significantly quicker than RTs to inverted faces. This suggests an overall cost of inversion, and suggests that low-level stimulus properties of the fearful face (rather the extraction of emotional meaning) could have caused it to emerge from suppression faster than neutral and happy expressions.

Additionally, CFS has proved useful in measuring afterimages without awareness (e.g. Adams, Gray, Garner & Graf, 2010). Adams et al., found that adaptation to emotional faces (i.e. a perceptual shift away from a previously presented emotion) does still occur when the adapting faces are presented unconsciously under CFS suppression. Participants classified the emotion of a test face, after being presented with an adapting face that was either suppressed using CFS, or clearly visible. Adaptation under suppression was found for all three emotions tested: fear, happy, and angry. Furthermore, an objective awareness check indicated that when the face was not reported as seen, participants were at chance at classifying emotion; indicating that the results were not due to objective awareness of the emotion. This provides further evidence that the emotional expression of a face can be processed unconsciously, to the extent that it can bias subsequent perception of emotion. Indeed, recent evidence has suggested that this is not the case for identity adaptation (Moradi, Koch, & Shimojo, 2005), or race and gender adaptation (Amihai, Deouell & Bentin, 2010).

1.4.4. Summary. Various experimental paradigms have been used to study the extent to which emotional information can be processed without awareness, including backward masking, evidence from patients, and binocular rivalry. One important issue that affects most of these methods is the criterion of awareness (subjective vs. objective; Pessoa et al., 2004). Backward masking has been used considerably more than other paradigms in this area of research. However, due to issues with awareness that blight backward masking research (Pessoa et al., 2004), converging evidence from different techniques is required to validate these results.

Binocular rivalry has only recently been applied to the area of emotion processing. Neurological activation in response to stimuli that are presented unconsciously using binocular rivalry/CFS has suggested that fear expression processing can occur outside of awareness (Pasely et al., 2004; Williams et al., 2004; Jiang & He, 2006). Neurological research from both backward masking and rivalry paradigms can be criticised on their lack of control for the low-level characteristics of the stimuli.

The experiments that have used binocular rivalry as a behavioural tool to investigate the relative predominance of emotional over neutral faces have shown that emotional faces (both threatening and positive) are prioritised; however, they suffer from major experimental flaws (Alpers & Gerdes, 2007; Bannerman et al., 2008). Using the initial dominance paradigm with well-controlled stimuli, it has been found that happy and fear faces dominate over angry and neutral faces, although the extent to which this effect is due to high- or low-level characteristics is unclear (Gray et al., 2009). Presenting a face in CFS and measuring the time it takes to overcome suppression ensures that results are due exclusively to the unconscious processing of that stimulus. However, only one study has used this method to date (Yang et al., 2007), and their results are inconclusive regarding the origin of the effect (the extraction of emotional meaning vs. low-level characteristics).

1.5. Individual differences

Although not key to this thesis, individual differences in anxiety may significantly impact on emotion processing (Mogg & Bradley, 1998). Symptoms of anxiety typically include extensive rumination and worry, intrusive negative thoughts, apprehension towards certain situations and a general enhanced perception of threat when evaluating stimuli (Mathews & MacLeod, 2005). Individual differences in anxiety can be seen as the predisposition to respond anxiously to a situation (or trait anxiety; Spielberger, Grosuch, Luchene, Vagg & Jacobs, 1983). Anxiety disorders are at the extreme end of the individual difference scale, and develop when the intensity and duration of anxious feelings are disproportionate to the risk associated with the current situation or stimulus (Bishop, 2007).

Information processing biases towards threat in anxious individuals are central to cognitive theories of anxiety (Mogg & Bradley, 1998; Williams, Watts, MacLeod & Mathews, 1997; Beck & Clark, 1997). These processing biases have been found to primarily affect the interpretation of ambiguous information (Mathews & MacLeod, 1994; Richards, et al., 2002), and the deployment of attention (Mogg & Bradley, 1998; Eysenck, 1992). Biases in early stages of stimulus processing are also fundamental to evolutionary considerations of anxiety (Ohman & Mineka, 2001). More recent neurocognitive models of anxiety propose that the interpretative and attentional biases result from dysfunctional subcortical-prefrontal circuitry (Bishop, 2007; Bishop, Duncan, Brett & Lawrence, 2004). Both hyper-responsivity of the amygdaloid complex, and reduced recruitment of prefrontal-cortical control leads to the maladaptive threat-related processing biases found in anxiety (Bishop, 2007; Bishop, Duncan, Brett & Lawrence, 2004).

Indeed, anxiety has been found to modulate attention on the emotional dot-probe task (Bradley, Mogg, Falla, & Hamilton, 1998, Mogg & Bradley, 1999b; Bradley, Mogg, White, Groom & de Bono; 1999; Bradley, Mogg & Millar, 2000; Fox, 2002), the disengagement component of attention in the exogenous cueing task (Fox et al., 2001; Fox, Russo & Dutton, 2002; Georgiou et al., 2005), performance in visual search tasks (Byrne & Eysenck, 1995; Gilboa-Schechtman, Foa & Amir, 1999; Juth, Lundqvist, Karlsson & Ohman, 2005), and modulate neurological activation in the amygdala outside the focus of attention (Bishop, Duncan & Lawrence, 2004; although when under high perceptual load, this modulation disappears, Bishop, Jenkins & Lawrence, 2007). In unconscious viewing, anxiety has been found to modulate amygdala activation in response to backward masked fearful faces (Etkin et al., 2004), behavioural responses to masked visual-probes (Mogg & Bradley, 1999; Fox, 2002), and in binocular rivalry paradigms, anxiety has been found to modulate the selection of the initially dominant facial expression (Gray et al., 2009). Individual differences in anxiety are therefore an important variable to consider when investigating emotional face processing.

1.6. Summary and conclusions

Overall, there is evidence to suggest that emotional information may be preferentially processed over neutral information. There is evidence to suggest that the neural architecture can support such prioritisation via a fast, coarse subcortical processing pathway (LeDoux, 2000). It has been shown that attention is preferentially allocated to emotional stimuli (e.g. Armony & Dolan, 2002; Pourtois et al., 2004, Koster et al., 2004), largely independently of attentional resources (e.g. Vuilleumier et al., 2001), largely capacity free (Hortsmann, 2007), can be processed independently of conscious awareness (e.g. Williams et al., 2004; Williams et al., 2006; Jiang & He, 2006), and may facilitate perception (Phelps et al., 2006). Individual differences in anxiety may also contribute to the size of the emotion-related effects (e.g. Bradley et al., 1998; Byrne & Eysenck, 1995).

Fitting with neurological theories of prioritisation of emotion (Vuilleumier et al., 2003), there is some suggestion that these effects may be due to the LSF content of the faces (Holmes et al., 2005; Vuilleumier et al., 2003). Additionally, the eye region of a fearful face may be particularly important in its prioritisation, and unconscious processing (Whalen et al., 2004; Feng et al., 2009).

Very little of the research investigating attentional prioritisation of emotional faces has adequately controlled for low-level visual differences between the stimuli. As discussed previously, it is impossible to indicate that results are exclusively due to the extraction of emotional meaning, if low-level characteristics are not adequately controlled for. By applying rigorous control to these high-level stimuli, it can be found whether results are indeed caused by emotion processing. This is important, as if the apparent emotion effects do not depend on emotional recognition, this would suggest that our physical facial expressions have evolved to be salient to low-level visual processes. This means that any stimulus that excites these early visual processes will be prioritised, irrespective of emotional meaning. This can be contrasted with the notion that we have evolved to preferentially process stimuli with emotional meaning, as has been previously suggested (Ohman & Mineka, 2001). Recent studies investigating visual search with both photographic and schematic stimuli have suggested that emotion effects (i.e. prioritisation of threat) are due to low-level visual characteristics (Calvo & Marrero, 2009; Coelho et al., 2010). It is yet to be seen if the same can be said of emotional research using other experimental paradigms.

Notwithstanding their substantial contribution to theories of emotion processing, some limitations (described in detail above) have been associated with the visual-probe, exogenous cueing, visual search, and backward masking paradigms. The present work attempts to overcome these limitations and investigate unconscious processing of emotional faces using a modified binocular rivalry paradigm. The binocular rivalry technique has only been applied to emotion processing research relatively recently, and investigations using it have been significantly flawed (e.g. Alpers & Pauli, 2007; Bannerman et al., 2008; Yang et al., 2007).

Chapter 2

Emotion categorisation of normal and manipulated faces

2.1. Introduction

To accurately dissociate between low-level (bottom-up) and high-level (top-down) effects of a stimulus, it is critical to control one (i.e. keep it constant) whilst varying (i.e. manipulating) the other. Low-level stimulus attributes, such as luminance, contrast and spatial frequency are processed at an early stage in the visual system. High-level stimulus attributes on the other hand, such as meaning, require evaluation of the stimulus. In some circumstances it is impossible to vary high-level attributes whilst holding low-level attributes constant: for example, sometimes simply by varying the high-level content of a stimulus, changes also occur in the low-level characteristics. This problem occurs within emotional face processing research, as different emotional faces have different low-level characteristics. How is it possible, then, to control for low-level characteristics, and still be able to tell with confidence that effects are caused by the extraction of emotional content from the face? A control set of stimuli is needed. These stimuli need to match the original images on one of the attributes (either high-level, or low-level), whilst disrupting the other. If the same effects are found in both the original, and control stimuli, they are likely to be caused by the attribute that is held constant across the two sets of stimuli. For example, as different emotional faces vary on both their high-level and low-level properties, control stimuli can be employed which have the same low-level characteristics as the original faces, but are manipulated so their high-level attributes are disrupted. If similar effects are found in both the original and control stimuli, they are likely to be due to low-level visual characteristics, as they are held constant across the two sets of stimuli. On the other hand, if a different pattern of effects is found between the original and control stimuli, the effects found in the original stimuli are likely to be due to their high-level attributes. In face identity processing research, inverted faces have been used as a control, as they contain the same low-level characteristics as an upright face, but identity recognition is severely impaired (i.e. they still vary on their high-level content; Valentine, 1991).

Investigations into emotional face processing have often overlooked the issue of controlling for low-level visual characteristics (e.g. colour, luminance, contrast, spatial frequency) between emotional faces. In a well-cited, early study, using visual search to investigate the prioritisation of emotional information, Hansen and Hansen (1988) reported finding a 'pop-out' effect for angry faces. However, this effect was later found to be due to a black mark on the angry face that made it very easy to detect (Purcell, Stewart & Skov, 1996). Some studies have tried to limit differences in low-level visual properties by using schematic face stimuli (Fox et al., 2000; Ohman et al., 2001; Horstman, 2007). However, despite partially controlling for low-level characteristics of the stimuli, schematic faces have reduced ecological validity compared with photographic faces (Horstmann & Bauland, 2006).

Emotional face processing research has also borrowed the control used in face identity research, by using inverted emotional faces as a control (e.g. Yang et al., 2007; Gray et al., 2009; Bannerman et al., 2008, Phelps et al., 2006). However, there has been inconsistency in whether high-level or low-level properties are implicated by the results: some studies have found that effects with upright faces disappear when the faces are inverted (suggesting that the effects found with the upright faces are caused by extraction of emotional meaning from the faces and not low-level factors; e.g. Bannerman et al., 2008; Phelps et al., 2006), whereas other studies have found the same effects in both upright and inverted emotional faces, suggesting the results are caused by low-level characteristics (e.g. Yang et al., 2007; Gray et al., 2009). In the latter case, it is possible that no difference is found because inversion may not be an adequate control for emotional expression (i.e. some emotion processing may still occur after spatial inversion). Indeed, it is unclear of the extent to which face inversion disrupts emotion processing, and therefore adequately controls for emotion.

2.1.1. The effect of inversion

The Face Inversion Effect (FIE) is defined as a larger decrease in performance for faces than for other objects when presented upside-down (Yin, 1969). There is consensus that the FIE for identity is caused by disruption of configural processing, which is defined as the processing of relations between features (e.g. Maurer, Le Grand & Mondloch, 2002). Maurer et al. describe three types of configural processing: “1) sensitivity to first-order relations – seeing a stimulus is a face because its features are arranged with two eyes above a nose, which is above a mouth; (2) holistic processing – glueing together the features into a gestalt; and (3) sensitivity to second-order relations – perceiving the distances among features.” (Maurer et al., 2002; p. 255). It has been suggested that inversion of a face interferes with all three types of configural processing for identity recognition (see Maurer et al., for a review). Researchers have employed different tasks to assess the contribution of the three types of configural processing on the FIE. However, definition of each type of configural processing has been problematic, and they have been operationalised in different ways (Tanaka & Sengco, 1998). Therefore, the present chapter will simply describe tasks and results, which type of processing that is considered disrupted by inversion is not important for the purposes of this thesis.

Using ERPs, it has been found that the N170, which is an electrophysiological response that is elicited by faces more than other objects (Bentin, Allison, Puce, Perez & McCarthy, 1996; Eimer, 1998), is delayed in inverted faces (e.g. Bentin et al., 1996).

With the composite face task, different faces are combined, so that the bottom half of one identity is paired and the top half of a different identity (Young, Hellawell, & Hay, 1987). When faces are presented in these composites, RTs to name the identity of either half are considerably longer than RTs to the same face halves when the mismatched components are not aligned (Young et al., 1987). This difference is eliminated when the faces are inverted (Young et al., 1987).

The effect of inversion on identity processing has also been investigated in a behavioural paradigm where the spatial distances between features are manipulated (e.g. by shifting the eyes sideways or up/down by a few pixels). Using stimuli that had been manipulated in this way, Freire, Lee and Symons (2000) found that participants were reasonably good at discriminating identical faces from those differing in configuration (with 81% accuracy on a 2AFC task). However, when the same faces were inverted, accuracy plummeted to near chance levels (55%; Freire et al., 2000).

The FIE research above has specifically investigated the effects of face inversion on *identity* recognition and consistently revealed diminished recognition of inverted compared to upright faces. The impact of face inversion on *emotion* recognition has been investigated far less. Early theories of face processing suggested that emotion and identity are processed separately, where emotion recognition can be considered as the effect of variant features on invariant identity recognition (Bruce & Young, 1986). More recent neuroimaging evidence has also supported the notion that emotion and identity are processed separately (Hoffman & Haxby, 2000; Andrews & Ewbank, 2004; Jiang & He, 2006). There are three bilateral regions in the extrastriate cortex that appear to be particularly important in face processing: the fusiform gyrus (FFA), the inferior occipital gyri (IOG), and the superior temporal sulcus (STS; Kanwisher et al., 1997). There is evidence to suggest that identity processing relies heavily on the FFA (Hoffman & Haxby, 2000; Sergent et al., 1992), whereas emotion processing relies more on the STS (Hoffman & Haxby, 2000; Jiang & He, 2006) and limbic structures, such as the amygdala (LeDoux, 1996).

The dissociation between emotion and identity processing has been supported by recent behavioural research, as adaptation to emotional expression can occur even whilst processed unconsciously (Adams, Gray et al., 2010), whereas adaptation to identity requires conscious processing (Moradi et al., 2005). Distinct processing of facial identity and emotion has also been investigated in patients with brain damage. Prosopagnosia is a selective inability to recognise people from their faces (Bodamer, 1947), and in the acquired form, is a consequence of lesions to occipito-temporal brain regions. Patients who show severe impairments on identity recognition, can still recognise emotional expressions (Tranel, Damasio & Damasio, 1988). However, it has been suggested that the methods used by Tranel et al., to measure emotion processing may have over-estimated the ability of the prosopagnosic patient to recognise facial expression (Calder & Young, 2005).

Calder and Young (2005) argue that fully separable visual pathways for emotion and identity processing are not entirely supported by empirical data. However, they do suggest that significant differences exist between the neural pathways for emotion and identity (Calder & Young, 2005). Therefore disruption of identity processing by inversion does not necessarily mean that inversion will also disrupt emotion processing.

Is emotional face perception disrupted by inversion? There is indication from the face composite task that expression recognition is disrupted by inversion (Calder et al., 2000). When different emotional faces are combined, it takes longer to name the expression of either half when aligned than when they are not aligned (Calder et al., 2000). This effect disappears when the stimuli are inverted (Calder et al., 2000), mirroring the effect found with identity recognition (Young et al., 1987).

Limited research has compared recognition of upright with inverted emotional faces (Prkachin, 2003; McKelvie, 1995). Prkachin (2003) studied the effect of inversion on emotion recognition by measuring sensitivity to six emotional expressions when they were upright, and again when they were inverted. Each face was presented for 100ms, after which participants were given a 6 AFC to select the emotional expression presented. Disruption of emotion processing was measured using signal detection theory (SDT), which provides a measure of sensitivity that is independent of potential response biases (MacMillan & Creelman, 1991). Results showed that inversion did significantly reduce sensitivity to all expressions. However, inversion affected sensitivity of the emotions differently: the recognition of happy, sad and surprised expressions was disrupted significantly less than angry, disgusted and fearful. And for all of the emotional faces, recognition remained well above chance. When viewed for 15 seconds, McKelvie (1995) found increased errors with inverted compared to upright faces when classifying their emotion (for all emotions aside from happy). Although, again, recognition of emotion in inverted faces remained well above chance.

Recall that some studies found that emotion effects were eliminated with inversion, whereas others did not. The evidence that inversion may not fully disrupt emotional face recognition goes some way to explaining the inconsistent effects of inversion in emotion processing research. It also suggests that inversion is not a good control for emotional faces, as although it satisfies one of the criteria (low-level differences remain constant), it does not satisfy the other (that they do not vary on the observer's ability to extract the emotional meaning). Therefore, a different control stimulus must be sought. Luminance polarity negation produces an image similar to a photographic negative (see Figure 2.1.c). With luminance polarity negation, each pixel's deviation in luminance from mean luminance is multiplied by -1. Critically, luminance negation retains the low-level characteristics of a stimulus (Kemp, McManus & Pigott, 1990). In identity processing research, there has been some preliminary evidence to suggest that the effects of luminance negation and inversion are additive (i.e. when combined, they reduce recognition further than either manipulation alone; Kemp, McManus & Pigott, 1990). Therefore, the effect of luminance negation will be explored on emotional face processing.

2.1.2. The effect of luminance polarity negation

Luminance negation disrupts face processing for identity (Kemp, McManus & Pigott, 1990; Nederhouser, Yue, Mangini, & Blederman, 2007; White, 2001; Galper, 1970). Theories pertaining to why negated faces are hard to recognise include the disruption of shape-from-shading information (Liu & Chadhuri, 1998; Kemp, Pike, White & Musselman, 1996), and the production of unusual pigmentation (Bruce & Langton, 1994; Russell, Sinha, Biederman & Nederhouser, 2006). However, these theories cannot account for all empirical data (e.g. Bruce et al., 1991; Kemp et al., 1996). Recent research has suggested that the difficulty in recognising luminance negated faces is caused by the destruction of consistent luminance polarity relationships found in the eye region of a normal face (Gilad et al., 2009). Gilad et al. (2009) found face identification was similar to normal faces when they used a stimulus in which the whole face was presented in negative luminance polarity apart from the eye-region, which was presented in positive luminance polarity. As eye-based information is particularly important for emotion recognition (e.g. Vuilleumier, 2005), negation may significantly disrupt emotion recognition by making it difficult to extract information from the eye region.

When composite identity faces were presented with negative luminance polarity, responses to aligned faces were longer than misaligned faces (Hole, George & Dunsmore, 1999), replicating the effect found with positive faces (Young et al., 1987). More recently, Calder and Jansen (2005) conducted a composite emotional face task. They found that the composite effect (longer RTs to aligned compared to misaligned faces) was disrupted with inversion (consistent with Calder et al., 2000), but not with luminance negated faces (consistent with identity processing, Hole et al., 1999). However, Calder and Jansen (2005) found that responses were generally slowed to negative luminance polarity emotional faces compared to the other face conditions, suggesting that negating a face does make it more difficult to process emotional information.

Kemp et al. (1990) presented 3 faces alongside each other, and asked participants to indicate which of the 2 faces matched the third. The identity of one face was manipulated by shifting the eyes vertically or horizontally. They found that accuracy was reduced for both inverted and negated faces compared to normal faces. There was no difference in accuracy between inverted and negative faces.

Very limited research has investigated the effect of luminance polarity negation on emotional face recognition. In fact, I have located only one study, and it does not support the idea that luminance negation disrupts emotion recognition (White, 2001). In this study, two faces, differing on identity or emotional expression, were presented alongside each other for two seconds and participants were required to indicate whether the faces were the same or different (White, 2001). Participants were either allocated to an 'identity condition', where they responded to the identity of the model (and ignored the expression of the face), or an 'emotion condition', where they responded to the emotion (and ignored the identity). When making same/different judgements, RTs were longer when judging the identity of negative faces compared to positive faces, but not when judging the emotion of negative faces compared to positive faces (White, 2001). However, using the same task difficulty across identity and emotion recognition is likely to result in ceiling effects for emotion recognition, or floor effects for identity recognition due to the differences in difficulty across these tasks. In White's study, a same/different task on emotional expressions presented for two seconds may have made the task too easy, and responses could have been resolved using cognitive/matching strategies.

2.1.3. The combination of spatial inversion and luminance polarity negation

The relationship between orientation and luminance polarity on identity recognition has been explored, with evidence suggesting that the combination of the two manipulations makes faces significantly harder to identify than either manipulation on its own (Kemp et al., 1990; McMullen, Shore & Henderson, 2000; Bruce & Langton, 1993). In their composite face task, Kemp et al. (1990) presented faces that were both inverted and negated. It was found that when the two manipulations were combined, accuracy was reduced even further than each manipulation alone. However, even in this combined condition, accuracy remained well above chance.

McMullen et al. (2000), trained participants to recognise the identities of eight individuals. After training, participants were given 10 seconds to identify a test face. The test face was manipulated in terms of its orientation (upright or inverted), and its luminance polarity (positive or negative). There was a cost of inversion and a cost of negation in recognition accuracy. When the two manipulations were combined, recognition accuracy was reduced even further. The effects were additive; there was no statistically significant interaction between orientation and luminance polarity, suggesting that inversion and negation disrupt separate processes in identity recognition (Kemp et al., 1990; McMullen et al., 2000).

2.1.4. The current experiment

Given the combined effects of inversion and negation on identity recognition (Kemp et al., 1990; McMullen et al., 2000), it is possible that these two manipulations might also independently disrupt emotion processing.

The primary aim of this experiment was to find a good control for low-level characteristics of emotional face stimuli. Therefore, the effects of face orientation and luminance polarity on the categorisation of facial expression were examined. The two manipulations (orientation and polarity) have been examined separately (e.g. Prkachin, 2003; White, 2001), but not together with respect to their effect on recognition of emotional expression. Evidence to date suggests that inversion does impair emotion recognition, but the effect may be limited (Prkachin, 2003; McKelvie, 1995). The effect of negation has been explored on the recognition of identity (Gilad et al., 2009), but only to a limited degree on recognition of emotion (White, 2001).

In the present study, angry, happy and fearful facial expressions were manipulated using spatial inversion and luminance polarity negation. These expressions were chosen from the set of seven basic emotions (including happy, fear, angry, surprise, disgust and sad; Ekman & Friesen, 1971). Fearful and angry expressions are both considered negative because they signal danger; fearful faces signal ambiguous danger (viewing a fearful face suggests that a threat is located elsewhere in the environment), whereas angry faces signal direct danger (Whalen et al., 1998). To tell if any threat-related effects dissociate these two types of threat (i.e. ambiguous versus direct), both fearful and angry expressions will be used throughout this thesis. Additionally, to find out whether effects are threat-specific, or whether they can be caused by any arousing stimulus, the positive expression of happy will be tested throughout this thesis.

Neutral expressions were not included in the current experiment. The emotional intensity of the faces was manipulated, to increase the sensitivity of the task. Two different emotion ‘strengths’ were made by morphing each emotional face with a neutral face to make expressions that varied in emotional intensity. If the neutral expression was also included, the increased number of neutral face presentations may have confounded responses. It was predicted that the emotional faces that were not morphed with neutral (high emotional intensity) would be easier to categorise than the emotional faces that were morphed with neutral (low emotional intensity).

When presented upright and with positive polarity, fear, angry and happy expressions tend to be recognised to the same extent (Prkachin, 2003). However, it has been found that when inverted, happy expressions tend to suffer less disruption than fear and angry expressions (Prkachin, 2003; McKelvie, 1995). Given the limited research investigating the recognition of negative luminance polarity emotional faces, it is unclear whether some expressions are more disrupted than others by negation.

As individual differences in anxiety can contribute to emotion processing (e.g. Bishop, 2007), general and social anxiety were measured using standardised questionnaires.

Key Hypotheses

1) Inversion will disrupt emotion processing
2) Luminance polarity negation will disrupt emotion processing
3) Combining inversion and luminance polarity negation will be additive (i.e. there will not be a statistically significant interaction between orientation and polarity)
4) High emotional intensity faces will be recognised better than those with low emotional intensity
5) Happy expressions may be less impaired by inversion than fear and angry expressions.

2.2. Method

2.2.1. Participants

Twenty-one postgraduate and undergraduate students at the University of Southampton participated in the study (undergraduates participated in exchange for course credit). The mean age was 25.43 years (*SD*=8.59), 8 were male. All observers had normal or corrected-to-normal visual acuity.

2.2.2. Ethics

The experiment was approved by the University of Southampton, School of Psychology's ethics committee. Informed consent was obtained from each participant at the start of the experiment, and they were also made aware that all information would be treated confidentially, and all questionnaire measures would be retained securely. On completion of the experiment, participants were given a debriefing form that outlined the purpose of the experiment, and gave contact details of the experimenter. This procedure was followed for all studies in this thesis.

Questionnaires

Participants completed the state and trait versions of the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983), the Fear of Negative Evaluation Scale (FNE; Watson & Friend, 1969), and the Social Avoidance and Distress Scale (SADS; Watson & Friend, 1969). Participants also completed a short form of the Social Desirability Scale (SDS; Strahan & Gerbasi, 1972), this was used to measure the extent to which participants gave socially desirable responses (and therefore possibly invalidating the questionnaire measures).[6]

2.2.3. Apparatus and Visual Stimuli

Four male models were selected from the NimStim face set (models 20M, 21M, 33M, 36M; Tottenham, Borscheid, Ellertsen, Marcus & Nelson, 2002), each displaying fear, happy, and angry expressions. The models were chosen due to their high emotional validity, assessed using standardised ratings[7]. Participants classified each face as one of three emotions (fear, happy or angry) in a 3 alternative forced choice (AFC). The morphs were produced by creating an intermediate shape between the two faces using interpolation based on triangulation (by defining corresponding feature points; the same technique has previously been used to create emotional face morphs; Adams, Gray et al., 2010). After the specified morph was interpolated, the pixel luminance values were cross-dissolved, giving each pixel the required weighted average luminance between the two images. The low morph intensity faces were 50% neutral: 50% emotion. The high

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[6] Although anxiety measures were taken, the impact of anxiety on emotional face processing is not directly addressed in this thesis, and therefore will not be described in great detail. The STAI measures anxiety with 20 questions presented on a 4-point Likert scale. The state measure (STAI-S) asks participants to rate how they feel ‘at this moment’, whereas the trait version of the scale (STAI-T), asks them to rate how they ‘generally feel’. STAI scores can range from 20-80. The FNE presents 30 true or false questions related to a participant’s expectation, apprehension, and avoidance of being negatively evaluated. FNE scores can range from 0-30. The SADS presents 28 true or false questions related to the extent to which a participant feels anxious in, and avoids, social situations. SADS scores range from 0-28. The SDS consists of 10 statements; participants are required to decide whether each statement is true or false for them. The statements focus on socially desirable, or undesirable behaviour.

[7] These are supplied with the NimStim face set, see http://www.macbrain.org/resources for details.

morph intensity faces were 100% emotion (i.e. the original expression, and therefore not morphed).

Stimuli were prepared and presented using Matlab (The MathWorks, USA), with PsychToolbox (Brainard, 1997; Pelli, 1997). The faces were scaled, cropped and displayed within a black elliptical mask, removing any external features (see Figure 2.1). They were also matched for mean luminance and root mean square (RMS) contrast[8], and presented at 3.5° x 2.5° of visual angle (viewing distance = 65cm). There were four manipulation conditions (see Figure 2.1): a) On *upright positive* trials, faces were presented upright and with normal luminance polarity; b) On *inverted positive* trials, faces were rotated by 180°, and retained normal luminance polarity; c) On *upright negative* trials, faces were presented upright but with reversed luminance polarity; d) On *inverted negative* trials, stimuli were rotated by 180˚ and had reversed luminance polarity.

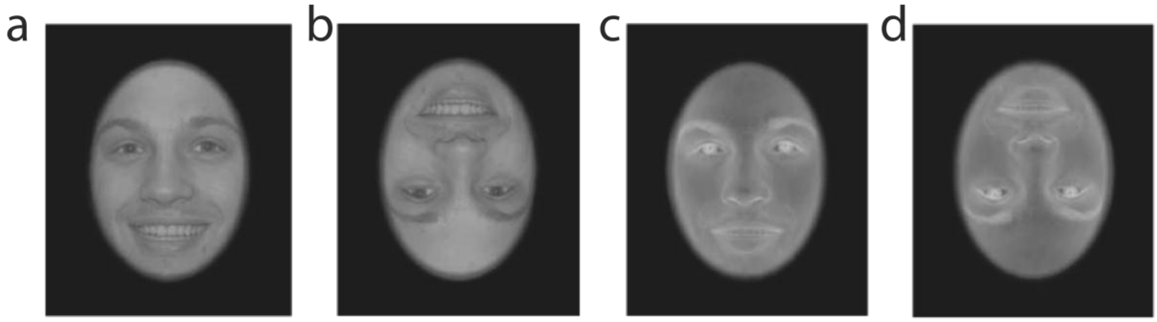

Figure 2.1. Example stimuli from the four stimulus conditions: a) Upright Positive, b) Inverted Positive, c) Upright Negative, d) Inverted Negative.

2.2.4. Procedure

On each trial a fixation cross was presented for 500ms, followed by a face (see Figure 2.2). To ensure that participants were not using cognitive strategies to infer the emotion of the face, such as trying to determine the curvature of the mouth, the face was presented briefly (100ms), and followed immediately by a noise mask (consisting of different sized ellipses with various luminance values). The mask remained visible until observers responded by selecting one of the three emotion labels displayed at the bottom of the screen. Participants used arrow keys to toggle through the possible options and selected their response using the space bar. There were 384 trials, (2

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[8] RMS contrast is the standard deviation of the luminance values, and does not depend on the spatial frequency content or spatial frequency distribution of the image (Peli, 1990; Bex & Makous, 2002).

orientations x 2 polarities x 3 emotions x 2 emotion strengths x 4 models x 4 repetitions) in a single session lasting approximately 20 minutes. At the end of the testing session, participants completed the anxiety questionnaires.

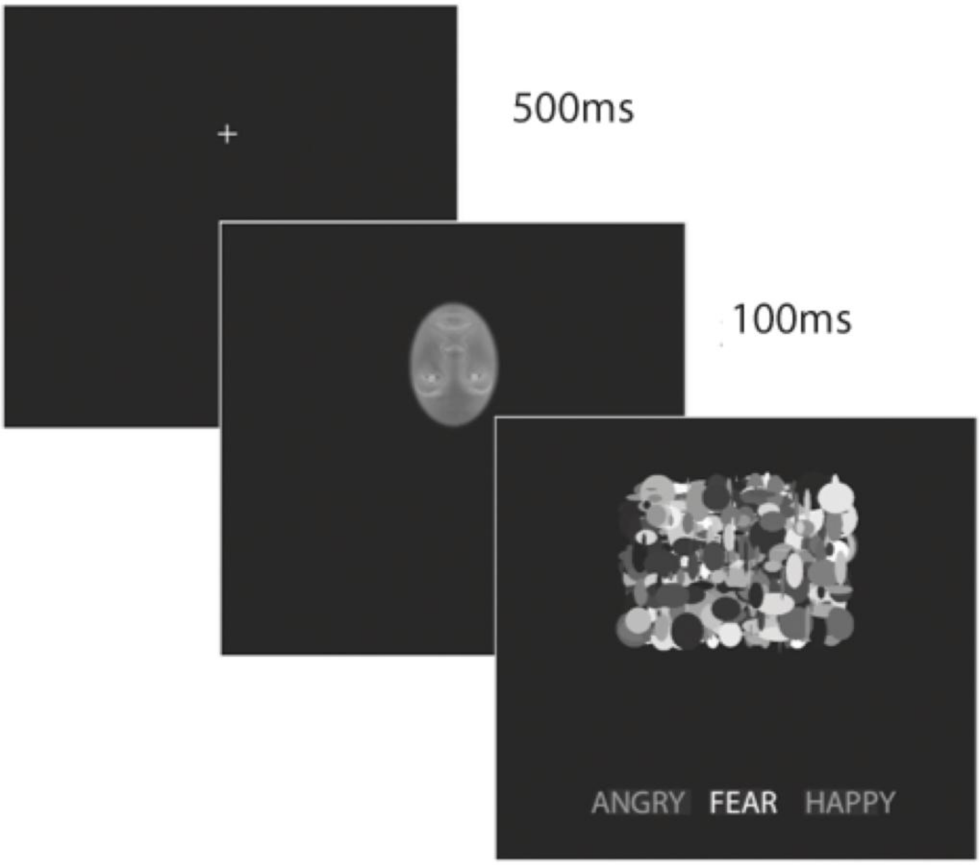

Figure 2.2. Schematic representation of a single trial from Experiment 1.

2.2.5. Design

Sensitivity (A′) scores were the dependent variable, and were entered into a 3 x 2 x 2 x 2 repeated measures ANOVA, with emotional face (angry, happy, fear), orientation (upright, inverted), luminance polarity (positive, negative), and morph strength (low, high) as within subject independent variables (IVs).

2.2.6. Data Analysis

Signal detection theory (SDT) was used to analyse the data. For each emotion, e.g. fear, a hit was defined as correctly identifying the emotion when it was presented (e.g. selecting the fear response when a fearful face was presented). A false alarm was defined as incorrectly identifying another emotion (e.g. happy or angry) as the target emotion (fear). The hits (H) and false alarms (FA) were converted into proportions, and then into A′ a non-parametric measure of sensitivity, which is given as

$$A' = 0.5 + \left[\frac{(H - FA)(1 + (H - FA))}{(4H)(1 - FA)} \right] \quad (2.1)$$

If the proportion of hits was lower than the proportion of false alarms, a different formula was used (Snodgrass & Corwin, 1988), where

$$A' = 0.5 - \left[\frac{(FA - H)(1 + (FA - H))}{(4FA)(1 - H)} \right] \quad (2.2)$$

A′ was used to index sensitivity because, as a non-parametric measure, it does not assume a normal distribution of scores. As the false alarm rates were calculated across two distributions, it is unlikely that this assumption would have been met. A′ scores vary from 0-1, where 1 is maximum sensitivity, and chance is 0.5 (Snodgrass & Corwin, 1988). There was no indication that parametric assumptions were not met for the A′ scores (K-S tests, p>.1).

When using a SDT framework, and considering sensitivity, it can also be useful to examine bias (Snodgrass & Corwin, 1988). Bias gives an indication of whether participants are systematically more liberal or conservative in their emotion judgements in particular conditions. Non-parametric bias data (B″; Grier, 1971) are not relevant to the present research questions; namely to examine whether orientation and luminance polarity manipulations impair the recognition of emotional expressions. However, the bias data do show that participants used different criteria across conditions, and are therefore included in Appendix A.

Repeated measures ANOVAs were used to discover if there were any differences between sensitivity for different emotions and conditions. Significant main effects were investigated using pairwise comparisons (using Bonferroni correction[9]), and significant interactions were analysed with post-hoc ANOVAs and (Bonferroni-corrected) paired t-tests.

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[9] Where applicable, Bonferroni correction was applied by multiplying the given p-value by the number of comparisons made. Therefore the alpha-level for all comparisons is 0.05.

2.3. Results

2.3.1. Sample Characteristics

On each of the questionnaire measures there was a normal range of scores (see Appendix B), and correlations with performance measures were non-significant (see Appendix C).

2.3.2. Recognition of Emotional Expression

Group data are shown in Figure 2.3. Both spatial inversion and luminance polarity reversal significantly impaired emotion recognition. As expected, discrimination was better for the upright than the inverted faces (upright: *M*=.74, *SD*=.06, inverted: *M*=.64, *SD*=.05; $F(1,20) = 48.37$, $p<.001$) and also better for positive than negative faces (positive: *M*=.84, *SD*=.07, negative: *M*=.55, *SD*=.05; $F(1,20) = 257.99$, $p<.001$). This shows that inverting, or negating the luminance of an emotional face disrupts emotion recognition. However, these two manipulations differed in their ability to disrupt emotion recognition; negation had a larger effect on discrimination than inversion (effect sizes: η_p^2 =.93 and η_p^2 =.73 for negation and inversion, respectively).

Also, as predicted, there was a main effect of morph strength, sensitivity was higher in the high (*M*=.73, *SD*=.05) compared to the low (*M*=.66, *SD*=.05) emotional morph intensity, $F(1,20) = 51.05$, $p<.001$.

Additive disruptive effects of inversion and luminance negation on identity processing suggest that inversion and luminance negation affect independent mechanisms (Kemp et al., 1990). Therefore, it was predicted that there would be no statistical interaction between orientation and polarity on this emotion categorisation task. However, there was a significant orientation x polarity interaction, $F(2,40) = 6.92$, $p<.05$. There was a significant effect of polarity at both levels of orientation, where sensitivity was higher to the positive than negative faces when upright (positive: *M*=.91, *SD*=.04; negative: *M*=.58, *SD*=.09; $t(20) = 18.66$, $p<.001$), and inverted (*M*=.76, *SD*=.10; negative, *M*=.52, *SD*=.06; $t(20) = 8.58$, $p<.001$). However, although there was a significant effect of orientation on sensitivity in the positive faces (discrimination for upright > inverted: $t(20) = 11.06$, $p<.001$), the orientation effect on sensitivity was not significant in the negative faces ($t(20) = 1.93$, $p>.05$). Therefore, the orientation x polarity interaction is due to the lack of an orientation effect on sensitivity in the negative polarity faces. Given that the mean sensitivity to the negative faces is not far above chance (*M*=.55, *SD* = .05; chance = .50), it is possible that this orientation x polarity interaction is driven by a floor effect in the negative polarity data.

In accord with this suggestion, there was also a significant polarity x morph interaction, $F(1,20) = 84.46$, $p<.001$, whereby sensitivity was not affected by morph in the negative faces ($p>.05$), but was in the positive faces (sensitivity for high-intensity > low-intensity: $t(20) = 11.46$, $p<.001$).

There was a main effect of emotion, $F(1,20) = 3.70$, $p<.05$, subsumed under a significant emotion x morph interaction $F(2,40) = 3.26$, $p<.05$. Post hoc comparisons of the interaction suggest that the emotion effect was marginal as none of the pairwise comparisons reached significance when Bonferroni corrections were applied. However, sensitivity was marginally higher to fear than happy in the 50% morphs ($t(20) = 2.54$, $p=.06$), and marginally higher to fear than angry in the 100% morphs ($t(20) = 2.50$, $p=.06$).

Previous research has found that expressions differ in their resilience to inversion (Prkachin, 2003; McKelvie, 1995). In the present experiment sensitivity to all expressions were similarly resistant to the orientation manipulation (emotion x orientation interaction, $p>.05$). Similarly, there was no emotion x polarity interaction ($p>.05$). This suggests that sensitivity to all three emotions were equally disrupted by the orientation and polarity manipulations (emotion x polarity x orientation, $p>.05$). All other effects were non-significant.

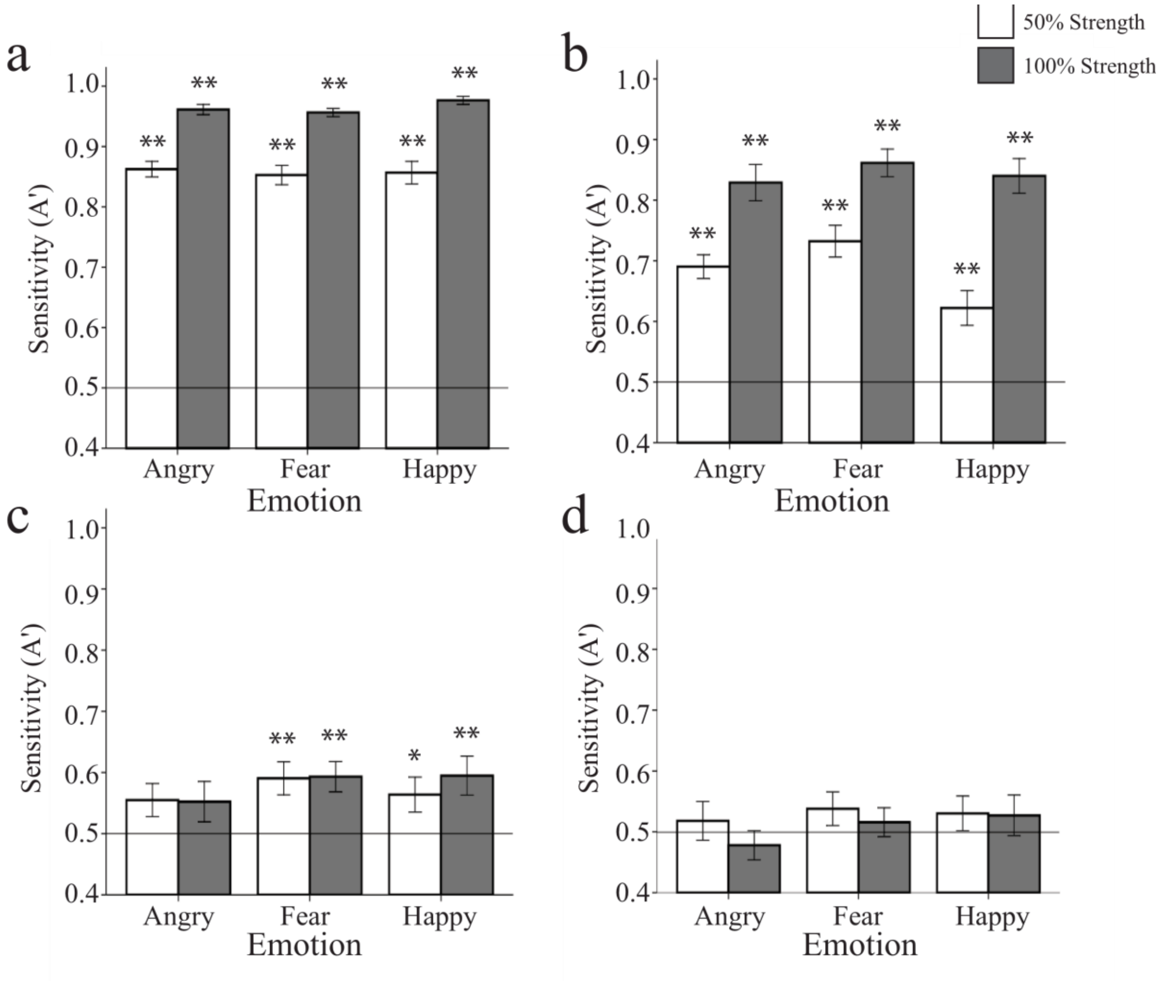

*Figure 2.3. Sensitivity as a function of emotional expression and emotion strength for a) Upright Positive, b) Inverted Positive, c) Upright Negative, and d) Inverted Negative faces. Scores that are significantly different from chance are denoted with *=p<.05 and **=p<.01.*

To examine whether performance differed from chance the different emotions (in the different manipulation conditions) were analysed using one-sample *t*-tests, and were tested against chance performance (0.5; see Figure 2.3.). Importantly, these results show that when the two manipulations are combined (i.e. faces are both inverted and negated), facial expression categorisation is impossible in this task.

2.4. Discussion

Recognition of emotional faces that were manipulated in terms of their orientation and luminance polarity were explored using SDT. Both inversion and negation disrupted emotion face recognition. The significant detrimental effect of inversion is consistent with previous research that has found that inversion reduces sensitivity/accuracy in categorising emotional expressions (Prkachin, 2003; McKelvie, 1995). Despite inversion significantly reducing performance, its effect was limited (as can be seen from Figure 2.3). Previous reports investigating the effect of inversion on emotion processing have also found that categorisation stays well above chance for inverted faces (Prkachin, 2003; McKelvie, 1995). The results of the current experiment suggest that inversion is not a good control for emotion processing, as emotional information can be extracted from inverted faces.

Negation had a larger, and substantial effect on discrimination. This was surprising given that one previous report suggested that negation had no effect on emotion recognition (White, 2001). As noted above, White presented faces for a relatively long period of time and observers reported the identity as well as the emotional expression of the face. With long presentation durations, it is possible that judgements were based on cognitive reasoning (e.g. trying to determine the curvature of the mouth), rather than the perceptual attributes of the face. Therefore, White's results may not reflect perceptual processes, but more likely cognitive strategies. On the other hand, with a short presentation duration, results from Experiment 1 of this thesis show that there is a larger detrimental effect of luminance polarity negation compared to inversion on emotion processing.

Gilad et al. (2009) found that activation in the right FFA was reduced for fully negative faces, but was close to normal levels for their contrast chimeric stimuli (faces presented in negative luminance polarity with exception of the eyes). From this study it was concluded that luminance polarity relationships are critically important for face recognition, and destruction of these highly consistent ordinal relationships leads to poor recognition. Only the eye region of the face was tested in Gilad et al.'s study, but it was able to account for most of the variability in identity recognition performance. The eye region of a face is the only place in which a luminance change reflects a pigment change (i.e. irrespective of any change in lighting, the luminance relationship of the pupil, iris and eye white will not change order). The rest of the face (other than the small change for lip colour) can be explained in terms of shape-related shading. It is possible that the eye region is also critical to emotion recognition. This would explain the large detrimental effect of luminance negation on emotion recognition found in the current experiment.

Neither manipulation on its own was sufficient to reduce performance to chance in the task. When they were combined, it was predicted that they would combine additively, as evidence from identity processing suggests that inversion and luminance negation work through independent mechanisms (Kemp, et al., 1990; McMullen et al., 2000). However, results of the present experiment indicated an interaction between the two manipulations. Exploration of the results suggest that this is because negative luminance polarity faces were very difficult to correctly recognise, and were approaching chance levels. This suggests that it is likely that the manipulations may be combined additively, but the task sensitivity was not able to discern this.

Critically for the aims of the present study, performance was reduced to chance when inversion and luminance negation were combined. This suggests that combining these two manipulations produces an ideal control for emotional faces, as high-level (the extraction of emotional content) processing is disrupted, yet low-level characteristics are unchanged from the normal (upright positive) faces.

Accuracy was marginally better for some emotions that others, and this varied by morph strength. Sensitivity was slightly higher to fear expressions than happy when presented in low-emotional intensity, and angry when presented in high-emotional intensity. These results are counter to the predicted direction, given previous reports of happy expressions being recognised better than other expressions (including fear and angry; Prkachin, 2003; McKelvie, 1995). However, the effect found in the present experiment was small, and there is a need to replicate it given the lack of consensus with previous findings.

Previous reports have found that emotions are differentially affected by spatial inversion, whereby happy face categorisation has been found to survive inversion better than fearful and angry faces (Prkachin, 2003; McKelvie, 1995). In the present experiment all three emotions were equally affected by the orientation and polarity manipulations. This is important, as it suggests that combining these two manipulations is an ideal control for all three of the emotional expressions tested here.

To conclude, findings from Experiment 1 indicate that both orientation and polarity impair emotional face categorisation. The effect of inversion is limited, suggesting that it is a poor control for emotional faces. A far superior manipulation that retains the low-level characteristics of an emotional face, but eliminates accurate emotional face categorisation is a combination of both inversion, and negation. Future studies investigating emotional face processing should employ such stimuli as a control.

Chapter 3

Emotion categorisation of normal and manipulated faces with different spatial frequency components

3.1. Introduction

Naturally occurring images contain information over many different spatial scales, from fine grain to coarse grain (Morrison & Schyns, 2001). Analysis of the spatial frequency (SF) spectrum of an image is an early step in visual processing (De Valois & De Valois, 1988; Morrison & Schyns, 2001). Complex luminance changes over different spatial scales would be difficult to analyse optimally with one filter, therefore it has been suggested that images are decomposed by spatial filters in the visual system that simplify the luminance contrasts for analysis (Marr & Hildreth, 1980). SF bands convey different information of an image; high spatial frequencies (HSFs) represent abrupt spatial changes in the image, and generally correspond to detail, whereas low spatial frequencies (LSFs) represent global information about the shape of the stimulus (Livingston & Hubel, 1988)[10]. Attentional prioritisation of fearful faces may be driven by their LSF content (Holmes et al., 2005), and there is evidence that the increased amygdala activation towards fearful faces is driven by their LSF components (Vuilleumier et al., 2003). Given this evidence, SF appears to be an important variable in the investigation of threat prioritisation, and will be explored more in this thesis (see Chapter 5). In order to ascertain whether LSF vs. HSF emotion effects are caused by the evaluation of emotional content, and/or low-level visual characteristics, it is important to have adequate control stimuli. Therefore, the effect of

[10] There has been some variation in the spatial frequency thresholds used for low, middle and high spatial frequencies. For the present thesis, the following thresholds are considered as indicative for each band: low spatial frequency = less than 6 cycles per image; high spatial frequency = greater than 24 cycles per image; and middle spatial frequency = 8-16 cycles per image.

inversion and luminance polarity reversal on emotion recognition will be investigated in HSF and LSF faces in the present chapter.

A large number of studies have aimed to identify the critical SF bands that support face processing (Costen, Parker & Craw, 1994; 1996; Fiorentini, Maffei & Sandini, 1983; Gold, Bennett & Sekuler, 1999; Hayes, Morrone & Burr, 1986). Results from these experiments suggest that the important information for identity recognition is contained in the middle spatial frequency (MSF) range (e.g. Costen et al., 1994; 1996, Gold et al., 1999, Nasanen, 1999). There is some disagreement about which exact SF bands below or above which identity recognition deteriorates (e.g. Fiorentini et al., 1983; Costen et al., 1994, 1996; Gaspar, Sekular & Bennett, 2008), however, this may be due to early research not controlling for contrast across the different spatial scales (Costen, et al., 1996).

HSF and LSF information may be processed somewhat separately, via parvocellular and magnocellular visual channels, respectively (see *Section 1.1*; Livingston & Hubel, 1988). This evidence for dissociable routes in processing HSF and LSF information has triggered research investigating the role of different SF components in face processing. There have been a number of conflicting findings regarding HSF and LSF processing in faces, with some suggesting that HSF information is particularly important for encoding identity (Fiorentini et al., 1983; Vuilleumier et al., 2003), whereas others suggest that LSFs are more important (Goffaux et al., 2003; Goffaux & Rossion, 2006; Goffaux et al., 2005). It has been suggested that HSFs are critical for extracting information about facial features, (Sergent, 1986; Shulman & Wilson, 1987), as HSF information contains the small variations in luminance that are important for processing slight differences between features. On the other hand, it has been suggested that LSFs are critical for extracting configural information from a face (Sergent, 1986). Fiorentini et al. (1983) found that LSFs were not useful for identity recognition when presented on their own, whereas faces containing only HSFs were well recognised.

The suggestion that configural processing is supported largely by LSF information is controversial (Goffaux & Rossion, 2006; Cheung, Richler, Palmeri & Gauthier, 2008; Wegner & Townsend, 2000; Boutet et al., 2003; Goffaux et al., 2005). Goffaux et al. (2003) compared ERPs between broad spatial frequency (BSF), HSF and LSF faces and chairs, and found a face specific N170 in BSF, and LSF faces, but not for HSF faces. However, recently it has been found that BSF, LSF and HSF faces elicit the

N170 to a similar extent (compared to cars; Flevaris, Robertson & Bentin, 2008). In a recent behavioural experiment, Goffaux and Rossion (2006) used the composite face paradigm with filtered faces. They replicated the effect found for BSF faces: that accuracy is lower for aligned, compared to misaligned faces (Young et al., 1987). In addition, Goffaux and Rossion found the effect size was greatest for LSF faces, followed by BSF faces, and finally HSF faces. However, recently this evidence has been challenged (Cheung, Richler, Palmeri & Gauthier, 2008). Cheung et al. replicated the findings of Goffaux and Rossion, but looking closely at the data, they found that differential response biases explained the results. When these biases were accounted for, the composite effect did not differ between the HSF and LSF faces.

Although historically HSF components have been implicated in featural processing, and LSF components in configural processing (Sergant, 1986), findings to date have been inconsistent. Rather than being fixed, there may be a bias in favour of the spatial scales which are task relevant, so the scale used may be flexible and determined by the usefulness of that cue for the specific task (Schyns & Olivia, 1999; Morrison & Schyns, 2001; Sowden & Schyns, 2006). Although this finding may account for various findings across tasks, it cannot account for the inconsistent effects within a given task.

In emotional face processing research there have been several studies suggesting that LSF and HSF information is processed differently across expressions and brain locations (Vuilleumier et al., 2003; Winston, Vuilleumier & Dolan, 2003; Pourtois, Dan, Grandjean, Sander & Vuilleumier, 2005). Winston et al. (2003) presented hybrid faces, which consisted of complimentary SF information from models with different genders and expressions; on each trial, both genders were represented, one in HSF and the other in LSF. So, for example, one hybrid stimulus might have been composed of a HSF neutral female component and a LSF fearful male component. Participants had to report the gender of the face they perceived. As both genders were represented in the hybrid stimuli, the participants' gender report indicated which of the SFs they were attending to. Faces containing the LSF 'fear' component were associated with increased activation (compared to those containing the LSF neutral component) in the FFA, and in the amygdala. This was true for both the FFA and amygdala, irrespective of the gender that was reported. However, brain activation (in the FFA and amygdala) in response to fear vs. neutral faces did not differ when the emotions were conveyed by HSF information. This indicates that LSF fearful faces modulate FFA and amygdala activation, even when these faces are not explicitly reported.

Behavioural results from Pourtois et al. (2005)'s study showed that participants were faster to judge gender in fearful and neutral faces for BSF compared to HSF, or LSF faces, but that there was no difference between the two types of filtered faces. ERPs were also recorded, and results showed that fearful faces selectively increased amplitudes at P1 latency for BSF and LSF faces, but not for HSF faces (Pourtois et al., 2005). Taken together these findings suggest that LSF fearful faces are associated with increased brain activation (compared to LSF neutral, and HSF fearful faces), despite not being particularly informative for the tasks in hand.

The studies described above (e.g. Vuilleumier et al., 2003; Winston et al., 2003; Pourtois et al., 2005), used only neutral and fearful faces. This poses the question of whether the same effects will also be found for different expressions compared to neutral, or whether they are fear-specific. Additionally, the studies above show that the LSF and HSF information contained in faces are processed differently depending on the expression of the face (or that the LSF and HSF information differs across expressions). However, these studies do not address which SFs are important for explicit emotion recognition.

Gosselin and Schyns (2001) created a novel paradigm to investigate the SF components that are important for object recognition. In this 'Bubbles' technique, a stimulus is filtered into separate SF bands, and then a proportion of information from each SF band is selected and combined. By randomly sampling a part of the image from each SF band on each trial, after a number of trials, it is possible to discern the information that is important for the recognition of the stimulus (Gosselin & Schyns, 2001). Using the Bubbles technique, Smith et al. (2005) found that LSFs are more important when categorising happy and angry expressions, whereas HSFs are more important when categorising fearful expressions.

In a recent experiment, Goren and Wilson (2006) used synthetic faces to probe recognition of happy, sad, fear and angry faces. Their synthetic faces were derived from photographs of faces, but digitized using a series of feature-based points. On a 2AFC matching task, they found discrimination of emotion from neutral was impaired for LSF fear and happy expressions, but not LSF angry expressions (compared to MSF bands). For HSF faces, discrimination of all emotions did not differ in comparison to MSF faces. This suggests that LSFs are useful for angry recognition, whereas HSFs are important for angry, happy and fear recognition.

Schyns and Oliva (1999) help to explain these conflicting results. Using hybrid stimuli (faces comprising of HSF information taken from one emotion, and LSF information taken from another expression), they found that when asked to indicate whether a face was expressive or not, participants were biased to use HSF information, whereas in a categorisation task (‘which emotion is it?’), participants were biased to use LSF information. However, these biases were not fixed (initial bias transferred to a subsequent task, and learning influenced the bias). This suggests that the spatial scale used in the categorisation of emotional expression is based on the usefulness of the scale cues in a particular task.

It should be noted that although research suggests LSFs may be used to preferentially process emotional faces (e.g. Vuilleumier et al., 2003), the present study is investigating the effect of SF on emotional recognition. It is possible that visual information may be explicitly recognised very poorly, but still undergo preferential processing. Therefore, previous research citing the importance of LSF information on emotional face prioritisation should not be taken as an indication that LSF information will be particularly helpful in recognising emotion. Holmes et al., (2005) conducted a series of behavioural studies investigating the prioritisation of fearful expressions, and in particular, the involvement of LSF information in this prioritisation. They provide evidence that the LSF components of a fear face promote selection within a visual-probe task. However, Holmes et al., (2005; Experiment 4) found that when participants were asked to categorise ‘which face is fearful’ out of a pair of HSF or LSF faces, they were marginally better at discriminating fear in the HSF faces. This suggests that HSF information may be useful for explicit recognition of emotion, whereas LSF information plays more of a role in involuntary appraisal mechanisms that boost salience and direct attentional resources towards it.

3.1.1. The effect of inversion

There is some controversy over which SF components support configural processing (e.g. Goffaux et al., 2003; Goffaux & Rossion, 2006; Goffaux et al., 2005; Cheung et al., 2008; Wenger & Townsend, 2000; Boutet et al., 2003). Therefore, it is unclear whether inversion will disrupt processing of HSF and LSF faces to a similar extent. This is the first study to investigate the recognition of inverted emotional faces with different SF profiles.

3.1.2. The effect of luminance polarity negation

Luminance polarity negation does not equally impair identity recognition in HSF and LSF faces (Hayes, Morrone & Burr, 1986). In faces containing LSFs, polarity negation impairs recognition; however, in faces that contain only HSFs, polarity negation has little effect on recognition of identity (Hayes et al., 1986). This suggests that the effect of polarity negation on BSF faces is due to the effect it has on the LSF information. To date, no experiment has looked at the effect of polarity negation on the emotional recognition of faces with different spatial frequency profiles.

3.1.3. The combination of inversion and luminance polarity negation

There has been no study to date that has investigated the combination of inversion and luminance polarity reversal on faces with specific SF components. This is true for both identity and emotion processing research.

3.1.4. The current Experiment

The primary aim of the present study was to identify a control stimulus that can be used with HSF and LSF filtered faces, as well as BSF faces (Experiment 1).
The present experiment aims to examine the effects of orientation and luminance polarity on the recognition of facial expressions with HSF, LSF, and BSF content. In identity processing, it has been suggested that LSF information is important for configural processing, whilst HSF information is important for featural processing (Sergent, 1986). However, recent research suggests that both SFs may be used for configural processing (e.g. Cheung et al., 2008). Importantly, there is some indication that the spatial scale used is task dependent, and flexible (Sowden & Schyns, 2006).

In emotion research, there has been imaging (Vuilleumier et al., 2003) and behavioural (Holmes et al., 2005) evidence to suggest that LSFs are important for the prioritisation of fearful emotional expressions. The prioritisation of LSF fear faces may not necessarily correlate with better overt recognition of LSF over HSF fearful faces. There is some evidence to suggest that the SF bands that are important for recognition of emotion differ across emotions (Smith et al., 2005; Goren & Wilson, 2006). Therefore, a possible SF by emotion interaction is predicted, although the direction of this effect is not clear, as there have been inconsistencies in the SF information implicated for each expression (Smith et al., 2005; Goren & Wilson, 2006). It is possible that these inconsistent results reflect that the importance of each SF band may be flexible and change across tasks (Schyns & Olivia, 1999).

In the present experiment it is predicted that inversion and luminance polarity negation will reduce sensitivity to emotional faces in each of the SF bands. Due to the possibility that HSF faces are less affected by polarity negation than BSF and LSF faces (Hayes et al., 1986), an interaction between SF and polarity is predicted: the recognition of HSF faces is predicted to be impaired less by luminance polarity negation than the recognition of LSF and BSF faces.

As with Experiment 1, morph strength is also manipulated in the present experiment. There were a number of interactions involving morph strength that emerged in Experiment 1. Over all SFs it is predicted that sensitivity will increase as morph-level increases.

Key Hypotheses

1) Inversion will disrupt emotion processing for faces in each SF.
2) Luminance negation will disrupt emotion processing for each SF, but this effect will be reduced in HSF compared to LSF or BSF faces.
3) Combining inversion and luminance negation will be additive (i.e. there will not be a statistically significant interaction between orientation and polarity) in the BSF and LSF faces.
4) Combining inversion and luminance negation will be interactive in the HSF faces, due to the reduced effect of negation on HSF information.
5) High emotional intensity faces will be recognised better than those with low emotional intensity within each SF, orientation and polarity.

3.2. Method

3.2.1. Participants

Nineteen undergraduate students (3 males) at the University of Southampton participated in the study in exchange for course credit. The mean age was 25.1 (*SD*=8.38). All observers had normal or corrected-to-normal visual acuity. All gave informed consent.

3.2.2. Questionnaires

The same questionnaire measures were administered as in Experiment 1, including the: STAI (Spielberger et al., 1983), FNE (Watson & Friend, 1969), SADS (Watson & Friend, 1969), and SDS (Strahan & Gerbasi, 1972).

3.2.3. Apparatus & Visual Stimuli

Apparatus and visual stimuli were identical to Experiment 1, with the exception that in the current experiment, HSF, LSF and BSF faces were used. Images were filtered to contain only particular SFs. This is done by transforming an image from the spatial domain into the frequency domain, using a Fourier transform. The Fourier transform is a way of decomposing a signal into its constituent sine and cosine frequencies (Nixon & Aguado, 2008). A raised cosine filter was applied using the Image Processing Toolbox for Matlab (The Mathworks) to extract either the HSF or the LSF content of the image before using an inverse Fourier transform. SF is the measure of over how many pixels a cycle of repeating intensity variations occurs, and can be measured in cycles per degree (cpd), cycles per image (cpi), or in face processing research, cycles per face (cpf; which is the same as cpi, when the face fills the image). For this thesis, SF will be described in cpf where possible, as cpf is an absolute, stimulus-based measure of the SFs contained in an image (Sowden & Schyns, 2006). HSF faces contained information greater than or equal to 24 cpf (8 cpd), whereas LSF faces contained information less than or equal to 6 cpf (2 cpd); similar cut-off values have been used in previous experiments (Winston et al., 2003; Vuilleumier et al., 2003; see Figure 3.1).

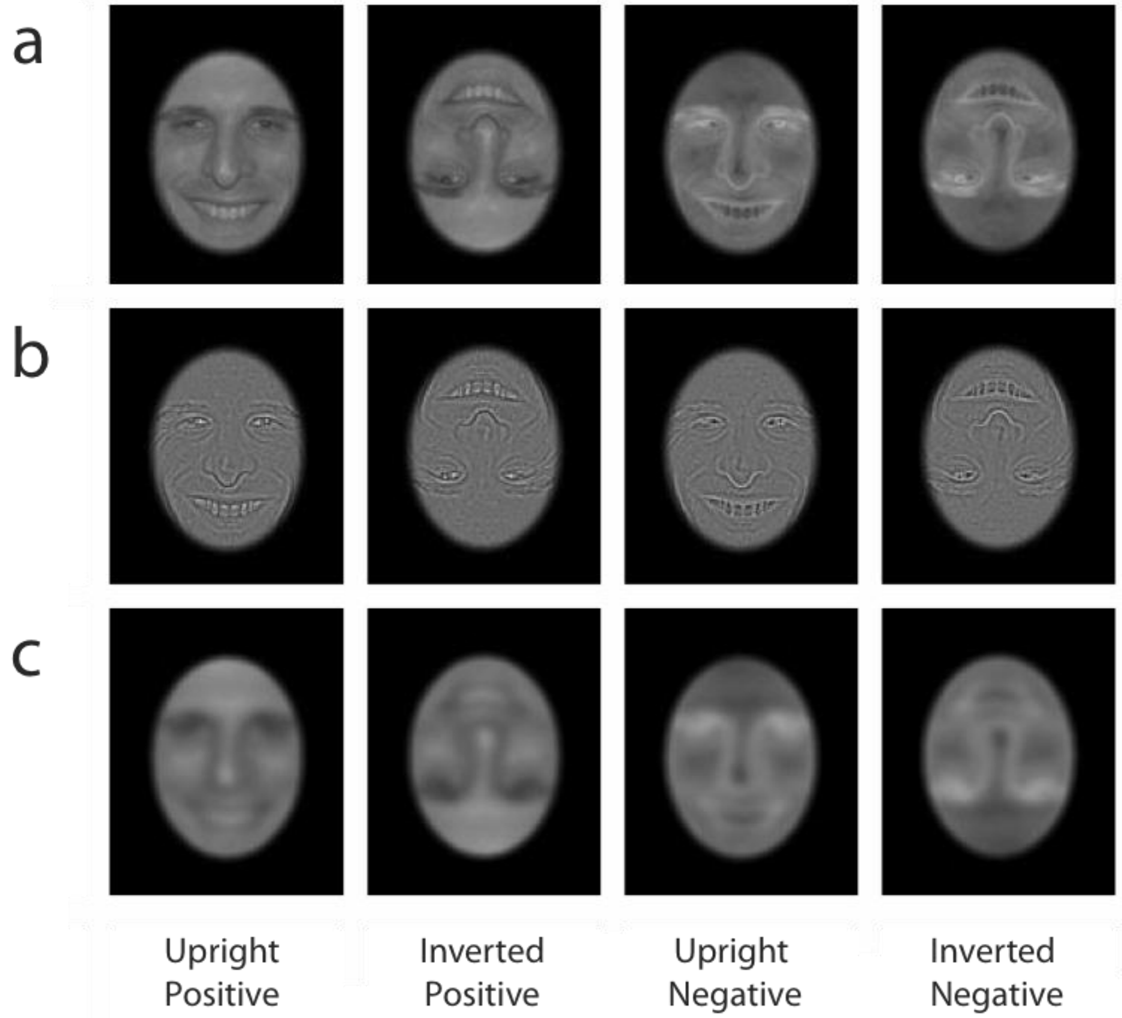

Figure 3.1. Examples of high emotional intensity happy faces from each condition in a) broad spatial frequency, b) high spatial frequency, and c) low spatial frequency.

3.2.4. Procedure

The procedure was also identical to Experiment 1, with the exception that the faces in the current experiment were displayed for 200ms (rather than the 100ms presentation duration used in Experiment 1). This increase in presentation duration was used to account for the possibility that HSF and LSF faces may be more difficult to categorise than BSF faces. There were 1152 trials (2 orientations x 2 polarities x 3 emotions x 2 morph strengths x 3 spatial frequencies) with 16 repetitions per condition. The session lasted for approximately 1 hour.

3.2.5. Design

Sensitivity (A′) scores were the dependent variable, and were entered into a 3 x 2 x 2 x 2 x 3 repeated measures ANOVA, with emotional face (angry, happy, fear), orientation (upright, inverted), polarity (positive, negative), morph strength (low, high), and spatial frequency (BSF, HSF, LSF) as within subject IVs.

3.2.6. Data Analysis

The data were analysed using the same method as Experiment 1. As previously suggested, when considering sensitivity it can also be useful to examine bias (see Appendix D).

Repeated measures ANOVAs were used to discover if there were any differences between sensitivity for different emotions and conditions. Significant main effects were investigated using pairwise comparisons (using Bonferroni correction[11]), and significant interactions were analysed with post-hoc ANOVAs and (Bonferroni-corrected) paired *t*-tests.

3.3. Results

3.3.1. Sample Characteristics

On each of the questionnaire measures there was a normal range of scores (see Appendix E), and correlations with performance measures were non-significant (see Appendix F).

3.3.2. Recognition of Emotional Expression

There was a main effect of SF, $F(2,36) = 330.80$, $p<.001$, subsumed by a SF x polarity interaction, $F(1.2,22) = 27.97$, $p<.001$. There was a difference across SF in the positive faces ($F(1.3,23.2) = 158.99$, $p<.001$), as sensitivity was higher to both BSF and HSF faces than LSF faces (BSF compared to LSF, $t(18) = 13.92$, $p<.001$; HSF compared to LSF, $t(18) = 12.59$, $p<.001$), but sensitivity to HSF and BSF faces did not differ ($p=.56$). There was also a significant difference across SF in the negative faces ($F(1.2,22) = 233.68$, $p<.001$), whereby sensitivity was lowest to LSF faces (compared to BSF, $t(18) = 9.76$, $p<.001$; and HSF, $t(18) = 20.66$, $p<.001$), and sensitivity was higher

[11] Where applicable, Bonferroni correction was applied by multiplying the given *p*-value by the number of comparisons made. Therefore the alpha-level for all comparisons is 0.05.

to HSF than BSF faces (*t*(18) = 17.21, *p*<.001). This concurs with predictions that HSF faces would be less affected by polarity negation than BSF and LSF faces.

Given the research questions of the current experiment, and due to the main effect of SF, and the number of unpredicted interactions that contain the SF variable[12], it was deemed appropriate to split the remaining analyses by SF. The data were entered into three separate (3 emotions x 2 orientations x 2 polarities x 2 morph-strengths) repeated-measures ANOVAs.

Broad spatial frequency. Group data are shown in Figure 3.2. As expected, both spatial inversion and luminance polarity reversal significantly impaired emotion recognition, replicating effects found in Experiment 1. Discrimination was better for the upright than the inverted faces (upright: *M*=.87, *SD*=.06, inverted: *M*=.78, *SD*=.08; *F*(1,18) = 77.93 *p*<.001) and also better for positive than negative faces (positive: *M*=.92, *SD*=.04, negative: *M*=.73, *SD*=.09; *F*(1,18) = 219.95, *p*<.001). This replicates findings from Experiment 1 and suggests that in BSF faces, inversion and luminance polarity negation disrupt emotion recognition. Also in agreement with Experiment 1, the orientation and luminance polarity manipulations differed in their ability to disrupt emotion recognition; negation had a larger effect on discrimination than inversion (effect sizes: η_p^2 =.92 and η_p^2 =.81 for negation and inversion, respectively, *t*(18) = 8.16, *p*<.001).

As predicted, there was a main effect of morph strength, as sensitivity was higher to high (*M*=.85, *SD*=.06) than low (*M*=.79, *SD*=.08) emotional intensity morphs, *F*(1, 18) = 51.84, *p*<.001.

In contrast to the findings from Experiment 1, there was no orientation x polarity interaction (*p*=.11). However, there was a significant three-way orientation x polarity x morph interaction, *F*(1,18) = 9.49, *p*<.01, qualifying a two-way orientation x morph interaction, *F*(1,18) = 6.15, *p*<.05, and a polarity x morph interaction, *F*(1,18) = 14.97, *p*=.001. There was no orientation x polarity interaction in the low morph-strength condition (*p*<.05), but a significant interaction in the high morph-strength condition, *F*(1,18) = 16.08, *p*=.001, which in turn was caused by an effect of orientation (sensitivity to upright faces > inverted faces) in the negative faces (*t*(18) = 3.66, *p*<.01),

[12] Including: SF x Orientation x Polarity, *F*(2,36) = 15.24, *p*<.001; SF x Morph, *F*(1.2, 22.3) = 6.75, *p*=.012; SF x Orientation x Morph, *F*(1.5,26.5) = 14.45, *p*<.001; SF x Polarity x Morph, *F*(1.4,24.6) = 12.70, *p*=.001; SF x Orientation x Emotion x Morph, *F*(2.4,42.5)= 4.12, *p*<.05; SF x Polarity x Emotion x Morph, *F*(4, 72) = 2.87, *p*<.05; SF x Orientation x Polarity x Emotion x Morph, *F*(2.4, 43.5) = 3.01, *p*=.051.

but not in the positive faces (*p*>.05). This orientation x polarity x morph-level interaction indicates that when the faces are high in morph strength, and positive polarity, inversion does not disrupt emotional categorisation.

Also in contrast to Experiment 1, there was no main effect of emotion (*p*>.05). This suggests that generally no emotional expression was more accurately categorised across all conditions. However, there was a significant orientation x polarity x emotion interaction, $F(2,36) = 4.35$, $p<.05$, where although there was no orientation x polarity interaction in the angry expression ($p>.05$) or happy expression ($p>.05$), there was a significant interaction in the fearful expression, $F(1,18) = 12.60$, $p<.01$. In the fear expression, sensitivity was reduced with inversion in the positive faces ($t(18) = 5.32$, $p<.001$) and the negative faces ($t(18) = 4.80$, $p<.001$). There was a significant effect of polarity (sensitivity to positive > negative) in the upright faces ($t(18) = 9.38$, $p<.001$), but a slightly larger effect of polarity in the inverted faces ($t(18) = 11.25$, $p<.001$). This suggests that in the fear expression, the manipulations may interact and when combined reduce sensitivity further than the sum of their independent costs.

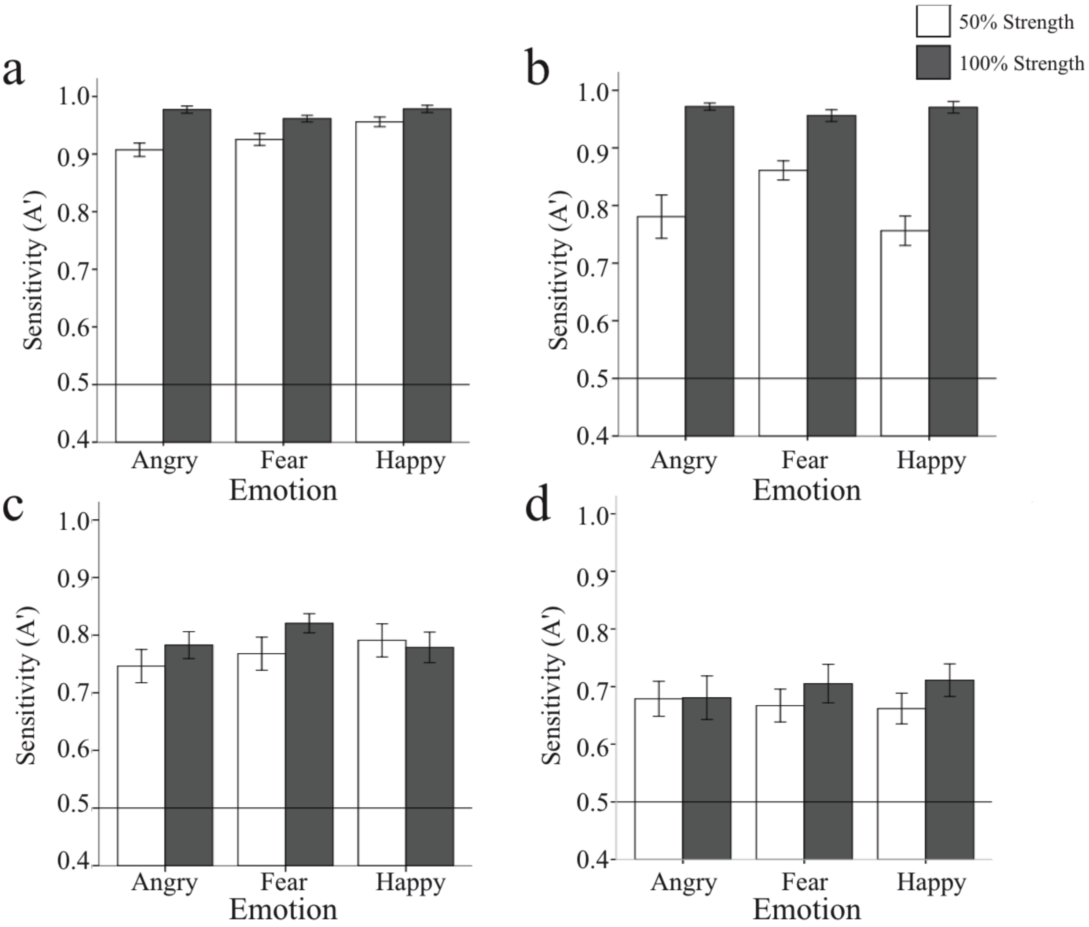

Figure 3.2. *Sensitivity as a function of emotional expression and emotion strength for BSF a) Upright Positive, b) Inverted Positive, c) Upright Negative, and d) Inverted Negative. Average sensitivity for all conditions was significantly above chance (0.5; p<.001).*

High spatial frequency. As predicted, both spatial inversion and luminance polarity reversal significantly impaired emotion recognition in the HSF faces. Discrimination was better for the upright than the inverted faces (upright: M=.93, SD=.05, inverted: M=.87, SD=.08; $F(1,18) = 28.48$ $p<.001$) and also better for positive than negative faces (positive: M=.91, SD=.06, negative: M=.89, SD=.06; $F(1,18) = 20.18$, $p<.001$). The two manipulations differed in their ability to disrupt emotion recognition; inversion had a larger effect on discrimination than negation (effect sizes: η_p^2 =.61 and η_p^2 =.53 for inversion and negation, respectively, $t(18) = 2.85$, $p<.05$). The interaction between orientation and polarity was not significant ($p>.05$), suggesting that the effects of the two manipulations were additive (see Figure 3.3).

There was a main effect of morph, $F(1, 18) = 87.25$, $p<.001$, where sensitivity was higher in the high ($M=.95$, $SD=.05$) than the low ($M=.85$, $SD=.08$) morph-strength condition.

There was a polarity x morph interaction, $F(1,18) = 7.18$, $p<.05$, due to a significant effect of polarity (sensitivity to positive > negative) in the low morph-strength faces, $t(18) = 4.20$, $p=.001$, but a non-significant effect of polarity in the high morph-strength faces ($t(18) = 2.11$, $p>.05$). This suggests that in the full strength HSF emotional faces, there is no cost of negation on sensitivity.

There was a main effect of emotion, $F(2,36) = 3.78$, $p<.05$, qualified by an emotion x polarity interaction, $F(2, 36) = 4.17$, $p<.05$. The emotion x polarity effect was due to a difference in sensitivity between the emotions in the negative faces ($F(2,36)= 7.77$, $p<.01$), but not in the positive faces ($p>.05$). In the negative faces, sensitivity to both angry and fear faces was higher than happy faces (happy compared to angry: $t(18) = 3.96$, $p=.001$; fear: $t(18) = 3.14$, $p<.05$). When looking at the effect of polarity on each emotion separately, it was found that for both happy and fearful faces, sensitivity was lower to the negative faces than the positive faces (happy: $t(18) = 4.09$, $p<.01$; fear: $t(18) = 5.11$, $p<.001$), but this was not the case in the angry expression ($p<.05$). These results suggest that the HSF emotional faces are differentially affected by the luminance polarity manipulation, with sensitivity to happy expressions being disrupted by negation to a greater extent than fear or angry. Indeed, sensitivity to angry expressions was not significantly disrupted by negation.

There was also a significant orientation x emotion x morph interaction, $F(2,36) = 24.12$, $p<.001$ (qualifying significant emotion x morph, $F(2,36) = 11.21$, $p<.001$; and emotion x orientation, $F(2,36) = 19.83$, $p<.001$ interactions). At low morph-strength, there was a main effect of orientation, $F(1,18) = 22.21$, $p<.001$, a main effect of emotion, $F(2,36) = 7.25$, $p<.01$, and a significant orientation x emotion interaction, $F(2,36) = 28.13$, $p<.001$. In the low morph-strength faces there was an orientation effect (sensitivity to upright > inverted) in the angry expression, $t(18)=3.81$, $p=.001$, and the happy expression, $t(18) = 6.25$, $p<.001$, but not in the fear expression ($p>.05$). This suggests that when presented in the low morph-strength condition, inversion does not significantly disrupt sensitivity to fear faces, but does disrupt sensitivity to happy and angry expressions. In the high morph-strength condition, there was only a significant main effect of orientation (sensitivity to upright > inverted), $F(1,18) = 14.89$, $p=.001$, suggesting that all emotions were similarly disrupted by inversion.

Sensitivity in the HSF faces was generally very high. The main aim of this experiment was to find stimuli that control for the extraction of emotional content in SF filtered faces. To test that high-level processing was significantly disrupted for all HSF emotions, paired *t*-tests were run between the positive upright faces, and their inverted negative counterparts. For all expressions and both morph-levels, sensitivity was significantly reduced in the combined manipulated faces, compared to the normal faces (*p*s<.01).

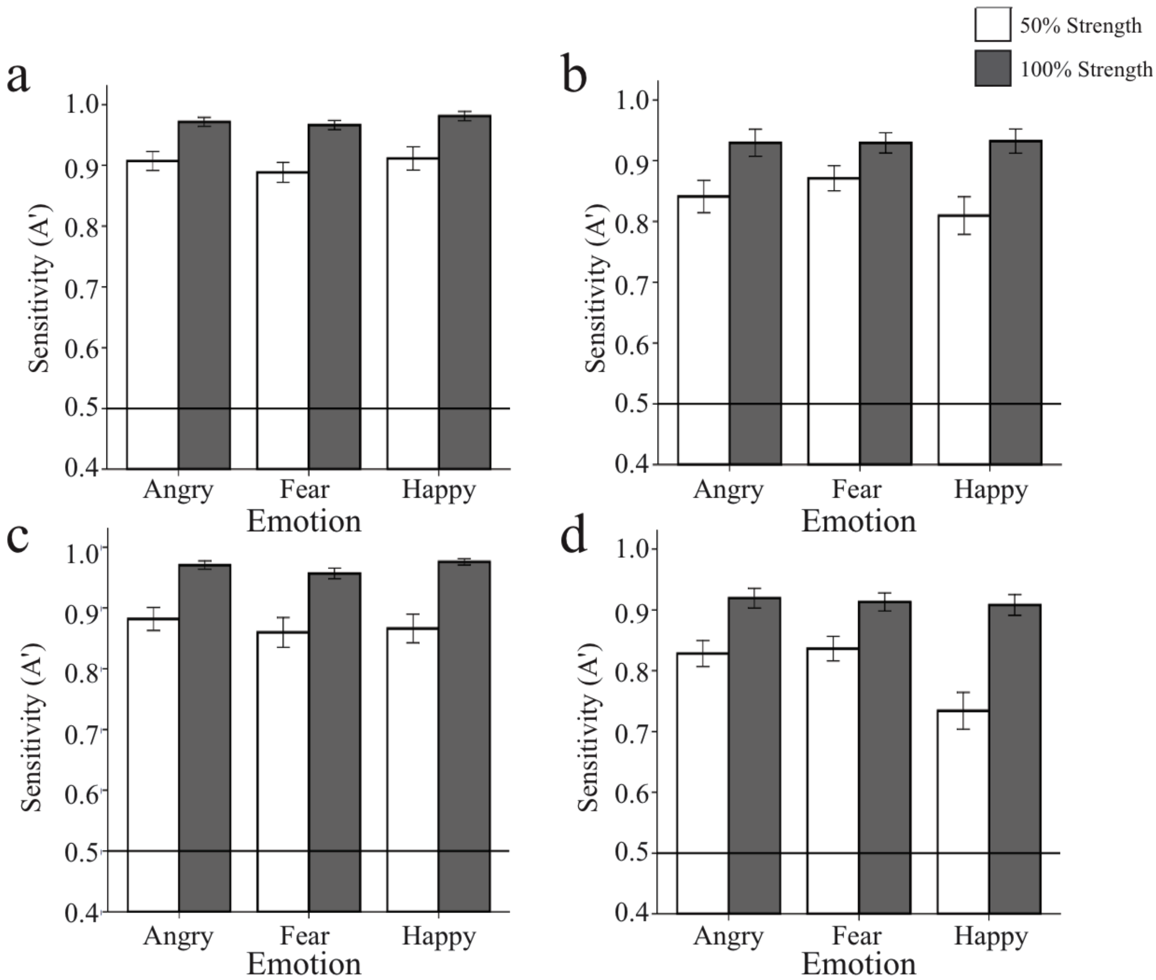

Figure 3.3. Sensitivity as a function of emotional expression and emotion strength for HSF a) Upright Positive, b) Inverted Positive, c) Upright Negative, and d) Inverted Negative. Average sensitivity for all conditions was significantly above chance (0.5; p<.001).

Low Spatial Frequency. In the LSF faces, both spatial inversion and luminance polarity reversal significantly impaired emotion recognition (see Figure 3.4).

Discrimination was better for the upright than the inverted faces (upright: *M*=.62, *SD*=.08, inverted: *M*=.55, *SD*=.06; $F(1,18) = 11.01$ $p<.01$) and also better for positive than negative faces (positive: *M*=.65, *SD*=.10, negative: *M*=.52, *SD*=.05; $F(1,18) = 45.10$, $p<.001$). The two manipulations differed in their ability to disrupt emotion recognition; negation had a larger effect on discrimination than inversion (effect sizes: $\eta_p^2=.72$ and $\eta_p^2=.38$ for negation and inversion, respectively, $t(18) = 3.69$, $p<.01$).

With the LSF faces there was an interaction between orientation and polarity, $F(1,18) = 15.86$, $p<.001$; inversion significantly impaired sensitivity in positive faces, $t(18) = 5.69$, $p<.001$, but not in the negative faces ($p>.05$). There was also an effect of polarity (sensitivity to positive > negative) in the upright faces, $t(18) = 6.50$, $p<.001$, and a weaker (but still marginally significant) effect in the inverted faces ($t(18) = 2.57$, $p=.076$).

There was not a significant effect of morph-level ($p>.05$), however, there was a significant orientation x morph interaction, $F(1,18) = 20.53$, $p<.001$, and a significant polarity x morph interaction, $F(1,18) = 18.42$, $p<.001$. The orientation x morph interaction was due to an effect of morph (sensitivity to high-intensity > low-intensity) in the upright faces, $t(18) = 3.74$, $p<.01$, but not in the inverted faces ($p>.05$). Similarly, the polarity x morph interaction was characterised by the effect of morph (sensitivity to high-intensity > low-intensity) in the positive faces, $t(18) = 3.70$, $p<.01$, but not in the negative faces ($p>.05$). These effects indicate that when the LSF faces are manipulated (i.e. they are inverted, or negated), there is no effect of emotional intensity.

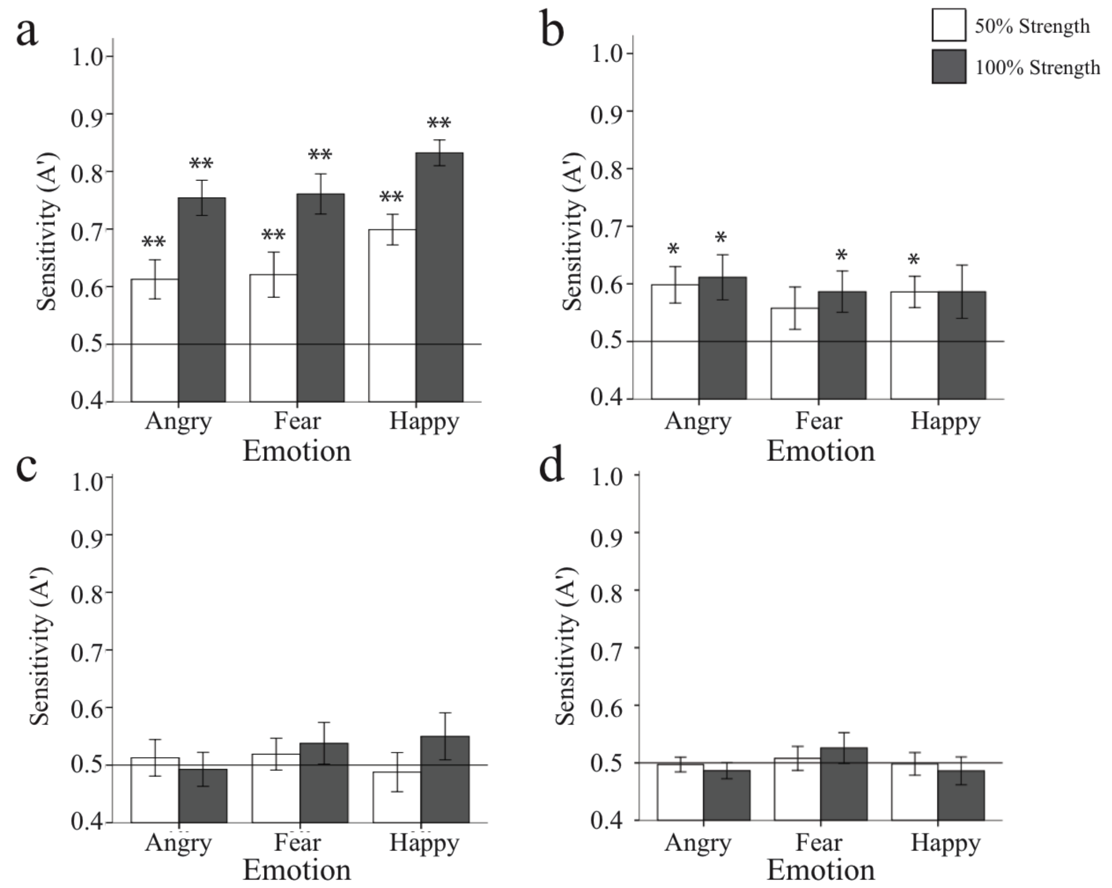

*Figure 3.4. Sensitivity as a function of emotional expression and emotion strength for LSF a) Upright Positive, b) Inverted Positive, c) Upright Negative, and d) Inverted Negative. Scores that are significantly different from chance are denoted with *=p<.05 and **=p<.01.*

3.4. Discussion

The present experiment investigated the extent to which orientation and polarity manipulations disrupted categorisation of emotional faces with different SF profiles. It was found that the SF of the face did affect sensitivity to emotional expression, with categorisation being very good in both BSF and HSF faces, but much worse in LSF faces.

This corroborates findings from Goren and Wilson (2006), which showed that HSF emotional faces were recognised as well as MSF emotional faces. However, in this previous study, recognition was impaired for LSF fearful and happy faces, but not angry. In the present study, there was reduced recognition of all expressions that were presented at LSF compared to HSF or BSF. The results of the present study also concur with evidence that fear is easier to discriminate when presented in HSF compared to LSF (Holmes et al., 2005).

In the BSF faces, recognition of emotion was impaired with inversion and negation. Even though the faces were displayed for twice the duration of the faces presented in Experiment 1, negation continued to have a larger effect on discrimination than inversion. Again, these results suggest that consistent luminance polarity relationships are important for emotion recognition, as with identity recognition (Gilad et al., 2009). Consistent with Experiment 1, there was an interaction between orientation and polarity, but in the present experiment, this was only in the high morph-strength condition. Inversion did not disrupt the recognition of intense expressions of emotion, highlighting that inversion alone is a poor control for emotion recognition.

Data from the present experiment indicates that in BSF faces, no emotional expression was recognised more accurately in general. In Experiment 1, there was a small effect of emotion that was not in the predicted direction. Previous results have suggested that happy faces are better recognised than fear or angry faces (Prkachin, 2003; McKelvie, 1995). However, in Experiment 1, fear was better recognised than happy in the low morph-strength and angry in the high morph-strength condition. The present results did not replicate this marginal emotion effect for BSF faces. This may be due to the longer presentation duration in the present experiment; alternatively, it may provide evidence to suggest the marginal effect found previously was unreliable, and non-replicable.

In the BSF angry and happy expressions, there was an additive effect of orientation and polarity manipulations. In the fear expression, the orientation and luminance polarity manipulations were found to interact, as when they were combined, sensitivity was reduced further than the sum of their independent costs. This effect seems to be driven by particularly high recognition of positive inverted fearful faces (see Figure 3.2.). Overall, the findings from the BSF faces compliment the results from Experiment 1 well. Even when the faces were presented for double the period of time, orientation and luminance polarity negation had significant detrimental effects on emotional recognition.

Emotional categorisation in the HSF faces was generally very high, suggesting that HSF information is more informative than LSF for recognition of emotion as well as identity (Fiorentini et al., 1983). However, it was found that even in faces only containing HSF information, orientation and polarity manipulations did reduce sensitivity in an additive way. As predicted, and concurring with previous findings with identity recognition (Hayes et al., 1986), the HSF faces were less affected by luminance polarity negation than the BSF and LSF faces. Both spatial inversion and luminance polarity negation significantly impaired emotion recognition in the HSF faces, but the effect of negation was not significant in the high emotional intensity faces. This suggests that luminance polarity negation alone would not be a suitable control for HSF faces. In the HSF faces, inversion disrupted emotion processing more than luminance polarity negation.

Recently it has been suggested that emotional information resides at different spatial frequencies across expressions (Smith et al., 2005; Smith & Schyns, 2009). Data from the present experiment indicates that there were no differences in the recognition of fear, happy and angry expressions when presented in HSF. This suggests HSF information is equally useful in the categorisation of the three emotional expressions tested here.

The luminance negation and orientation manipulations affected the HSF expressions differently. Negation disrupted recognition of happy expressions more than fear and angry expressions. Indeed, anger recognition was not significantly impaired by negation. When presented with low emotional intensity, inversion did not significantly further disrupt sensitivity to fear faces, although it did for happy and angry expressions. Despite these interactions between the manipulations and emotional expressions, sensitivity was significantly reduced for each expression for each of the morph-levels in the inverted negative compared to the upright positive faces.

Categorisation was much poorer in images with LSF profiles, in agreement with findings from identity recognition (Fiorentini, et al., 1983). Both neuroimaging (Vuilleumier et al., 2003) and behavioural (Holmes et al., 2005) data suggest that it is the LSF components of a fearful face that may drive its prioritisation. It is interesting that there is an apparent dissociation between the SF profiles used to attentionally prioritise emotional expressions (e.g. Holmes et al., 2005), and those used to explicitly categorise emotion. In the present experiment, LSF fearful faces were not recognised any better than LSF angry or happy faces.

In the LSF faces, both spatial inversion and luminance polarity reversal significantly impaired emotion recognition. Recognition of LSF faces was impaired more by luminance polarity negation than inversion. This follows the same pattern of results as the BSF faces, and suggests that consistent luminance polarity relationships are particularly important for the LSF components of expressive faces.

With the LSF faces there was an interaction between orientation and polarity, as there was an effect of orientation in the positive faces, but not in the negative faces. There was also an effect of polarity in the upright faces, and a weaker (but still marginally significant) effect in the inverted faces. These interactions were possibly due to the generally lower recognition rates in the upright positive LSF faces (relative to the upright positive BSF and HSF faces).

In summary, Experiment 2 largely replicated the results from Experiment 1 for BSF faces. Despite the faces being presented for 200ms (twice the presentation duration of Experiment 1), inversion and luminance polarity manipulations continued to significantly disrupt emotional face categorisation. In HSF faces, categorisation of all expressions was as high as BSF faces. Luminance polarity negation had a limited effect on HSF emotional face categorisation. However, when combined with inversion, categorisation was significantly impaired for all expressions compared to upright positive faces. In LSF faces, categorisation was generally quite poor, and there was no effect of emotion. Both inversion and luminance polarity reversal significantly impaired emotion categorisation. In conclusion, the processing of emotional information in BSF, HSF and LSF faces was disrupted by inversion and luminance polarity negation. This indicates that inverted negative faces will make good control stimuli for emotional faces in each of the SF bands.

Chapter 4

Unconscious processing of threat

4.1. Introduction

Evolutionary-based theories of emotion processing suggest that emotional information, and particularly threat-relevant information, enjoys a processing advantage (Ohman & Mineka, 2001). Adaptive behaviour would demand that potentially dangerous stimuli are prioritised in the competition for attention (LeDoux, 1996). There is evidence to suggest that as well as being prioritised for attention (e.g. Pourtois et al., 2004), threatening information can be processed unconsciously (e.g. Milders et al., 2006), possibly via a subcortical processing route (LeDoux, 1996). However, the extent to which emotionally laden information enjoys preferential unconscious processing is controversial (Vuilleumier et al., 2001; Pessoa, 2002).

Research investigating the unconscious processing of emotion has primarily used a backward masking technique. In backward masking, briefly presented emotional 'targets' are replaced by a neutral 'mask' (see *Section 1.4.1*). Even under masking conditions reported to induce full suppression from awareness, using backward masking, the amygdala is activated in response to threat (Vuilleumier et al., 2001). However the extent to which backward masking reliably prevents conscious processing has been recently questioned (Pessoa et al., 2004, see *Section 1.4.1*). The current experiment uses a new methodology based on binocular rivalry, to further investigate emotional expression processing outside of awareness.

Binocular rivalry (see *Section 1.4.3*) has been used extensively to explore visual perception. Dominance epochs in binocular rivalry typically last only a few seconds, and are stochastic (Levelt, 1965). Early theories posited that the competition during binocular rivalry occurred between the eyes, in monocular processing channels early in the visual system (Blake, 1989). If this were the case, then higher-level factors would have little effect on the resolution of binocular rivalry. However, it has since been convincingly shown that binocular rivalry is not exclusively resolved between monocular processing channels (Kovacs et al., 1996; Logothetis et al., 1996). In an elegant study, Kovacs et al., (1996) presented two complementary patchwork images to each eye. Instead of each patchwork image alternating in perception for the duration of the trial, as is predicted if binocular rivalry is resolved between the eyes, perceptual reversals occurred between two integrated images. Building on this finding, recent results show that binocular rivalry dominance can be affected by higher-level factors of the stimuli presented (Graf & Adams, 2008; Watson et al., 2004).

Whilst measuring neurological activation to emotional faces and despite full and unambiguous suppression from awareness induced by binocular rivalry, amygdala activation is increased in response to fearful versus neutral facial expressions (Williams, et al., 2004; Pasley et al., 2004). These fMRI results suggest that fearful faces are more salient than neutral faces. In concurrence with this, behavioural studies have found an effect of emotion on dominance in binocular rivalry (Alpers & Gerdes, 2007; Bannerman et al., 2008). Alpers and Gerdes (2007) found that happy and angry faces were more likely to dominate perception than neutral faces. Bannerman et al., (2008) found that happy and fearful faces had higher dominance over a house stimulus than the neutral expression. However, as these stimuli used binocular rivalry with periods of dominance and suppression of each stimulus, it is unclear whether these experiments have measured the effect of unconsciously processed emotion, or the saliency of the dominant, consciously evaluated image. Additionally, these studies suffer from experimental flaws that that make it impossible to discern whether the effects are driven by emotion, or other, confounding variables (e.g. low-level stimulus characteristics, or fusion; see *Section 1.4.3*).

Continuous flash suppression (CFS) is a method of interocular suppression based on binocular rivalry that has been used to render highly salient stimuli invisible, and can do so for relatively long periods of time (Tsuchiya & Koch, 2005; also see *p.22*). In CFS, highly salient, dynamic noise is presented to one eye, which successfully renders stimuli presented in the other eye invisible. Suppression of a stimulus in CFS is effective and reliable for long periods of time (sometimes longer than 3 minutes; Tsuchiya & Koch, 2005). Compared to binocular rivalry, and backward masking, the prolonged suppression afforded by CFS allows behavioural and neurological investigations of longer-term unconscious processing. Additionally, CFS suppression is much stronger than binocular rivalry suppression, as has been shown using a probe detection task in the suppression phase of these two paradigms (Tsuchiya, Koch, Gilroy & Blake, 2006). For these reasons, and although it has only recently been devised, CFS has been used extensively to investigate unconscious processing (Tsuchiya & Koch, 2005; Gilroy & Blake, 2005; Jiang & He, 2006; Jiang et al., 2007; Moradi et al., 2005; Yang et al., 2007; Adams et al., 2010).

In CFS, the period of time a stimulus is suppressed is defined by its strength (e.g. a low contrast stimulus takes longer to emerge from suppression than a high contrast stimulus; Tsuchiya & Koch, 2004). Higher-level stimulus properties have also been found to modulate the duration of suppression by CFS (Jiang et al., 2007). Jiang et al. (2007) conducted two CFS experiments in which the meaningfulness of the suppressed stimulus was manipulated, and the time taken for the stimulus to emerge from suppression was recorded. In the first experiment, upright and inverted faces were used. They found that upright faces emerged from suppression more quickly than inverted faces. To account for the possibility that these results were due to differences between recognition speeds in the upright and inverted faces, a control condition was composed. In this control condition, the upright and inverted faces were blended into the random noise, and their contrast gradually increased. Both the face and the noise were presented to both eyes (i.e. there was no rivalry). There was no difference between detection rates in the upright and inverted faces in the control condition, suggesting that the difference between the conditions under CFS was due to a processing advantage for upright faces under suppression, leading to their faster emergence into conscious awareness.

In their second experiment, Jiang et al., (2007) presented words under suppression. The stimuli were either Chinese characters or Hebrew words, and participants were Chinese speakers (could read Chinese, but not Hebrew), Hebrew speakers (could read Hebrew, but not Chinese) or English speakers (could read neither Hebrew, nor Chinese). Chinese characters emerged faster from suppression than Hebrew words for Chinese speakers, and the opposite was true for Hebrew speakers. Hebrew words also emerged faster for English speakers, but this may have been due to low-level properties of the stimuli (e.g. Hebrew words may be more salient because they extended a greater horizontal distance; Jiang et al.). From these two experiments, Jiang et al. conclude that familiarity may enhance the salience of a stimulus even when it is being processed unconsciously.

Given the proposed subcortical pathway for emotion processing (LeDoux, 2000), and the responsiveness of the amygdala to emotional faces under suppression (Williams et al., 2004; Pasley et al., 2004; Jiang & He, 2006), an interesting question is whether emotional information enjoys preferential access to awareness over neutral information when presented in CFS.

Yang et al. (2007) applied the CFS method to emotion processing to discover if emotional facial expressions gained access to awareness faster than neutral faces. In two experiments, they found that fearful faces emerged from suppression faster than happy or neutral expressions. They included an inverted face to control for the low-level visual characteristics of the faces. However, even when inverted, the fearful faces were detected more quickly than the happy or neutral faces, and the magnitude of the effect was the same irrespective of face orientation. There are two plausible accounts for the lack of an inversion effect in these data: either low-level stimulus characteristics are driving the effect; or inversion does not allow for full control of facial expression (i.e. residual emotion processing accounts for the effect in both upright and inverted conditions).

The primary aim of the present experiment was to distinguish between the low and high-level accounts of previous findings concerning the effect of emotion on the speed with which faces overcome CFS (Yang et al., 2007). Experiment 1 of the present thesis showed that inversion did reduce sensitivity to emotion, but the effect was limited. Thus it is possible that fearful faces emerge faster than other emotions even when they are presented upside-down, due to residual emotion processing. However, it is also possible that Yang et al.'s results are due to low-level stimulus properties; low-level characteristics, such as contrast, luminance, and colour are crucial in the resolution of perceptual dominance during binocular rivalry (Alais & Blake, 2005). Separating out these explanations (low- vs. high-level) is critical because if low-level stimulus properties account for the 'fear advantage' then such effects can be explained without reference to a subcortical emotion-sensitive pathway. This does not disprove the existence of such a pathway (see Pessoa & Adolphs, 2010, for related discussion), and indeed, there are a number of studies indicating differential neurological activation within this pathway to unconsciously presented fearful faces (Jiang & He, 2006; Williams et al., 2004; Pasley et al., 2004). However, a low-level explanation negates the need to hypothesise the involvement of any mechanism that evaluates emotional content in the absence of awareness.

By both inverting and negating facial expressions, data from Experiment 1 indicate that emotional categorisation is reduced to chance. Therefore, if the emotional content of the fearful face is driving its faster emergence from suppression, this faster emergence will be eliminated when faces are presented spatially inverted and with negative polarity. The fearful faces' processing advantage should only be evident in the conditions in which emotional content is available (i.e. when the face is presented upright and in positive polarity, and perhaps to a lesser extent when it is spatially inverted and positive polarity). On the other hand, if the emotion in the fearful face is not driving its faster emergence from suppression, and instead low-level characteristics are responsible for the effect, the relative difference between the fearful face and the emotions will be upheld across all manipulation conditions.

Another possibility is that fearful faces are detected faster after emergence into conscious awareness, giving the impression that they emerge from CFS quicker. To overcome this possible confound, a control task similar to the control used by Jiang et al., (2007) was used to measure detection times. In this task the face and dynamic noise were presented to both eyes, but the contrast of the face was gradually increased, and participants indicated when they could see a face. Therefore, this control condition was used to capture whether the unconscious emergence effect can be explained by differential detection times to the stimuli when they are consciously perceived. In their study, Jiang et al., (2007) found no difference in the detection time of upright vs. inverted faces. However, the detection times of different expressions have not previously been measured using this method.

Key Hypotheses

1) Fear faces will emerge from suppression faster than other expressions

And **either**:

2) Low-level visual differences between the stimuli account for the prioritisation (i.e. a similar 'fear' prioritisation will be seen for the inverted, negative polarity stimuli).

or:

3) The emotional content of the stimuli account for the prioritisation (i.e. fear faces will be prioritised in the upright, positive stimuli, but not in the inverted, negative polarity stimuli).

4.2. Method

4.2.1. Participants

Forty-one undergraduates (6 males) participated in the study in exchange for course credit. Their mean age was 21.05 (*SD*=5.35). All observers had normal or corrected-to-normal visual acuity, and gave informed consent.

4.2.2. Questionnaires

The same anxiety questionnaires were administered as in Experiments 1 and 2, including the: STAI (Spielberger et al., 1983), FNE (Watson & Friend, 1969), SADS (Watson & Friend, 1969), SDS (Strahan & Gerbasi, 1972).

4.2.3. Apparatus and Visual Stimuli

A mirrored stereoscope was used to present different images to each eye. Head movements were controlled using a chin rest.

The face stimuli were identical to the stimuli used in Experiment 1, apart from some minor changes: Firstly, only the 100% morph strength was used. Also, the size of the faces was reduced, so that they subtended 2.1 x 2.8 degrees of visual angle (DVA; viewing distance = 85cm). This reduction in size was used to make the stimuli comparable to the stimulus size used by Jiang et al., (2007). All four manipulation conditions were included in the current experiment (upright positive, inverted positive, upright negative, inverted negative). Both the upright positive and inverted negative faces were needed to answer the primary research question. In addition, the inverted positive condition was included to allow full replication of Yang et al., (2007). The upright negative condition was also included so each manipulation was presented an equal number of times to avoid potential problems of participants expecting particular stimuli (i.e. normal luminance stimuli), or asymmetric practice effects.

4.2.4. Procedure

In the CFS condition, a test face was presented to one eye, whilst random, dynamic noise was presented to the other (presented at approx. 10hz). The noise consisted of random sized ellipses each with a different, random luminance. The luminance range of the noise was reduced from 0-100% (to 25- 75%) after pilot work indicated that with this large range, the duration of suppression was unreasonably long. The left and right halves of the visual display were framed by a random-dot border (6.20 x 4.75 DVA) to facilitate convergence of the two eyes' images (see Figure 4.1.). A central fixation cross was always presented to both eyes, and participants were required to fixate at the cross for the duration of each trial. The contrast of the test face was ramped up linearly from 0 to 100% over the first 1 second of the trial, remaining constant until the observer responded. This was done to eliminate onset transients that may cause the face to gain immediate dominance (Jiang et al., 2007). On 99.8% of trials, the face was at full contrast before it entered awareness. Faces were presented randomly to one of four possible locations (of equal distance from the fixation cross), one in each quadrant of the visual field. Participants indicated which side of fixation the face appeared on using the left and right arrow keys.

As described above, a control condition was employed to indicate if any results found in the experimental condition could be explained by differences in detection speeds or biases in response criteria for the different stimuli. In the control condition, random dynamic noise was presented to both eyes and the contrast of the face stimulus (also presented to both eyes) was gradually increased. In this control condition (as in Jiang et al., 2007), the face was ramped in more slowly than in the rivalry condition, increasing by approximately 7% of full contrast per second, i.e. taking 15 seconds to reach full contrast. This stopped the faces being detected straight away (as would have been the case if they reached full contrast within 1 second).

There were 1024 trials (2 suppression conditions x 4 emotions x 4 stimulus manipulations) with 32 repetitions of each condition, balanced across eye of presentation, side of presentation, and identity of model. Sixteen of the repetitions were presented in a random order in the first session. The remaining 16 repetitions were randomised in the second session. State questionnaire measures were taken at the beginning of each session and trait measures were taken at the end of the first session.

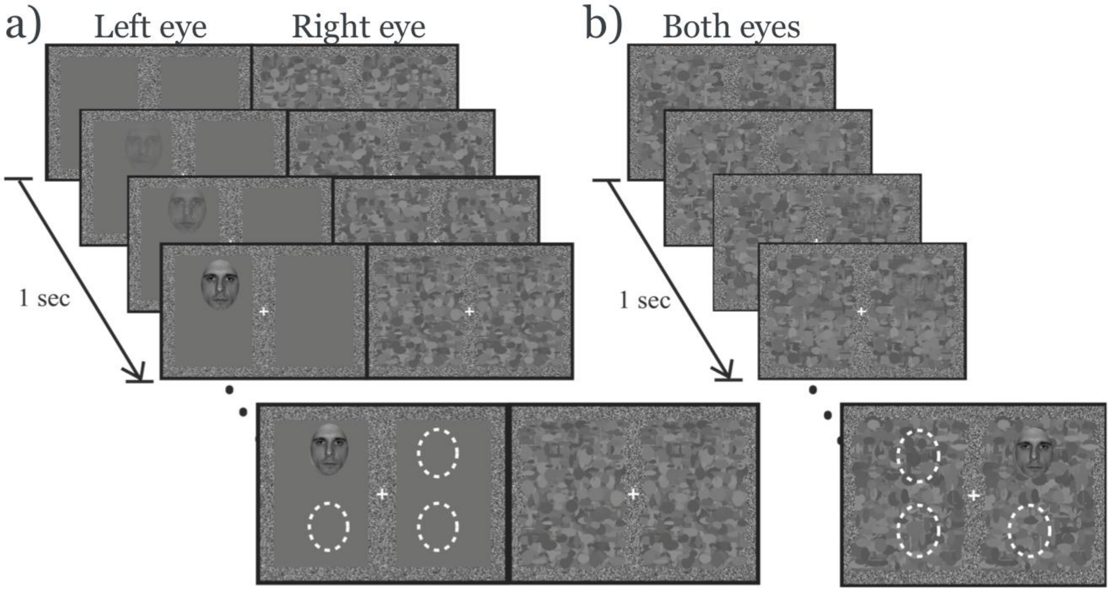

Figure 4.1. Schematic representation of the experimental paradigm, including a) the CFS condition, and b) the control condition. Dashed circles represent the (other) possible locations the faces could appear.

4.2.5. Data Analysis

RTs were computed on correct responses only. Four out of the 41 participants gave over 15% incorrect responses regarding the side of fixation that the face was presented, and were therefore excluded from the analyses (see Appendix G for a box-plot of the incorrect response distribution). The mean error rate from the remaining participants was 1.8% (*SD*=1.29%). RTs below 250ms were removed, as these scores are unlikely to reflect emergence from noise, but are probably due to error. To reduce the effect of outliers and to normalise the distributions (Ratcliff, 1993), the reciprocal (1/RT) of the data was taken. Following the transformation, outliers were removed: scores more extreme than the mean ±3SD within participant, emotion and manipulation were eliminated. The removed scores accounted for less than 0.5% of the data. According to Central Limit Theory, the shape of a sampling distribution (the distribution of sample means) will be normally distributed irrespective of the shape of the original distribution, given large enough samples. Therefore after the mean score was extracted from the reciprocal data, the means were transformed back into RTs. There was no indication that the parametric assumptions were not met for the mean RT data (K-S tests, *p*s>.1).

Repeated measures ANOVAs were used to discover if there were any differences between the RTs for different emotions and conditions. Significant main effects were investigated using pairwise comparisons (using Bonferroni correction), and significant interactions were analysed with post-hoc ANOVAs and (Bonferroni-corrected) paired *t*-tests.

4.3. Results

4.3.1. Sample Characteristics

On each of the questionnaire measures there was a normal range of scores (see Appendix H), and anxiety did not predict any of the dependent measures (see Appendix I).

4.3.2. CFS condition

Firstly, exploration of the *CFS* condition showed a replication of the effects found by Yang et al. (2007; see Figure 4.2.). There were significant main effects of emotion, $F(3, 108) = 55.36$, $p<.001$, $\eta_p^2=.61$, and manipulation, $F(3,108) = 51.55$, $p<.001$, $\eta_p^2=.59$, and an interaction between emotion and manipulation, $F(9, 324) = 4.94$, $p<.001$, $\eta_p^2=.12$. Critically, in the upright positive condition fear faces were responded to significantly faster than all other emotions (Bonferroni corrected *t*-tests of each emotion vs. fear: angry, $t(36)=8.09$, $p<.001$; happy, $t(36)=3.79$, $p<.01$; neutral, $t(36) =4.31$, $p<.001$). This result suggests that when the faces were presented normally, fearful faces were unconsciously prioritised. These results are directly comparable to those found by Yang et al. (2007), with the exception that they found significantly faster responses to the neutral face than the happy face. In the present results, there was no difference in response time between the neutral and happy faces ($p>.05$; see Figure 4.2.).

Critically, the prioritisation of fear was also shown in the other manipulation conditions; the fearful face was responded to faster than all other expressions in the inverted positive condition (Bonferroni corrected t-tests of each emotion vs. fear: angry, $t(36) = 7.08$, $p<.001$; happy, $t(36) = 5.04$, $p<.001$; neutral, $t(36) = 5.22$, $p<.001$; replicating Yang et al., 2007), the upright negative condition (angry, $t(36) = 7.25$, $p<.001$; happy, $t(36) = 2.80$, $p<.01$; neutral, $t(36) = 6.47$, $p<.001$), and the inverted negative condition (angry, $t(36)=5.43$, $p<.001$; happy, $t(36) = 2.72$, $p<.05$; neutral, $t(36)=4.10$, $p<.001$). This suggests that the observed prioritisation of fearful faces in the current experiment (and perhaps other experiments, e.g. Yang et al., 2007) is due to low-level visual properties that are present whether the faces are recognisable or not. If recognisable emotional content did contribute to stimulus prioritisation, then the fear advantage (faster fear than neutral response times) would be larger in the upright positive condition, where expression was easily categorised, than in the inverted negative, unrecognisable, condition. On the contrary, the 'fear advantage' was marginally *smaller* in the 'normal' condition (Neutral – Fear (upright positive): μ=11msec; Neutral – Fear (inverted negative) μ=26msec). In other words, the presence of recognisable emotion does not add any emotion-based prioritisation for fear faces.

In summary, low-level visual characteristics can explain the apparent emotion effect in the CFS condition. It is interesting to note, however, that Yang et al. (2007), and Jiang et al. (2007) found that upright faces emerged faster than inverted faces. The main effect of manipulation in the present experiment showed that upright positive faces were responded to faster than all other manipulation conditions (inverted positive, $t(36) = 8.67$, $p<.001$; upright negative, $t(36) = 8.57$, $p<.001$; inverted negative, $t(36) = 7.81$, $p<.001$). Also there was a marginally significant difference between the two conditions that moderately disrupt emotion processing; inverted positive was responded to marginally faster than upright negative ($t(36) = 2.85$, $p=.076$). And, the inverted negative condition was responded to significantly slower than both the inverted positive ($t(36) =4.86$, $p<.001$) and upright negative ($t(36) = 4.53$, $p<.001$) conditions. The main effects were replicated in each of the emotional expressions. However, the difference between inverted positive and upright negative was only significant in the neutral expression ($t(36)=3.51$, $p<.01$). Also in the neutral expression the upright negative faces were not responded to any faster than the inverted negative faces ($p>.05$).

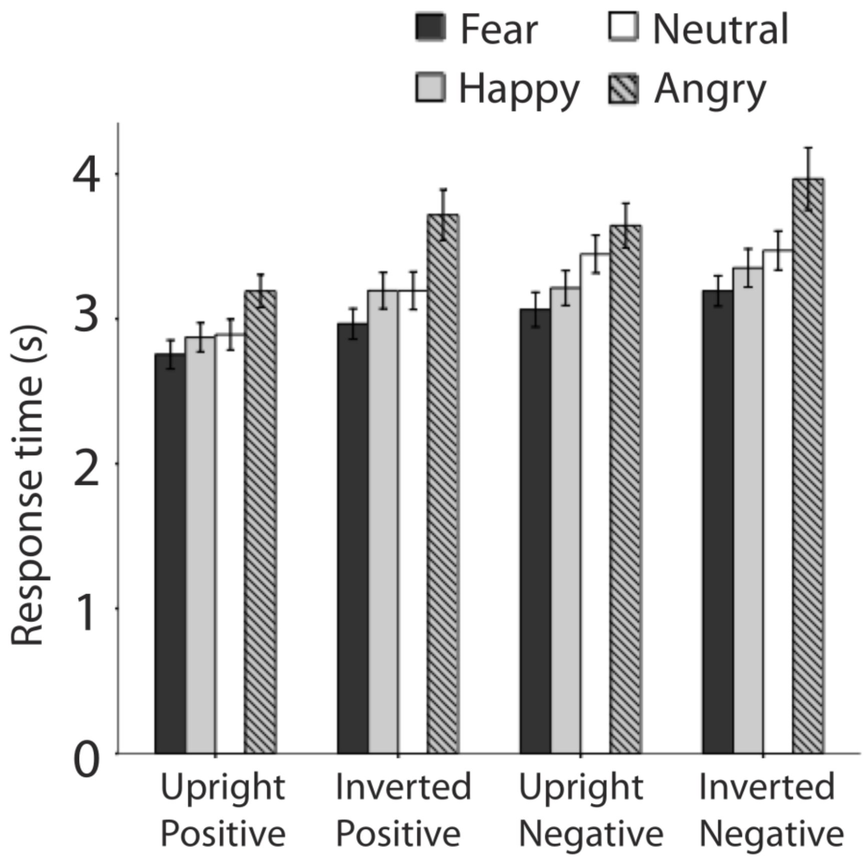

Figure 4.2. Mean response time (±1 SE) for each emotion as a function of manipulation condition.

4.3.3. Control condition

Data from the control condition suggest that systematic response biases to visible stimuli may have affected the CFS data. The effects of emotion (F(3,108)=62.01, p<.001, η_p^2=.63), and stimulus manipulation (F(3,108)=36.86, p<.001, η_p^2=.51), were remarkably similar to the CFS data: fearful faces were detected significantly faster than all the other emotions (followed by happy, neutral, then angry faces; all pairwise comparisons significant, p<.001). In the control task, observers were also faster to detect 'normal' faces; upright positive faces were detected fastest, followed by inverted positive, then upright negative, and finally inverted negative (all pairwise comparisons significant, p<.001). To create an unbiased measure of emergence time, these response biases were subtracted from the CFS data. As variability across conditions was slightly higher in the control than the CFS data, each data set was first normalised using a zscore transformation. Thus the unbiased measure of emergence time for each emotion and stimulus manipulation was given by CFS zscores – control zscores[13].

4.3.4. Unbiased measure of emergence

The transformed difference scores were entered into a repeated-measures ANOVA. In this unbiased measure of emergence time, there were significant main effects of emotion, $F(3,108) = 13.99$, $p<.001$, $\eta_p^2 = .28$, manipulation, $F(3,108) = 9.45$, $p=.001$, $\eta_p^2 = .21$, and a significant emotion by manipulation interaction, $F(9, 324) = 2.44$, $p<.05$, $\eta_p^2 = .06$ (see Figure 4.3). Although there were significant emotion effects in each condition (One-way ANOVAs on emotion within each manipulation condition: upright positive, $F(3,108) = 6.12$, $p=.001$; inverted positive: $F(3,108) = 11.43$, $p<.001$; upright negative: $F(3,108) = 5.99$, $p<.01$; inverted negative: $F(3, 108) = 6.53$, $p<.01$), pairwise comparisons revealed that these emotion effects were generally caused by the angry expression emerging slower than the other expressions. In the critical upright positive condition, the angry expression emerged slower than all others (Bonferroni corrected t-tests of each emotion vs. angry: fear, $t(36)=3.91$, $p<.001$, happy, $t(36) = 6.36$, $p<.001$, and neutral, $t(36) = 6.70$, $p<.001$), but no other comparisons were significant.

The same pattern of results was also found in the other manipulation conditions. In the inverted positive condition the angry expression emerged significantly slower than the other expressions (Bonferroni corrected t-tests of each emotion vs. angry: fear, $t(36) = 3.90$, $p<.001$; happy, $t(36) = 3.10$, $p<.01$; neutral, $t(36) = 4.17$, $p<.001$). In the upright negative condition, the angry expression emerged significantly slower than the fear, $t(36) = 3.12$, $p<.01$, and the happy, $t(36) = 2.86$, $p<.01$, but not the neutral expression ($p>.05$). And in the inverted negative condition, the angry expression emerged significantly slower than all expressions (fear, $t(36) = 2.64$, $p<.05$; happy, $t(36) = 3.23$, $p<.01$, neutral, $t(36) = 3.46$, $p=.001$). The slowed emergence of the angry expression across manipulation conditions suggests that this effect is due to low-level characteristics of the angry face, not the emotional content.

In the unbiased measure of emergence time, upright positive faces generally emerged faster than the inverted and negated faces. Upright positive faces emerged

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[13] Parallel analyses using the difference between the raw scores, rather than z-scores produced almost identical results.

faster than inverted positive faces for fearful, $t(36)=3.65$, $p<.01$, angry, $t(36)=3.92$, $p<.001$, and happy expressions, $t(36)=3.37$, $p<.01$, although not for the neutral expression ($p>.05$). Generally, the upright positive condition also emerged faster than the upright reversed (angry, $t(36) = 2.55$, $p=.06$; happy, $t(36) = 2.82$, $p<.01$; neutral, $t(36) = 3.05$, $p< .01$; but not fear, $p>.05$), and the inverted reversed faces (angry, $t(36) = 2.78$, $p<.01$; fear, $t(36) = 4.93$, $p<.001$; happy, $t(36) = 2.35$, $p<.05$; but not for neutral, $p>.05$). Thus, upright positive faces emerge from suppression faster than manipulated faces, even after response biases are controlled for. Importantly, both the analyses of (i) the CFS data and (ii) the ‘unbiased emergence times’ lead to the same key conclusion: the emotional content of visual face stimuli does not modulate their effective salience; recognisable emotional content does not lead to faster access to conscious awareness.

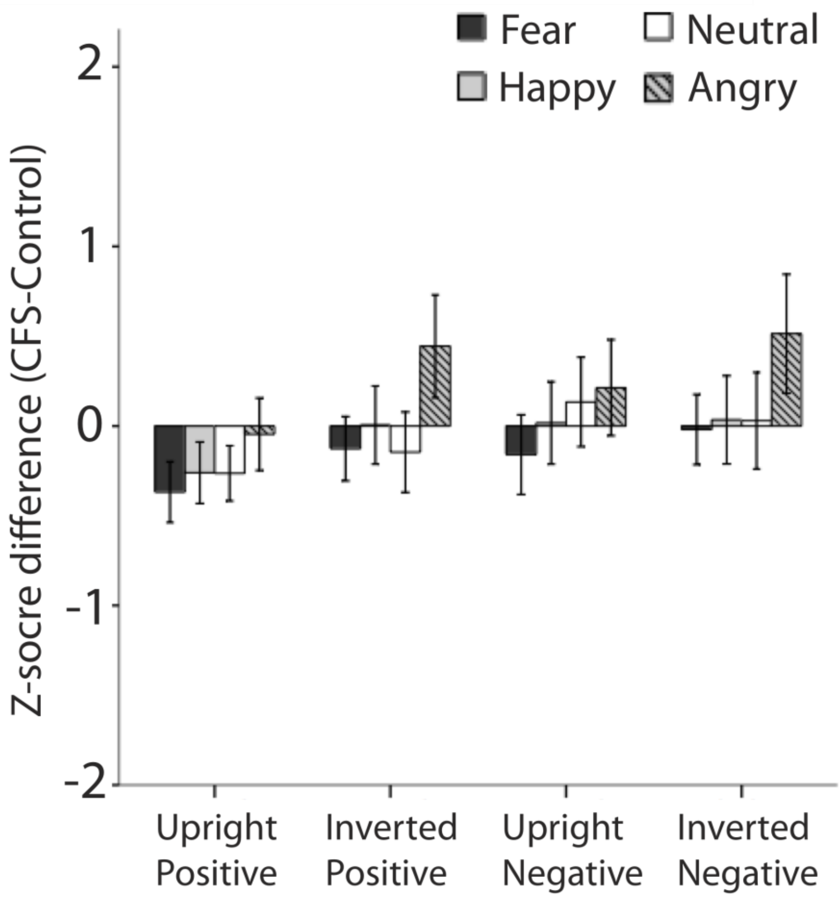

Figure 4.3. Mean CFS corrected by control data (CFS-control) for each emotion as a function of manipulation condition (±1 SE).

4.4. Discussion

The present experiment used a well-controlled CFS procedure to explore the unconscious processing of different emotion expressions. Results from the present experiment replicated the unconscious fear prioritisation effect found previously in normal faces (Yang et al., 2007); fear faces emerged from CFS faster than neutral, happy or angry expressions. Additionally, this fear prioritisation was found when the faces were inverted, again, replicating previous findings by Yang et al. (2007). Critically, the fear prioritisation was also evident in the unrecognisable faces. Therefore the meaning, or emotional content of the faces were found to add nothing to the advantage afforded by basic image properties. Which low-level visual properties might cause the emotion effects found here? Although the stimuli were matched for mean luminance and contrast, there were a number of low-level properties that were not controlled for (including local contrast and luminance, spatial frequency). Particularly important to the fear prioritisation may be that fearful expressions contain a local region of high contrast around the eyes. Indeed, Yang et al. (2007, Experiment 3) presented only the eye region of faces under CFS and found that fear eyes were detected faster than happy or neutral eyes. It appears that the low-level image properties of a fear face (such as the high contrast eye region) enable it to emerge faster from suppression.

Previously it has been suggested that a subcortical processing pathway can rapidly evaluate and prioritise emotional information for attention and awareness (Tamietto & de Gelder, 2010). The results of the present experiment are particularly important because they indicate that the fear prioritisation effect can be explained without reference to a subcortical pathway specialised in threat detection. Recently, Pessoa and Adolphs (2010) have proposed a framework that redefines the role of the subcortical pathway in emotion processing. It suggests that the primary role of subcortical brain regions, including the amygdala and pulvinar, is to modulate the response driven by cortical networks. This description thus emphasises the role of cortical responses to emotional stimuli more than previous descriptions (see Tamietto & de Gelder, 2010). Results from the present experiment fit well within this framework and are consistent with the notion that our physical facial expression of fear has evolved to be salient to low-level visual processes.

The present results suggest that fear prioritisation is due to the low-level properties of the stimuli. Recently, Tsuchiya, Moradi, Felsen, Yamazaki & Adolphs, (2009) used a similar method to that used by Yang et al., (2007) to investigate the prioritisation of fearful faces in an individual with bilateral amygdala lesions. They found that upright fear faces emerged from CFS suppression faster than upright happy faces in control participants. Importantly, this was also found (to the same extent) in the amygdala lesion patient. This was taken as evidence that threat-related prioritisation is intact in the absence of the amygala (Tsuchiya et al., 2009). Results from the present experiment would predict this effect, as they indicate that threat-detection in a CFS paradigm is driven by low-level properties of a stimulus that are likely to be salient to early visual cortex, with little need for input from subcortical structures (such as the amygdala). Therefore, previous findings, such as those from Yang et al., (2007) and Tsuchiya et al., (2009) should be interpreted carefully.

Response biases may have contributed to the CFS data, as suggested by the data from the control condition (e.g. faster responses to both recognisable and unrecognisable visible fear faces after emergence). The control condition was based on a similar control used in Jiang et al.’s (2007) experiment. However, in the control condition, the rate of stimulus contrast increase was arbitrary (despite Jiang et al. previously using this rate). Perceptually, the similarity between the control and CFS conditions is also slightly problematic. When stimuli emerge from rivalry suppression (or CFS), they do not tend to gradually appear, as if their contrast is being increased. Instead, it is far more of an ‘all or none’ process (it is possible that local patches may appear, rather than the whole stimulus, i.e. piecemeal rivalry). Therefore, extracting the biases found in the control condition from the CFS condition may be overly conservative.

There is an additional problem with using this control paradigm in which the contrast of the stimuli is gradually increased. With this method there is a slightly different type of emergence effect (the stimuli are consciously detected when their contrast reaches threshold), as well as the button response effect that was postulated to occur in both the CFS and control conditions. Therefore, in calculating the ‘unbiased emergence times’ and effectively subtracting out the effects of the control condition, some of the emergence effect is being removed at the same time. Again, this suggests that extracting the biases found in the control condition may be overly conservative.

Given that the control condition may include both emergence effects and effects due to conscious processing, what can be interpreted from the ‘unbiased emergence’ data? Despite the limitations described above, the measure of bias in the control condition is informative, as is the ‘unbiased emergence’ data that were calculated.

Although the data from the control condition may overestimate biases, any effects in the emergence data that withstand this overly conservative correction must be particularly robust. Therefore, the unbiased emergence data will still be discussed.

Generally, the unbiased emergence times agreed with that of the CFS data, as angry expressions were found to take significantly longer to reach visual awareness than other expressions. This same response pattern across normal and unrecognisable angry faces, implicates low-level visual characteristics in its increased suppression. In addition, this effect must be particularly robust given that it survived the conservative bias correction. The low salience of angry faces (in both CFS and corrected emergence data), contrasts with the prioritisation of threat-related emotions proposed by evolutionary-based theories (Ohman & Mineka, 2001). It is consistent, however, with previous findings that happy and fearful faces dominate over neutral and angry faces on the initial percept in binocular rivalry (Gray et al., 2009).

Backward masking paradigms (presenting a brief emotional face, followed immediately by a neutral face 'mask') have been used to support the notion that facial emotion is processed outside of awareness. Backward-masked emotional faces elicit physiological responses (Esteves et al., 1994), and subcortical neural activation (Morris et al., 1998; Whalen et al., 1998). However, these findings have been questioned using more stringent, objective measures of awareness (Pessoa et al., 2005; Pessoa et al., 2006). Selective amygdala responsivity to fearful faces (versus neutral faces, Jiang & He, 2006; Williams et al., 2004) and emotion aftereffects (Adams et al., 2010) have been found under rivalry and CFS suppression, suggesting relatively high-level processing of emotional faces without awareness. However, these studies do not imply recognition (either implicit or explicit) of unconsciously presented emotional faces. The results of the present experiment suggest that the higher-level emotional information displayed in the faces has no effect on whether they gain prioritised access to awareness.

Across emotion, it was found that normal (upright positive) faces emerge from suppression faster than inverted or negated faces, in agreement with previous work (Jiang et al., 2007). These results suggest that some face-related processing causes normal faces to appear more quickly than inverted and negated faces. This is true in both the CFS and the 'unbiased emergence time' data (suggesting that it is a robust effect that exists when the overly conservative response biases are accounted for). Given that the resolution of binocular rivalry has been suggested to be resolved over multiple stages of the visual system (e.g. Nguyen et al., 2003), it is possible that the suppressed image is processed in the cortex to the extent that the difference between normal and manipulated faces can affect the time taken for them to emerge from suppression. This is particularly interesting, as it suggests that some high-level processing persists under suppression from CFS, in concordance with other studies (e.g. Jiang et al., 2007).

Despite finding that recognisability of a face impacts on the time taken for it to emerge from CFS, the results from the present experiment show that emotion effects can be explained by low-level visual properties. The stimuli used in the present experiment were controlled, in terms of their low-level properties, as far as possible (for colour, mean luminance and RMS contrast). It has been suggested that the subcortical pathway processes low spatial frequency (LSF) information (Livingston & Hubel, 1988), and prioritises threat-relevant expressions based on their LSF content (Vuilleumier et al., 2003). Thus, it would be interesting to investigate whether LSF emotional faces are prioritised for awareness using a CFS paradigm, and whether any emotion effects are due to low-level properties or the extraction of emotional meaning. Therefore Chapter 5 explores the effect of SF and emotion in a CFS paradigm.

In conclusion, CFS is an interesting method with which to study emotional processing outside of awareness, allowing for stimuli to be suppressed for greater periods of time than traditional methods (e.g. backward masking, binocular rivalry). The results of the present experiment suggest that emotion effects are caused solely by low-level visual characteristics. This indicates that some effects that have been attributed unconscious emotion evaluation via a subcortical pathway (e.g. Yang et al., 2007) are more likely to be caused by low-level properties that are salient to the visual cortex.

Chapter 5

Investigating the visual characteristics that contribute to unconscious emotion processing: spatial frequency

5.1. Introduction

As stated in Chapter 3, the spatial frequency (SF) content of an image is analysed early in visual processing (De Valois & De Valois, 1988; Morrison & Schyns, 2001). High spatial frequency (HSF) and low spatial frequency (LSF) information may depend on somewhat separate neural pathways (Livingston & Hubel, 1988). HSF information tends to be processed by parvo cells, which have slow responses and small receptive fields, whilst LSF information tends to be processed via magno cells, which have fast responses but larger receptive fields (Campbell & Robson, 1968; De Valois & De Valois, 1988; Shapley & Lennie, 1985). LeDoux (2000) suggested that threat-relevant information is preferentially processed via a subcortical processing pathway, which bypasses the visual cortex. The subcortical pathway is dominated by magno cells (Miller et al., 1980), and therefore should use LSF information to prioritise threatening stimuli (Vuilleumier et al., 2003).

A seminal paper by Vuilleumier et al. (2003) showed that the increased amygdala activation found in response to fearful faces was due to their LSF components. In their study, Vuilleumier et al. presented faces that displayed fearful or neutral expressions and contained broad spatial frequency (BSF), HSF or LSF information. In the behavioural task, gender judgements were faster and more accurate when the face consisted of BSFs compared to HSFs and LSFs; there was no difference in judgement accuracy between the HSF and LSF faces. The neurological data showed increased amygdala activation in response to fearful compared to neutral faces. This effect held for the BSF and LSF faces, but not for the HSF faces. Following this experiment, a number of studies have investigated brain activation in response to emotional faces with different SF profiles (Winston, Vuilleumier & Dolan, 2003; Pourtois et al., 2005; Holmes, Winston & Eimer, 2005; Vlamings, Goffaux & Kemner, 2009).

One criticism that can be levelled at Vuilleumier et al. (2003) is that their stimuli were not matched for contrast and luminance across the SF bands (although there was not a significant difference in mean luminance across stimuli). For natural images, there is less energy in HSFs compared to LSFs (Loftus & Harley, 2005). Thus, it is possible that there was relatively little HSF contrast energy in Vuilleumier et al.'s face stimuli, reducing the possibility of detecting emotion-specific responses in the HSF stimuli. This 'energy' confound was inadvertently addressed by Winston et al. (2003) who used hybrid stimuli to investigate the effect of attention on brain activation in response to emotional faces with different SF profiles (described in Chapter 3). Winston et al. found that LSF fear faces were associated with increased activation compared to neutral faces in the FFA and amygdala, irrespective of the SF of the gender participants reported perceiving.

Several studies have investigated the effects of SF on emotional face processing using ERPs as a dependent measure (Pourtois, et al., 2005; Vlamings et al., 2009; Holmes, Winston & Eimer, 2005). Pourtois et al. (2005) and Vlamings et al. (2009) found that fearful faces selectively increased ERP amplitudes at P1 latency for LSF faces (and BSF faces; Pourtois et al., 2005), but not for HSF faces. Holmes, Winston and Eimer (2005) also recorded ERPs in response to faces whilst manipulating SF and emotion. In contrast to Pourtois et al., a fear effect was only found in BSF faces (fearful faces displayed an enhanced positivity at 155-255ms post stimulus compared to neutral faces; no such effect was found in the HSF or LSF faces). These conflicting results suggest that using ERPs to investigate the effect of SF on emotion processing is not straightforward. Different methods were used to control stimulus energy over these experiments, but the impact of this is unclear (Pourtois et al. used hybrid stimuli with inverted faces as the non-target image, whilst Holmes et al. and Vlamings et al. equalised mean luminance and contrast across all faces).

Do the findings from neuroimaging/electrophysiological studies translate into differences in behaviour elicited by LSF and HSF emotional faces? Recall that in Chapter 1 (*Section 1.2.1*) a study was described in which attentional prioritisation was shown for LSF fearful faces using a behavioural paradigm. Holmes, Green and

Vuilleumier (2005) conducted a series of experiments to investigate the importance of LSF and HSF components for the attentional prioritisation of fearful faces. In Experiment 1, they measured attentional bias to LSF and HSF fearful faces compared to neutral faces using a dot probe task. Participants were required to indicate the orientation of a probe presented after a briefly presented (30ms/100ms) emotional face. When faces were presented in LSF, probes following fearful faces were responded to significantly faster than those following neutral faces. This was not the case for HSF faces. To explore whether the results were caused by low-level visual characteristics, the experiment was replicated with inverted faces. When presented upside down, there was no difference in RTs to fear and neutral expressions irrespective of SF condition. As an additional control, Holmes et al. equalised mean luminance and contrast across the different SF bands, and repeated the original experiment. It is unlikely that low-level characteristics such as contrast or luminance would be driving the effect found in their first experiment, given the null result found with inverted faces. This proposition was confirmed, as the effect was still evident with these more controlled stimuli.

In Chapter 3, it was found that conscious facial expression recognition is dramatically reduced for LSF compared to HSF or BSF faces (also found by Holmes et al., 2005). However, conscious recognition of emotion may be dissociated from subcortical neuronal activation, and unconscious prioritisation. Although Winston et al. (2003) showed increased amygdala activation to LSF fear faces even when they are unattended, no study to date has explored whether LSF emotional faces are preferentially processed when presented outside of awareness.

A recent study investigated the impact of SF on unconscious identity processing using a priming technique. De Gardelle and Koudier (2010) required participants to make a fame judgement on normal faces (half were famous) that were preceded by a consciously or unconsciously presented prime face. Normal prime faces were either a full repetition of the target face (full priming), or a different face altogether (full baseline). They also presented hybrid primes so that LSF or HSF information could be selectively primed. Their hybrids consisted of LSF components from one identity, and HSF components from another. For example, to prime LSF, the LSF content of the image was the same as the target face, and the HSF content was taken from a different face. A baseline hybrid prime was also created, which consisted of HSF and LSF from different faces, neither of which was the target face. The response time (RT) to classify the target face as famous (or not) was recorded. Priming was calculated as the difference in RT between baseline conditions and repetition conditions. There was significant priming for the BSF faces, and also significant priming for LSF and HSF components. This was true in both conscious and unconscious presentation methods (in the unconscious condition, backward masking was used with an objective awareness check). The amount of priming was associated with prime duration (more priming was found for increased prime durations) when the primes were BSF and HSF. However, no increase in prime effect was found with increased prime duration for LSF components. These results suggest that both HSF and LSF information contribute to unconscious vision, but that LSF information can be processed entirely independently from awareness. On the other hand, this result may be found because the priming from LSF information saturates more quickly.

Although the subcortical pathway may predominately process LSFs (Vuilleumier et al., 2003), it has recently been argued that the amygdala both receives and uses HSF information to process expressions (see Pessoa & Adolphs, 2010). There is evidence to suggest that the amygdala receives highly processed cortical input (via feedback from the visual cortex; Amaral, Price, Pitkanen & Carmichael, 1992), which may influence amygdala activation and help explain differential amygdala responses to fearful and neutral faces. HSF information does seem to be important for fear processing in the amygdala; in an amygdala lesion patient, impaired perception of fear has been attributed to reduced processing of HSF information around the eye region (Adolphs et al., 2005). These results indicate that HSF information is important in fear recognition and suggest that the amygdala has a role in this HSF processing. Nevertheless, studies have shown differential amygdala activation to LSF fear vs. LSF neutral faces, and no such difference between HSF emotional faces (e.g. Vuilleumier et al., 2003). However, it is unclear whether these results are caused by feedback to the amygdala from the visual cortex (see Pessoa &Adolphs, 2010), thus questioning the direction of the relationship between amygdala activation and prioritised visual processing.

In summary, there is both behavioural and neurological evidence suggesting that it is the LSF components of fearful faces that drive their prioritisation (e.g. Vuilleumier et al., 2003; Holmes, Green & Vuilleumier, 2005). In contrast, there is also evidence that HSFs provide input to the subcortical pathway, and are important for fear processing (see Pessoa & Adolphs, 2010, for a review). The present experiment will use a CFS procedure to investigate whether the SF content of an emotional face modulates visual prioritisation as measured by emergence from suppression.

If emotional prioritisation is found for the LSF faces, but not the HSF faces, it would indicate that LSFs are important for the unconscious processing of emotional faces. The results from Experiment 3 of this thesis suggest that the prioritisation of fearful expressions in gaining awareness can be explained by low-level visual characteristics rather than the extraction of emotional meaning. Both normal (upright positive) and manipulated (inverted negative) faces will be presented in the current experiment, and will allow an investigation into whether any SF effects are based on low-level characteristics, or the extraction of emotional meaning. Given the findings from Experiment 3, it is predicted that low-level characteristics will also explain any LSF emotion effects.

Many researchers have investigated the prioritisation of fearful faces over neutral faces without also considering any other emotion. This is particularly true for SF investigations (e.g. Vuilleumier et al., 2003; Pourtois, et al., 2005; Vlamings et al., 2009; Holmes, Winston & Eimer, 2005). In Experiment 3, the inclusion of additional emotional expressions was very informative, as they did not follow the pattern predicted by evolutionary-based theory (e.g. Ohman & Mineka, 2001); threat-relevant angry faces emerged from suppression slowest. In the present experiment, four emotions will again be tested (as in previous Experiments in this thesis), namely, fear, happy, angry and neutral expressions. It is unclear whether the additional expressions included in the present experiment will be granted prioritised access to awareness when presented in HSF and LSF. When presented in BSF, neither happy nor angry faces were unconsciously prioritised over neutral expressions (Experiment 3).

Normal faces have consistently emerged faster from CFS suppression than inverted (Yang et al., 2007; Jiang et al., 2007) and manipulated faces (Experiment 3 of this thesis). This suggests that face-specific processes are engaged under suppression and more ‘face-like’ stimuli are prioritised. Therefore, a face effect is predicted in the present experiment for BSF faces. Using the present methodological design it will be possible to discover whether the face effect found in previous experiments exists in faces containing only HSF or LSF information. In this way we can assess which SF components are responsible for the unconscious prioritisation of normal faces.

A control condition (similar to that used in Experiment 3, and Jiang et al., 2007) will also be included in the present experiment. Despite there being some methodological issues with this control condition (see Chapter 4, *Section 4.4*), the inclusion of this condition will allow an approximation of conscious response biases that may be contaminating the CFS data.

Key hypotheses:

1. BSF emotion effects will follow the pattern found in Chapter 4, with a significant prioritisation of fear faces.
2. For LSF faces, emotion effects will be at least as large as in the BSF condition
3. Emotion effects will be reduced in magnitude in HSF faces compared to BSF and LSF faces
4. Emotion effects will be explained by low-level visual characteristics, i.e. the emotion effect will be similar in both the normal, and manipulated faces
5. There will be a 'face effect', as normal faces will emerge faster than manipulated faces

5.2. Method

5.2.1. Participants

Eighteen undergraduate and postgraduate students at the University of Southampton (2 males) participated in the study in exchange for course credit or payment. Their mean age was 21 years (*SD*=3.11). All observers had normal or corrected-to-normal visual acuity, and gave informed consent.

5.2.2. Questionnaires

The same anxiety questionnaires were administered as in previous Experiments, including the STAI (Spielberger et al., 1983), FNE (Watson & Friend, 1969), SADS (Watson & Friend, 1969), and SDS (Strahan & Gerbasi, 1972).

5.2.3. Apparatus and Visual Stimuli

A mirrored stereoscope was used to present different images to each eye. Head movements were controlled using a chin rest. The same face stimuli were used as in Experiment 3 (i.e. 100% morph strength, presented at 2.1 x 2.8 DVA, viewing distance =85cm). 'Normal' faces (upright positive) and 'manipulated' (inverted negative) faces were used in the current experiment. However, to address the current research questions, the faces were presented in BSF (unfiltered), HSF (>24cpf), and LSF (<6cpf). The faces were filtered using the same method as Experiment 2.

5.2.4. Procedure

The procedure was broadly the same as Experiment 3. In the CFS condition, a face was presented to one eye, whilst dynamic noise was presented to the other (at approx. 10hz). The contrast of the test face was increased linearly from 0 to 100% over the first 1 second of the trial, remaining constant until the observer responded. Faces were presented randomly in one of four possible locations (of equal distance from the fixation cross), one in each quadrant of the visual field. Preliminary investigations[14] indicated that the HSF faces were difficult to locate on the grey background, as they do not have a contour at the edge of the face (unlike LSF and BSF faces). To eliminate the influence of this potential confound, a random-dot ellipse 'placeholder' was presented in each of the four possible locations (see Figure 5.1). On every trial (irrespective of the face SF), four placeholders emerged at the same rate as the faces (to avoid onset transients), and the face was positioned in one of them. Participants indicated which side of fixation the face appeared by using the left and right arrow keys.

A control condition was used to determine whether results were influenced by differences in detection speeds or biases in response criteria. In the control condition, random dynamic noise was presented to both eyes and the contrast of the face stimulus (also presented to both eyes) was gradually increased. In this control condition, the face was ramped in more slowly than in the rivalry condition, increasing by approximately 7% of full contrast per second, i.e. taking 15 seconds to reach full contrast (similarly to Jiang et al., 2007). This was done in order to stop the faces being detected straight away (as would have been the case if they reached full contrast within 1 second). The placeholders were also used in the control condition to eliminate the contour confound discussed earlier. In the control condition, the placeholders reached full contrast by 1 second, therefore providing a full contrast contour from 1 second into each control trial.

There were 1536 trials (2 suppression conditions x 4 emotions x 4 stimulus manipulations x 3 SFs) with 32 repetitions of each condition, balanced across eye of presentation, side of presentation, and identity of model. Participants completed the

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[14] I collected data with myself as an observer in the first instance.

experiment over 3 sessions. State questionnaire measures were taken at the beginning of each session and trait measures were taken at the end of the first session.

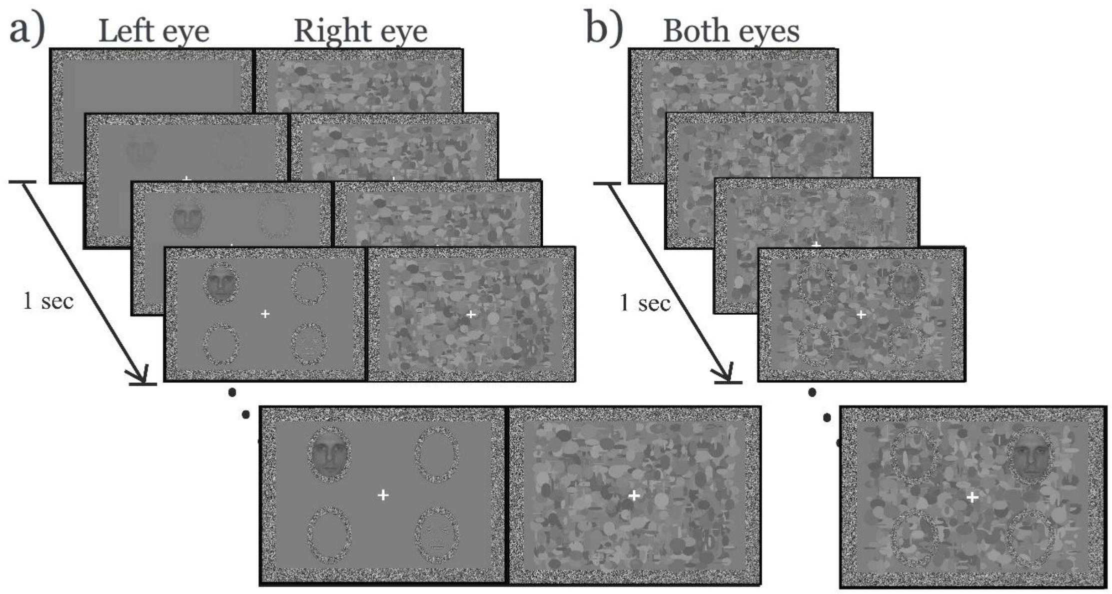

Figure 5.1. Schematic representation of the experimental paradigm, including a) the CFS condition, and b) the Control condition.

5.2.5. Data Analysis

The data were prepared in same way as Experiment 3. RTs were computed on correct responses only. The mean error rate was 1.41% (*SD*=1.15%). RTs below 250ms were removed. Following the reciprocal transformation (1/RT), outliers were removed: scores more than ±3SD from the mean within participant and condition were eliminated. The removed scores accounted for less than 0.4% of the data. There was no indication that the parametric assumptions were not met for the transformed data (K-S tests, $p>.05$). In contrast to Experiment 3, the reciprocal scores were not transformed back into RTs (given the reduced sample size).

Repeated measures ANOVAs were used to discover if there were any differences between the transformed scores for different emotions and conditions. Significant main effects were investigated using pairwise comparisons (using Bonferroni correction), and significant interactions were analysed with post-hoc ANOVAs and (Bonferroni corrected) paired *t*-tests.

5.3. Results

5.3.1. Sample Characteristics

There was a normal range of scores on each of the questionnaire measures (see Appendix J), and anxiety did not predict any of the dependent measures (see Appendix K).

5.3.2. CFS condition

Firstly, in the CFS condition (see Figure 5.2), there were significant main effects of manipulation, $F(1,17) = 105.36$, $p<.001$, $\eta_p^2=.86$, and SF, $F(2,34) = 3.31$, $p<.05$, $\eta_p^2=.16$. There were also significant interactions between emotion and SF, $F(6, 102) = 2.34$, $p<.05$, $\eta_p^2=.12$, and manipulation and SF, $F(2,34) = 6.09$, $p<.01$, $\eta_p^2=.26$.

Decomposition of the main effect of SF suggests that HSF (*M*=.211, *SD*=.034) and LSF (*M*=.211, *SD*=.036) faces were responded to at a very similar rate ($p=.97$). BSF faces (*M*=.214, *SD*=.035), on the other hand, were responded to faster than HSF faces, $t(17) = 4.59$, $p<.001$, and marginally faster than LSF faces, $t(17) = 2.00$, $p=.064$.

If unconscious emotion effects are driven largely by a magnocellular, subcortical pathway, there should be greater emotion effects in the LSF compared to HSF faces. However, there was only a marginal effect of emotion in the LSF faces, $F(3,51) = 2.42$, $p=.08$, where only one paired comparison was marginally significant; happy faces were responded to faster than angry faces, $t(17) = 2.31$, $p=.07$. There was no significant difference between fear and the other expressions, indicating no evidence for prioritisation of fear faces via their LSF content. In the HSF faces, there was also an effect of emotion, $F(3,51) = 3.05$, $p<.05$, as fear faces were responded to faster than happy faces ($t(17) = 2.77$, $p<.05$; no other comparisons were significant). Contrary to findings from Experiment 3, there was no effect of emotion in the BSF condition, ($p=.64$). This lack of an emotion effect in the BSF faces was unexpected, given results from the previous Chapter, where all pairwise comparisons between emotions were highly significant in the CFS condition.

Normal (upright positive) faces (*M*=.216, *SD*=.035) were responded to faster than manipulated (inverted negative) faces (*M*=.207, *SD*=.035). This replicates the face advantage found in Experiment 3, and results from previous research (Yang et al., 2007; Jiang et al., 2007). This prioritisation of normal over manipulated faces was apparent in each of the SFs (Bonferroni corrected t-tests between upright positive and inverted negative faces in each of the SFs: HSF, $t(17) = 4.11$, $p = .001$; LSF, $t(17) = 8.88$, $p < .001$; BSF, $t(17) = 7.29$, $p < .001$). Interestingly, in the normal condition, BSF (*M*=.219, *SD*=.034) faces were responded to faster than HSF (*M*=.214, *SD* = .035), $t(17) = 5.57$, $p < .001$, and marginally faster than LSF faces (*M*=.214, *SD* =.035), $t(17) = 1.98$, $p = .06$, whereas there was no difference between the SFs in the manipulated condition ($p > .1$). This suggests that the faster responses towards BSF faces over HSF and LSF faces is not due to the low-level visual characteristics of the BSF stimuli.

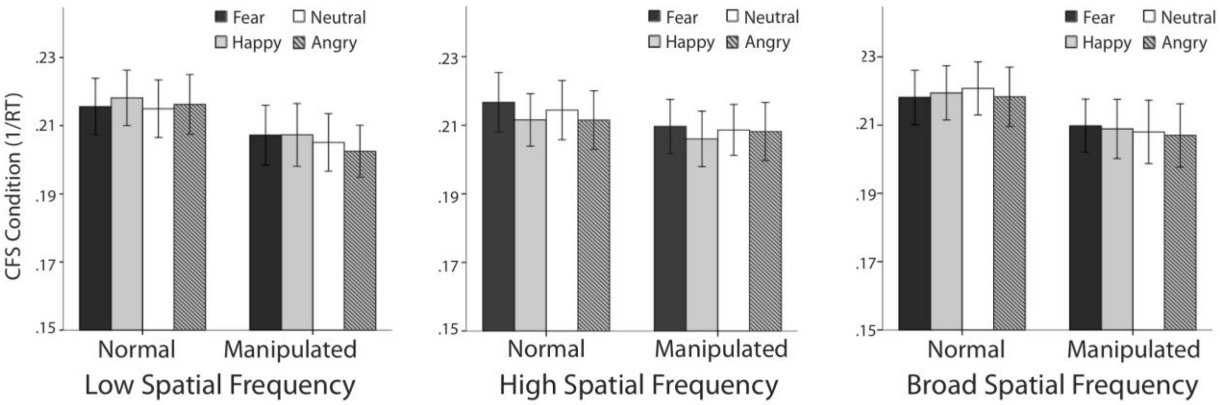

Figure 5.2. Mean reciprocal score (±1 SE) from the CFS condition for each emotion as a function of manipulation condition and spatial frequency profile of the face. Note that a higher reciprocal score is indicative of a faster response.

5.3.3. Control condition

Data from the control condition suggest that, once visible, the different stimuli might have taken different times to be detected / responded to (although it may not only be conscious biases that are captured using this control condition, see *Section 4.4*). There was a significant main effect of manipulation ($F(1,17) = 90.20$, $p < .001$, $\eta_p^2 = .84$), and SF ($F(1.15, 19.54) = 141.96$, $p < .001$, $\eta_p^2 = .89$), and an interaction between manipulation and SF ($F(2,34) = 20.49$, $p < .001$, $\eta_p^2 = .55$). The HSF components of the faces seemed to aid conscious detection as LSF faces (*M*=.165, *SD*=.023) were detected more slowly than both BSF (*M*=.202, *SD*=.023; $t(17) = 11.79$, $p < .001$, and HSF faces (*M*=.200, *SD*=.025; $t(17) = 12.32$, $p < .001$). However, there was no difference between the detection times of BSF and HSF faces ($p > .1$).

Under the assumption that the CFS and the control data were subject to similar response biases (Jiang et al., 2007), they can be combined to estimate unbiased emergence times. In Chapter 4, the value of the control condition in measuring response bias was discussed (*Section 4.4*), and it was concluded that the control data measure both an emergence effect and a conscious response bias. However, the data are interesting nonetheless, as only the most robust effects would withstand the conservative correction. Therefore an unbiased measure of emergence time was calculated by subtracting the control responses from the CFS data. As variability across conditions was slightly higher in the CFS than the control data, each data set was first normalised using a z-score transformation. Thus the unbiased measure of emergence time for each emotion and stimulus manipulation was given by CFS z-scores – control z-scores[15].

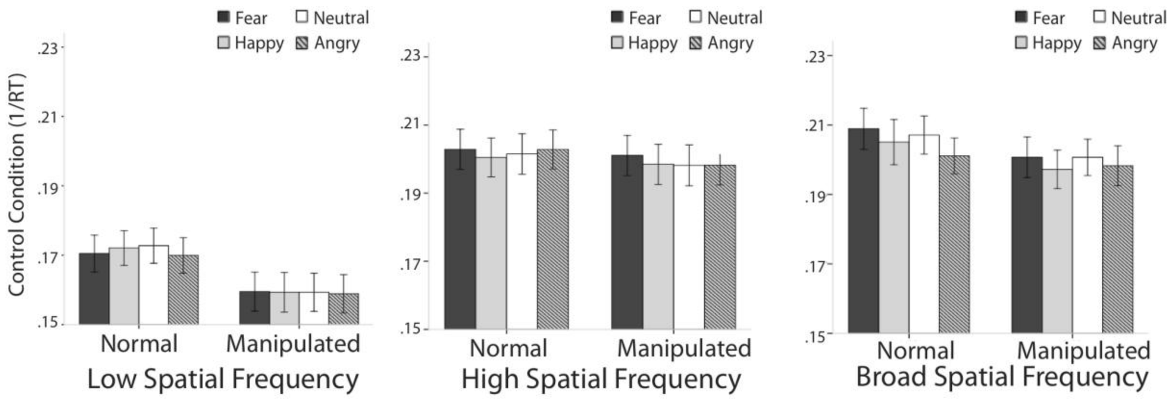

Figure 5.3. Mean reciprocal score (±1 SE) from the control condition for each emotion as a function of manipulation condition and spatial frequency profile of the face.

5.3.4. Unbiased measure of emergence

The transformed unbiased emergence data were entered into a repeated-measures ANOVA. Analysis of these emergence times reveals a main effect of SF, $F(1.3, 22.16) = 219.98$, $p<.001$, $\eta_p^2=.93$, where LSF faces emerged from suppression significantly faster than both HSF ($t(17) = 16.61$, $p<.001$), and BSF faces ($t(17) = 14.77$, $p<.001$; there was no difference between BSF and HSF faces, $p>.9$).

There was also evidence of a SF x manipulation interaction, $F(2,34) = 5.07$, $p<.05$, $\eta_p^2=.23$. The advantage for 'normal' (upright positive) faces apparent in the CFS data was not also present in the unbiased emergence data. There was no difference between the upright and manipulated faces when presented in HSF ($p>.6$), or BSF

15 Parallel analyses using the difference between the raw scores, rather than z-scores produced very similar results.

(p>.2), and the marginal effect of manipulation in LSF faces was caused by manipulated faces emerging faster than normal faces, $t(17) = 2.83$, p=.011.

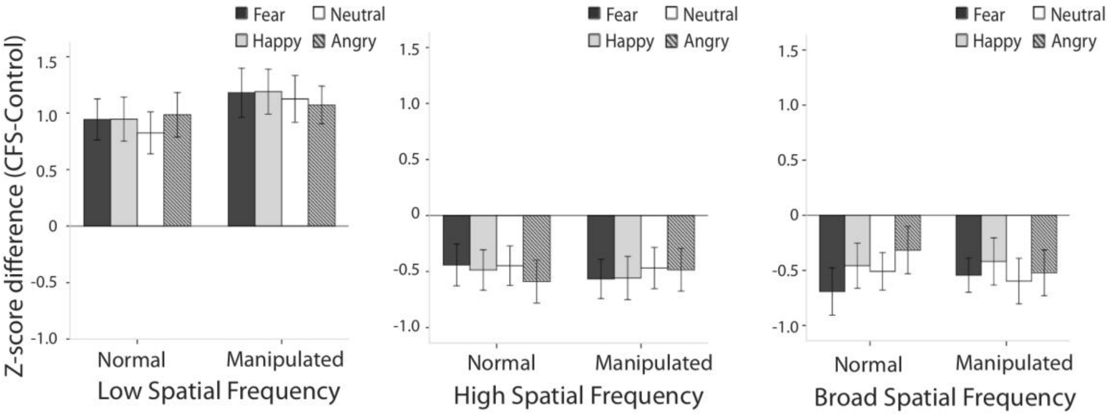

Figure 5.4. Mean CFS corrected by control data (CFS-control) for each emotion as a function of manipulation condition (±1 SE) and spatial frequency profile of the face.

5.4. Discussion

The present experiment used a CFS procedure to investigate the unconscious processing of emotional faces with different SF profiles. SF is a low-level visual property that is extracted at an early stage of visual processing (De Valois & De Valois, 1988). LSF fearful faces are associated with increased amygdala activation (Vuilleumier et al., Winston et al., 2003), and are prioritised in the competition for attention (Holmes, Green & Vuilleumier, 2005). Results from the present experiment do not provide evidence that unconscious prioritisation of emotion is driven by the LSF content of an emotional face. In the CFS data the effect of emotion was smaller in the LSF compared to the HSF faces. This is in direct conflict to experiments that have reported preferential processing of fearful faces when presented in LSF, but not HSF (Vuilleumier et al., 2003; Winston et al., 2003; Pourtois et al., 2005; Vlamings et al., 2009; Holmes, Green & Vuilleumier, 2005). However, the majority of these studies have measured neurological activation, and thus do not indicate any behavioural advantage for the LSF fearful faces. The one exception to this is the study by Holmes, Green and Vuilleumier (2005) in which LSF fearful faces were prioritised in a dot-probe paradigm. In Holmes, Green and Vuilleumier's study, the non-masked face stimuli preceding the probe were presented consciously for a minimum of 30ms. Indeed, the previous research cited here (from both neurological and behavioural paradigms) has investigated the SF components responsible for conscious fear prioritisation. Only one experiment has investigated unconscious processing of faces with different SF components, but with facial identity, not emotion (De Gardelle & Koudier, 2010). Therefore, it is possible that the LSF fear prioritisation effect does not exist in unconscious processing.

The limited emotion effects in the present experiment can be explained by low-level characteristics, rather than extraction of emotional meaning, as the same effects were found in both the normal and manipulated faces. This is in agreement with findings from Experiment 3, which indicated that the fear prioritisation effect was fully accounted for by low-level characteristics of the stimuli.

In Experiment 3 there was clear fear prioritisation (albeit explained by low-level properties). The present experiment failed to replicate this effect in the BSF faces, as well as the LSF or HSF faces. The size of the emotion effect measured in Experiment 3 was large (η_p^2=.61), and so should have been detectable given the power in the present experiment. There were several methodological differences between Experiment 3 and the present experiment: 1) placeholders were used to eliminate the contour confound found between the HSF and LSF/BSF faces; 2) HSF and LSF faces were also included. The inclusion of HSF and LSF trials may have affected results, as observers were responding to stimuli that on average (most of the trials were of HSF or LSF faces) appeared less face-like, and thus, may have changed the search strategy used.

Although there were only limited effects of emotion in the CFS condition, there were robust effects of manipulation. In each of the SFs, normal faces emerged from suppression faster than manipulated faces. This replicates the face effect found in Experiment 3, and concurs with previous evidence that normal faces emerge from suppression faster than inverted faces (Jiang et al., 2007; Yang et al., 2007). Results from the CFS data in the present experiment extend these previous findings, as they show that BSF faces are prioritised when presented unconsciously, compared to LSF and HSF faces. Importantly, this prioritisation is not based on their low-level characteristics (there was no difference between the three SF conditions when the faces were manipulated). This suggests that high-level processing does exist for face stimuli under CFS, and it is specific for BSF faces. Evidence indicates that the most important SF band for face processing is the MSF range (Costen et al., 1994; 1996, Gold et al., 1999, Nasanen, 1999); the only stimuli that contained information from this band in the present experiment were the BSF faces.

Response biases may have contributed to the CFS data. However, it is unclear whether the control condition accurately measures bias (as discussed in Chapter 4, *Section 4.4*). When control data were subtracted from the CFS data in the present experiment, the emergence data were not consistent with the CFS data. In the emergence data, there was no effect of manipulation, which is incompatible with findings from the CFS condition (in this experiment), and with previous findings (from Experiment 3). Also, LSF faces were found to emerge faster than HSF and BSF faces. It is possible that this effect is due to the SF distribution of the CFS masking stimulus (i.e. if the dynamic noise used to suppress a stimulus has more HSF information, LSF stimuli may emerge faster). Note that there was no effect of emotion in the LSF emergence data, indicating no advantage for any particular LSF emotion. Overall, it is possible that that pattern of effects found in the present experiment in the 'unbiased emergence' data was driven by the liberal estimation of bias taken from the control condition (which may have measured both emergence and conscious bias). When the effects measured in the control condition were removed from the CFS data, the remaining 'unbiased emergence' responses may have underestimated the CFS emergence effect.

Overall, the results from both the CFS and emergence data are inconsistent with a subcortically driven unconscious emotion-processing pathway that is sensitive to LSF components of a face, extracts emotional meaning from the face, and preferentially processes faces that are attributed with threat-related value. It is clear that subcortical brain structures, including the amygdala, are activated by emotional faces whilst under binocular suppression (Williams, et al., 2004; Pasley et al., 2004). Furthermore, LSFs have been implicated in subcortical threat processing (Vuilleumier et al., 2003). So why does this not translate into behavioural prioritisation? Face-related processing effects were evident in the CFS data. Given that emotional information is argued to be an important, adaptive cue (as suggested by Ohman, 2002), response times should also have been modulated by emotion. It is possible that the use of placeholders in the present experiment may have independently impacted on emotion processing (whilst not also disrupting face processing), but this is unlikely. In Experiment 3, the effect of emotion (η_p^2=.61) was very similar to the effect of manipulation (η_p^2=.59). Taken together, the results of Experiments 3 and 4 suggest that high-level processing does exist under CFS suppression, but that the emotional content of a face may not be its most salient component.

CFS has been used in several different ways to probe unconscious processing of stimuli at a behavioural level. For example, by measuring the time a stimulus takes to emerge from suppression (the paradigm used here and by Jiang et al., 2007, Yang et al., 2007). Experiments 3 and 4 used suppression duration as the dependent measure. Suppression duration gives an index of prioritisation; previous reports have found that emergence time is reflective of the salience of the suppressed stimulus (Tsuchiya & Koch, 2004; Jiang et al., 2007). Measuring the time taken for a stimulus to emerge from suppression is dependent on respose time data. Response times are generally very skewed, variable, and outliers can have a strong effect on results (Whelan, 2008). The experiments in this thesis addressed the limitations of using reaction time data through a variety of methods (see *Sections 4.2.5* and *5.2.5*). However, it would be advantageous to explore unconscious processing of emotional faces using a different dependent variable (e.g. measuring the effects of unconscious faces on contrast sensitivity), to seek to provide convergent evidence and to utilise a methodology that avoids the problems inherent in the control condition used previously.

A different way in which CFS has been used to probe unconscious processing is to measure the influence of a suppressed stimulus on subsequent perception (as used by Morodi et al., 2005; Adams, Gray et al., 2010; Yang, Hong & Blake, 2010 in adaptation paradigms). To date no experiment has investigated the effect of an image suppressed using CFS on attentional engagement using a probe detection technique. Recall that there have been a number of studies that have used backward masking to present competing faces unconsciously before probing attention with a visual-probe (e.g. Mogg & Bradley, 1999; Carlson & Reinke, 2008; Carlson, Reinke & Habib, 2009). There are issues with this literature, particularly relating to the use of subjective awareness checks (Pessoa et al., 2005), and the lack of adequate control stimuli for low-level characteristics. The next chapter will use a conscious visual probe task to investigate attentional prioritisation to emotional stimuli, which may be adapted to an unconscious version using CFS.

In conclusion, the results of the present experiment suggest that LSF emotional faces are not granted privileged processing when presented unconsciously. This does not concur with results of increased amygdala activation elicited by LSF fear faces (compared to neutral faces; Vuilleumier et al., 2003), early ERP components in response to LSF fear (Pourtois, et al., 2005; Vlamings et al., 2009) or attentional prioritisation of LSF fear faces (over neutral faces, Holmes, Green & Vuilleumier, 2005). The present results add further evidence that the extraction of emotional meaning from faces does not occur when they are presented unconsciously. In addition, the results from this experiment add to the evidence provided by a number of studies that have found a ‘face’ effect in speeded emergence from suppression (including those found in Experiment 3, and also by Jiang et al., 2007; Yang et al., 2007).

Chapter 6

Investigating the effect of a previously presented emotional face on probe contrast discrimination

6.1. Introduction

Visual-probe tasks have been used to investigate whether emotional stimuli capture attention. Attentional prioritisation of fearful faces (Pourtois et al., 2004; Pourtois et al., 2006) and angry faces (Cooper & Langton, 2006; Holmes et al., 2009) has been found using the visual-probe task (see Chapter 1, *Section 1.2.1*). However, these findings have been somewhat inconsistent (e.g. Bradley et al., 1998), especially in low-anxious individuals (Bar-Haim et al., 2007). Additionally, almost all studies that have investigated emotional prioritisation using the visual-probe task have not controlled for low-level visual characteristics of the stimuli. In Chapter 4, it was found that low-level characteristics fully explained the unconscious fear prioritisation effect. Therefore, it is unclear whether the emotional prioritisation found in visual-probe tasks is based on the extraction of emotional meaning from the faces, or visual properties, such as luminance or contrast.

The modulation of spatial attention by unconscious stimuli can be investigated by probing attention after the presentation of a briefly presented and masked emotional face (Mogg & Bradley, 1999; Carlson & Reinke, 2008; Carlson et al., 2009). Using this unconscious version of the visual-probe task, Mogg and Bradley (1999) found faster responses to probes replacing masked angry faces than those replacing masked happy or neutral faces. In their study, Mogg and Bradley used an objective awareness check in which participants were unable to discriminate, confirming that the faces did not reach consciousness. Other experiments reporting an attentional advantage for unconscious emotional faces have not employed checks for awareness, making it impossible to attribute findings to unconscious processing (Carlson & Reinke, 2008; Carlson et al., 2009).

Attentional prioritisation has also been investigated using a more sensitive version of the visual-probe task, by measuring contrast sensitivity of the probe rather than its location (Phelps et al., 2006; Bocanegra & Zeelenberg, 2009). To measure contrast sensitivity, participants are required to discriminate the orientation of the probe, for which accuracy is measured at various contrast-levels. Experimenters have used this method to examine the selective processing of competing stimuli (analogous to the classic visual-probe task; Bocanegra & Zeelenberg, 2009; Experiment 2), and exogenously cueing attention (Phelps e al., 2006; Experiment 2). It has also been used to probe temporal attention, by presenting a face centrally and measuring contrast sensitivity of a peripheral target (or presenting the same face at a number of different locations on the screen; Phelps et al., 2006, Experiment 1; Bocanegra & Zeelenberg, 2009, Experiment 1). Using this paradigm, temporal attention is probed, as the position of the probe does not vary; therefore spatial attention is not manipulated.

Outside of emotional face processing research, contrast sensitivity to visual probes has helped inform our understanding of attention (Carrasco, Ling & Read, 2004). In a seminal paper published in 2004, Carrasco et al., found that attention boosts the apparent contrast of a probe stimulus. They measured contrast thresholds of a probe presented in the same location as a previous uninformative cue (that exogenously attracted attention), or the opposite location. Participants were more sensitive to the contrast of a probe presented in the same location as the cue, compared to the opposite location. These results suggest that attention increases the strength of a stimulus by increasing its apparent contrast. Is it possible that the same may be true of emotional faces?

Phelps et al., (2006, Experiment 1) presented a fearful or neutral face centrally for a brief period (75ms) and then measured contrast sensitivity of a probe presented briefly afterwards. Four probes were presented, one of which was oriented slightly away from vertical (the target) whilst the others were vertically oriented (distractors). Participants were required to indicate whether the target was oriented clockwise or counter-clockwise from vertical. Across trials probe contrast was varied. Phelps et al. found that a lower contrast was needed for the tilt task (i.e. the psychometric function was shifted further leftwards) when a fearful, compared to a neutral face, preceded it. This suggests that fearful faces enhance contrast sensitivity without directly manipulating spatial attention. Inverted faces were used as a control; no contrast threshold difference was found between inverted fearful and inverted neutral faces, suggesting that the expression effect in the upright condition was not explained by low-level visual characteristics. Phelps et al. suggest that the facilitation of contrast sensitivity following a fearful face (vs. a neutral face) is related to the enhanced activity found in the visual system in response to emotional vs. neutral stimuli (e.g. Schupp et al., 2003). Enhanced contrast sensitivity following an emotional event would be advantageous in order for potential threat to be detected and responded to effectively (Phelps et al., 2006; Bocanegra & Zeelenberg, 2009).

There is indication from some behavioural studies that emotion may not enhance sensitivity, but actually impair it (Bocanegra & Zeelenberg, 2009; Zeelenberg & Bocanegra, 2010). Zeelenberg and Bocanegra (2010) suggest that enhancement of perception may be obscured by attentional resources being directed towards the emotional cue at the expense of the probe target. This may especially be the case for modality-specific attention (Zeelenberg & Bocanegra, 2010).

It is not only the common-modality (i.e. within the same sense) between cue and target that is important to whether an emotion-induced enhancement or impairment is found. In a recent study, Bocanegra and Zeelenberg (2009) manipulated the spatial frequency (SF) of a contrast-varying probe, which followed the presentation of a fearful or neutral face. When a low spatial frequency (LSF) probe followed the presentation of a fearful face, probe sensitivity was increased compared to when it followed a neutral face; thus replicating Phelps et al.'s (2006) findings. However, when a high spatial frequency (HSF) probe followed the presentation of a fearful face, probe sensitivity decreased. This suggests that fearful faces selectively facilitate LSF information, and impede HSF information compared to neutral faces.

Experiments 3 and 4 of the present thesis investigated unconscious emotional face processing using a CFS paradigm, with suppression duration as the dependent variable. Results from Experiment 3 suggested that fearful (rather than emotional faces generally) are prioritised to awareness, but that this prioritisation is fully explained by low-level visual characteristics. Low-level properties can also explain speeded search of emotional faces (Coelho et al., 2010; see Chapter 1; *Section 1.3.1*). It has only been relatively recently that researchers have attempted to control for low-level visual characteristics in emotional face processing research. Thus, it is unclear the extent to which findings from Experiment 3 can be generalised across different paradigms. Indeed, Experiment 4 explored whether the SF content of an emotional face modulated the speed at which it emerged from suppression. Although there were differences between SF, and there was an overall 'face' effect (normal faces were found to emerge faster than manipulated faces), there was little effect of emotion.

Motivated by the intention to replicate findings from Experiment 3 using a different dependent measure, and by the intriguing findings from Phelps et al.'s (2006) study, the present Chapter aims to adapt the paradigm used by Phelps et al. into an unconscious version. If, in an unconscious version of the task, a null effect on contrast sensitivity of a probe following different expressions was found, the source of this null effect would be unclear (whether due to the unconscious nature of the task, or slight task moderations). Therefore, the paradigm will first be tested in a conscious version.

Experiment 5

6.2. Introduction

As with other research investigating the prioritisation of emotional expressions (see *Section 1.4.1*), both Phelps et al., (2006) and Bocanegra and Zeelenberg (2009), only compared fearful versus neutral expressions. The absence of any other expression makes the results of their studies difficult to interpret. Both studies inferred (using an inverted face control) that low-level characteristics were not responsible for the emotion effects found. However, it is impossible to tell whether these results are fear specific, threat-specific, or conform to the emotionality hypothesis. Therefore, happy expressions will be included in the present experiment, as well as fear and neutral expressions.

Phelps et al., (2006) showed a significant shift in probe contrast sensitivity when the probe followed a fearful compared to a neutral expression. This was interpreted as 'facilitation' of contrast sensitivity, driven by the fearful faces. However this interpretation is not supported by a close inspection of their data. In the upright face condition, the mean contrast sensitivity at threshold was 19% for fearful, and 22% for neutral faces; in the inverted face condition, the mean contrast sensitivity at threshold was 19% for fearful, and 18.7% for neutral faces (Phelps et al., 2006, p. 294). These descriptive statistics suggest that results might be better considered to reflect impaired contrast sensitivity by upright neutral faces, rather than enhanced contrast sensitivity by upright fearful faces, as contrast thresholds were equivalent in the upright and inverted fear faces. Therefore, their data do not support that probe contrast sensitivity is increased following the presentation of an emotional face due to the extraction of emotion from the face, and its threat-relevance.

In contrast, Bocanegra and Zeelenberg's (2009) findings suggest that it is the threat-relevance that drives the effect. In their second experiment, Bocanegra and Zeelenberg centrally presented fear or neutral expressions that were either upright or inverted and followed by a HSF or LSF Gabor. There was a significant interaction between emotion and SF when presented upright (fearful faces enhanced performance when the Gabors were LSF, and impaired performance when the Gabors were HSF; the opposite was true of neutral faces), but not when the faces were inverted. However, there was a difference between performance with the upright neutral face and the inverted faces (both fear and neutral), suggesting that the pattern found with the neutral faces was caused by their meaning. Due to this pattern of results, Bocanegra and Zeelenberg performed additional analyses and found that when comparing upright vs. inverted faces there was an interaction by SF for fearful faces but not neutral faces. This suggests that the 3-way interaction between orientation, SF and emotional expression was primarily caused by the content of the fear faces.

The primary aim of Experiment 5 was to examine the predicted facilitation of perception by consciously presented positive and negative emotional expressions. The method of Phelps, et al., (2006; Experiment 1) was followed, with the exception that there was an additional happy face. Neither Phelps et al. nor Bocanegra and Zeelenberg (2009) found an effect of emotion on contrast sensitivity when the faces were inverted, suggesting that their results were not due to low-level characteristics and that the extraction of emotional meaning was responsible for the emotion effects. However, given that Experiment 1 and 2 of the present thesis clearly demonstrate inversion alone is insufficient to disrupt emotion processing, and that inverted, negative luminance polarity faces are a better control than spatial inversion alone for emotion classification, the 'manipulated' (inverted negative) faces were used as controls in the current experiment.

Key predictions

1) Fearful faces will facilitate contrast sensitivity when presented normally (i.e. there will be lower contrast thresholds for probes that follow fearful, compared to neutral faces)

2) Happy faces may also facilitate contrast sensitivity when presented normally (i.e. there will be lower contrast thresholds for probes that follow happy compared to neutral faces)
3) This will not be explained by low-level characteristics (i.e. there will be no difference in contrast thresholds for probes that follow manipulated facial expressions)

And

4) Differences between expressions will be characterised by facilitation following emotional faces, rather than impairment following neutral faces (i.e. there will be a larger difference between upright and inverted fearful/happy faces than between upright and inverted neutral faces, consistent with Bocanegra & Zeelenberg, 2009)

or

5) Differences between expressions will be characterised by impairment following neutral faces, rather than facilitation following emotional faces (i.e. there will be a larger difference between upright and inverted neutral faces rather than upright and inverted fearful/happy faces, consistent with Phelps et al., 2006)

6.3. Method

6.3.1. Participants

Sixteen undergraduates (4 males) participated in the study in exchange for course credit. Their mean age was 24.88 years (*SD*=5.83). All observers had normal or corrected-to-normal visual acuity, and all gave informed consent.

6.3.2. Questionnaires

Consistent with previous Experiments, participants completed the following measures of general and social anxiety: STAI (Spielberger et al., 1983), FNE (Watson & Friend, 1969), SADS (Watson & Friend, 1969), and social desirability: SDS (Strahan & Gerbasi, 1972).

6.3.3. Apparatus and Visual Stimuli

Head movements were controlled using a chin rest. The stimuli were created and presented using MATLAB (The Mathworks, USA) with the Psychophysics toolbox (Brainard, 1997; Pelli, 1997), and were presented on a gamma-corrected monitor. A

BITS++ box (Cambridge Research Systems Ltd, Kent, UK) provided a 14-bit greyscale resolution, allowing for accurate presentation of very low contrast stimuli.

Eleven models were taken from the Pictures of Facial Affect series (Ekman, & Friesen, 1976; 6 females, 5 males)[16], each displaying fear, happy, and neutral facial expressions (the same models were used by Phelps et al., 2006). To control for low-level characteristics, ‘manipulated’ (inverted negative) faces were also presented. As an additional control for low-level visual properties between stimuli, the faces were contained in an elliptical mask, and matched for RMS contrast and mean luminance.

Gabor patches (a sinusoidal grating in a Gaussian window) were used as probes in the tilt discrimination task. Bocanegra and Zeelenberg (2009) found that fear faces showed facilitation for LSF Gobors (Gabors with SF of <3cpd), but impairment for HSF Gobors (SF of >3cpd). In the present experiment, Gobor SF was fixed at 2cpd (which is identical to the SF used by Phelps et al., 2006). Psychometric functions were obtained using the method of constant stimuli (contrast levels were varied randomly across trials). The contrast of the Gabors was randomly taken from a set of Michelson contrasts in nine log increments from 2% to 80% (percentage contrast: 2.00, 3.01, 4.54, 6.84, 10.31, 15.53, 23.39, 35.24, 53.10, 80.00).

6.3.4. Procedure

Participants began the experimental session by completing the anxiety questionnaires. In the experimental task, a central fixation cross was presented for 500ms, followed by the centrally presented emotional face cue (either neutral, fear or happy; at 5x6.6 degrees of visual angle; DVA), which was displayed for 75ms. Following an Inter Stimulus Interval (ISI) of 50ms, in which the fixation cross was presented, four Gabor patches (each 7.9 x 7.9 DVA) were presented for 40ms, equidistant from the central fixation cross (at 11 DVA eccentricity). On every trial, one of the Gabors was oriented ±8° from vertical (the target), with the three other Gabors always oriented vertically (distractors). Participants were required to indicate which direction the target Gabor was tilted in (2AFC), by pressing the left arrow key if the top of the Gabor was oriented to the left of vertical (counter-clockwise), and the right arrow key if the top of the Gabor was oriented to the right of vertical (clockwise). Correct

[16] Face numbers: Fear: 009, 016, 024, 037, 050, 059, 068, 079, 088, 095, 104; Neutral: 013, 021, 028, 041, 056, 065, 072, 083, 092, 099, 110.

responses were followed by a tone, whereas incorrect responses were not (see Figure 6.1. for a schematic of the procedure). Phelps et al., (2006) did not specify an inter-trial interval; the present experiment used 200ms between trials (after a response was given).

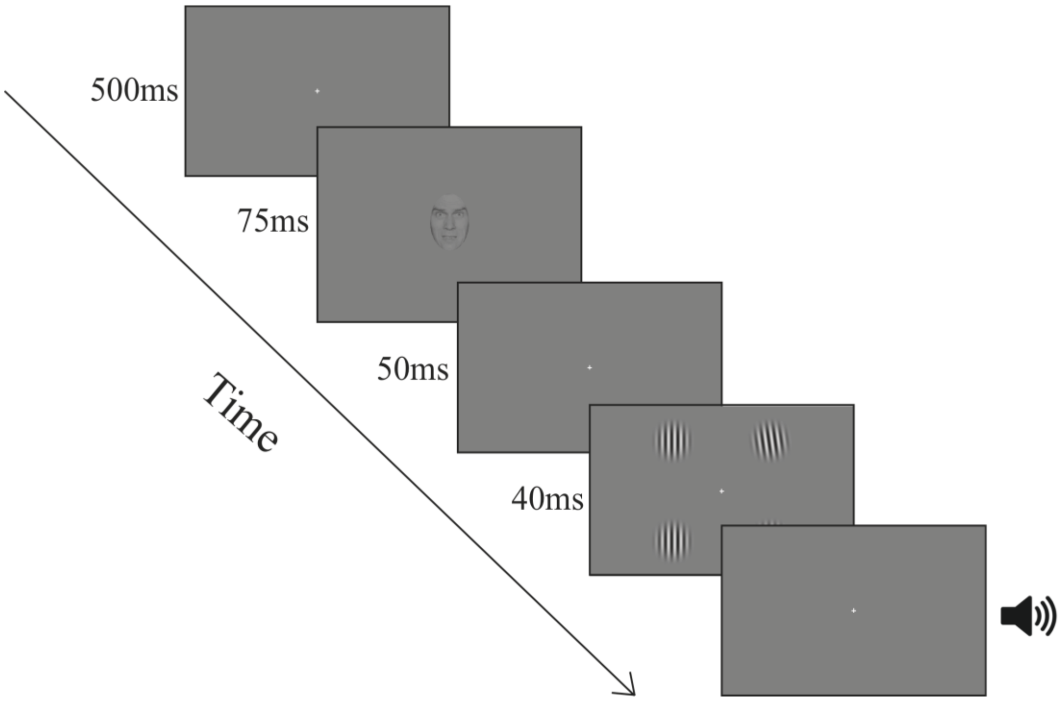

Figure 6.1, Schematic of an experimental trial used in Experiment 5. A tone was sounded when a correct response was given.

There were 1980 trials (3 emotions x 2 manipulation conditions x 10 contrast levels x 11 models x 3 repetitions). Target position (the four possible locations of the target Gabor), and target orientation (whether the target Gabor was oriented to the left or right of vertical), were randomly allocated on each trial.

6.3.5. Data Analysis

Phelps et al., (2006) took thresholds at 82% correct, however, lapsing (trials in which participants missed the presentation of the stimulus) made thresholds at 82% correct unreliable for some observers (i.e. some participants did not reach 82% accuracy at asymptote) in the present experiment, so thresholds were taken at 75%. The data for each person, and each condition, were fit with separate Weibull functions. Thresholds (75% accuracy) were entered into a repeated-measures ANOVA, with emotion (fear, happy, neutral) and manipulation condition (upright positive, inverted negative) as within participant variables.

6.4. Results

6.4.1. Sample Characteristics

On each of the questionnaire measures there was a normal range of scores (see Appendix L), and correlations with performance measures were non-significant (see Appendix M).

6.4.2. Facilitation of emotional expression

As can be seen from the averaged data, there seems to be little effect of emotion in either the normal (see Figure 6.2) or manipulated (see Figure 6.3) faces.

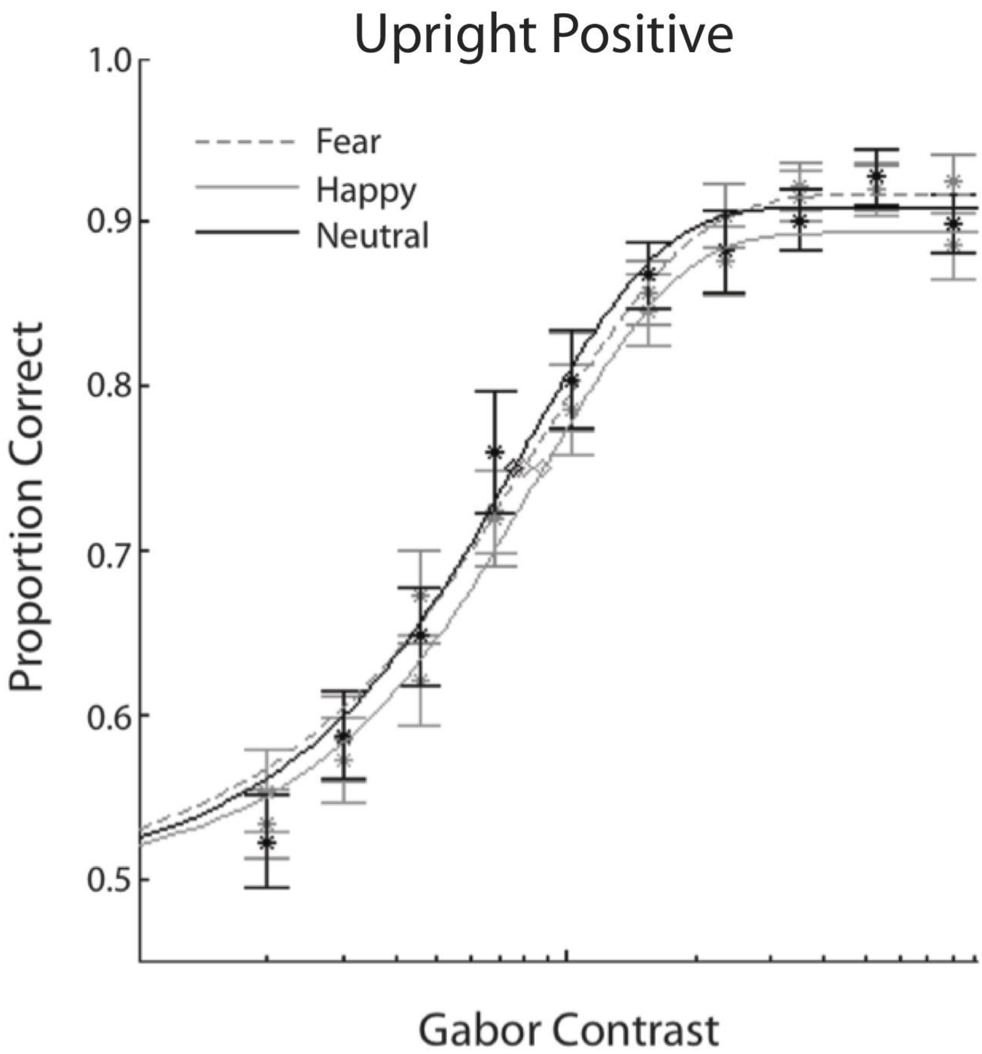

Figure 6.2. Averaged psychometric functions from Experiment 5. Observers' average accuracy for the orientation task as a function of whether the task was preceded by a fearful, happy or neutral upright positive face.

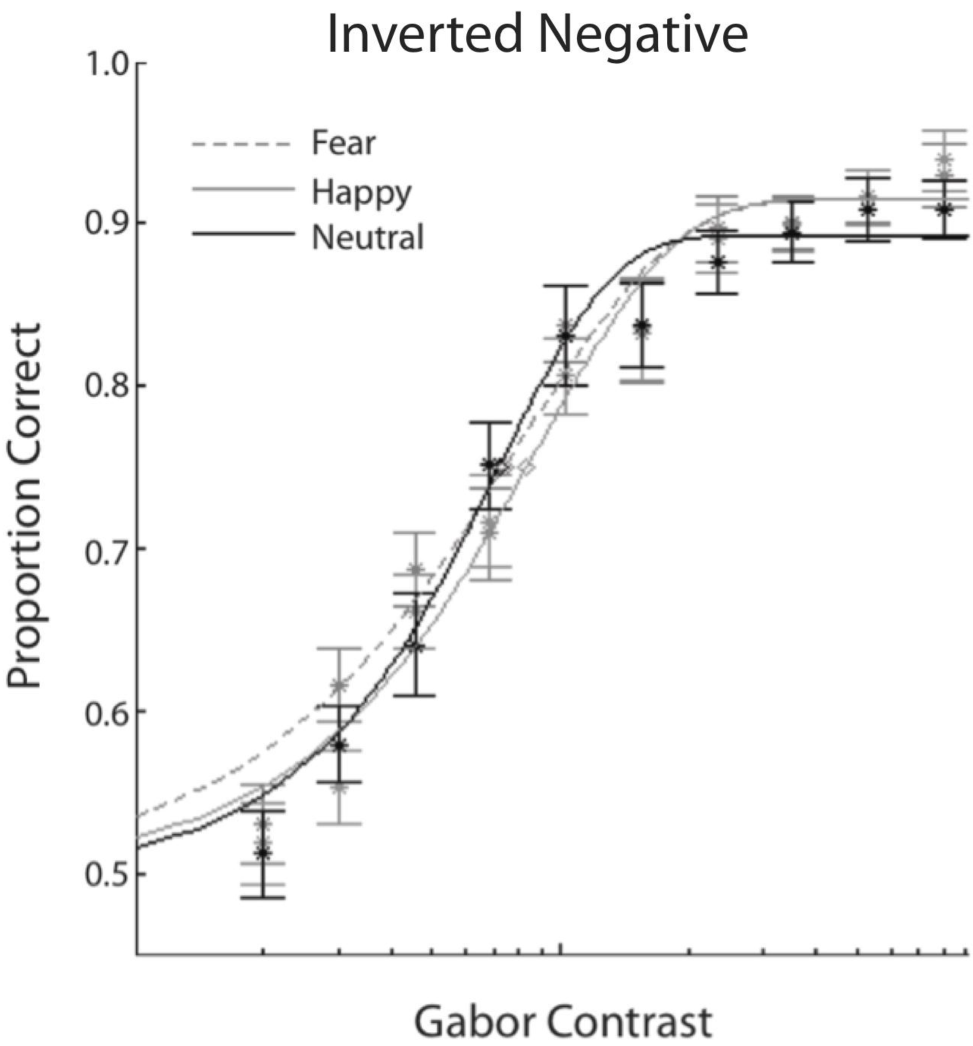

Figure 6.3. Averaged psychometric functions from Experiment 5. Observers' average accuracy for the orientation task as a function of whether the task was preceded by a fearful, happy or neutral inverted negative face.

Threshold data was entered into a 3 (emotion) x 2 (manipulation) repeated-measures ANOVA (see Figure 6.4). There was no effect of emotion (F(1.07, 16.05) = 2.84, p=.11), manipulation (F(1,15) = 2.10, p=.17), or emotion x manipulation interaction, (F(1.18, 17.73) = 1.27, p=.28).

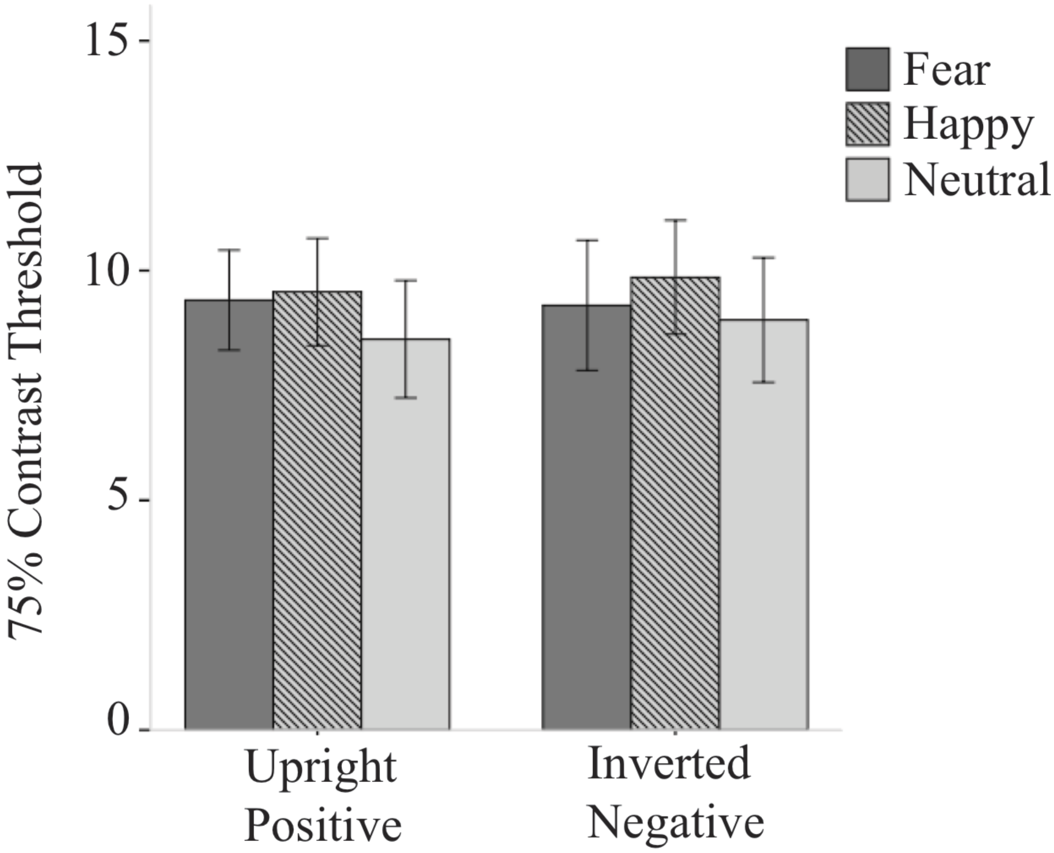

Figure 6.4. Average (±1 SE) 75% thresholds for each condition as a function of emotion.

This null result was unexpected given Phelps et al.'s (2006) findings. One major difference between the present experiment and Phelps et al.'s, was the addition of the happy expression in the present experiment. This had the effect of increasing the length of the experiment by half again, and may have been responsible for the large lapsing rates. To investigate whether the null effects of emotion and manipulation were due to the length of the task, an additional analysis was performed on the first 1320 trials of the present experiment (this is the same number of trials used by Phelps et al.). This analysis indicated no significant effects of emotion (F(1.12, 16.77) = .22, p=.80), manipulation (F(1,15) = 1.30, p=.27) , and no interaction between emotion and manipulation (F(1.38, 20.74) = 1.53, p=.23).

6.5. Discussion

Overall, the lack of an emotion effect was unpredicted, and somewhat surprising given previous research (Phelps et al., 2006; Bocanegra & Zeelenberg, 2009). It may suggest that the effect of emotion on probe contrast sensitivity is not robust, and therefore may not be useful in considering emotion processing outside of awareness.

The length of the present experiment was significantly longer than Phelps et al.'s, (2006) due to the inclusion of the happy expression. The additional analyses performed suggest null results were unlikely to reflect the longer duration of the study. However, this analysis may have been underpowered, given that the trials were divided over three expressions rather than two. Participants did seem to lapse rather a lot in the present experiment, making thresholds at 82% (the threshold cut-off used by Phelps et al.) unreliable for some.

The lack of emotion and manipulation effects are unlikely to have been caused by the full experiment being underpowered. The same number of trials per condition were performed by participants in the present experiment as those performed by participants in Phelps et al.'s (2006) experiment. Additionally, 16 individuals participated in the present experiment, compared to the 6 participants tested in Phelps et al.'s.

There were slight differences in the method used between Experiment 6, and Phelps et al.'s (2006) study. It is possible that the randomly interleaved happy expression trials had carry-over effects that affected probe sensitivity following the fear expressions. To discover which differences caused the dissimilar results between Experiment 5 and Phelps et al.'s experiment, it would be advantageous to follow their procedure exactly (i.e. present only fear and neutral expressions, use faces that are not matched RMS contrast and mean luminance, and use an inverted face as a control). If, with an exact replication, the results do not show the predicted emotion effects, it would suggest the method is unreliable. On the other hand, if the predicted emotion effects were found, it would suggest that the null effects found in Experiment 5 were caused by one of the methodological differences listed above. Therefore, in Experiment 6, the procedure used by Phelps et al. will be followed exactly.

Experiment 6

6.6 Method

Key predictions

1) Fearful faces will facilitate contrast sensitivity when presented normally (i.e. there will be lower contrast thresholds for probes that follow fearful, compared to neutral faces)
2) This will not be explained by low-level characteristics (i.e. there will be no difference in contrast thresholds for probes that follow inverted emotional faces)
3) Differences between expressions will be driven by facilitation following fearful faces, rather than impairment following neutral faces (i.e. there will be a larger difference between upright and inverted fearful faces than between upright and inverted neutral faces)

6.6.1. Participants

Twenty undergraduate and postgraduate students (6 males) participated in the study in exchange for course credit, or monetary payment. Their mean age was 25.65 years (*SD*=4.21). All observers had normal or corrected-to-normal visual acuity, and gave informed consent.

6.6.2 Questionnaires[17]

As in Experiment 5.

6.6.3. Apparatus and Visual Stimuli

The apparatus and visual stimuli were the same used in Experiment 5, with exception of the following changes:

1) Only fear and neutral expressions were presented
2) The faces were not contained within an elliptical mask
3) Mean luminance and contrast was not equalised across the faces
4) Inversion was used as a control for low-level characteristics

[17] Anxiety measures were not taken by Phelps et al., (2006), and so this is the only way in which Experiment 6 deviates from their design.

6.6.4. Procedure

The procedure was identical to Experiment 5 (see Figure 6.5).

There were 1320 trials (2 emotions x 2 manipulation conditions x 10 contrast levels x 11 models x 3 repetitions). Target position (the four possible locations of the target Gabor), and target orientation (whether the target Gabor was oriented to the left or right of vertical), were randomly allocated on each trial.

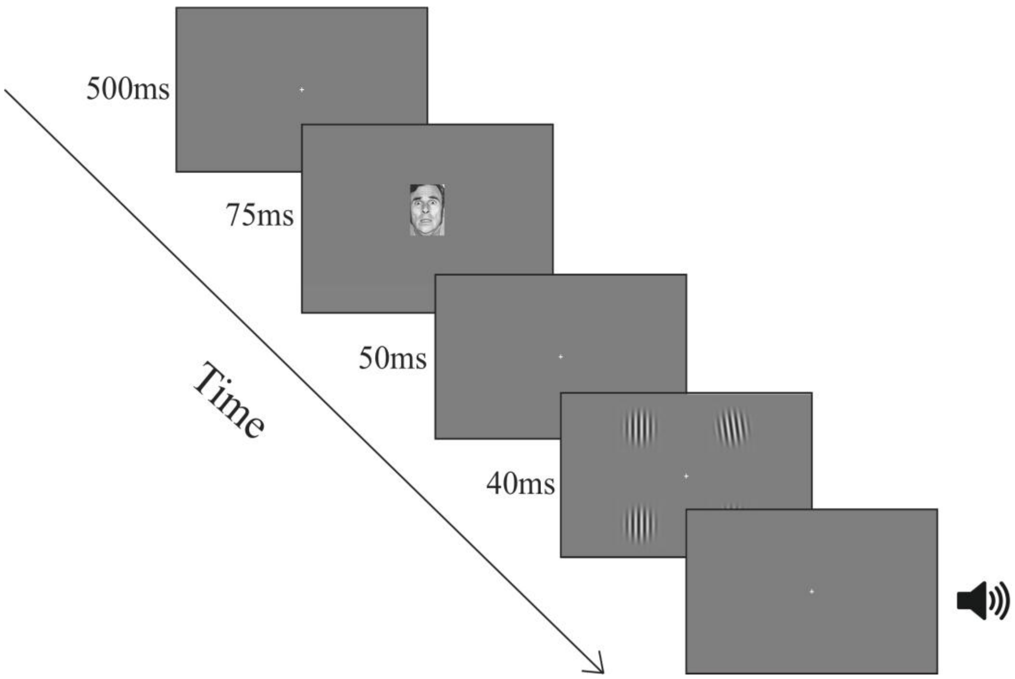

Figure 6.5. Schematic of Experimental paradigm for Experiment 6. A tone was sounded when a correct response was given.

6.6.5 Data Analysis

Three participants did not achieve more than 82% accuracy for any one of the conditions, and were therefore excluded. The data for each of the 17 remaining participants was fit with a separate Weibull function within each condition. Thresholds (82% accuracy) were entered into a repeated-measures ANOVA, with emotion (fear, neutral) and manipulation condition (upright positive, inverted positive) as within participant variables.

6.7. Results

6.7.1. Sample Characteristics

On each of the questionnaire measures there was a normal range of scores (see Appendix N), and correlations with performance measures were non-significant (see Appendix O).

6.7.2. Facilitation of emotional expression

As can be seen from the averaged data, there does seem to be a small effect of emotion on contrast sensitivity in the normal (see Figure 6.6) and inverted (see Figure 6.7) faces.

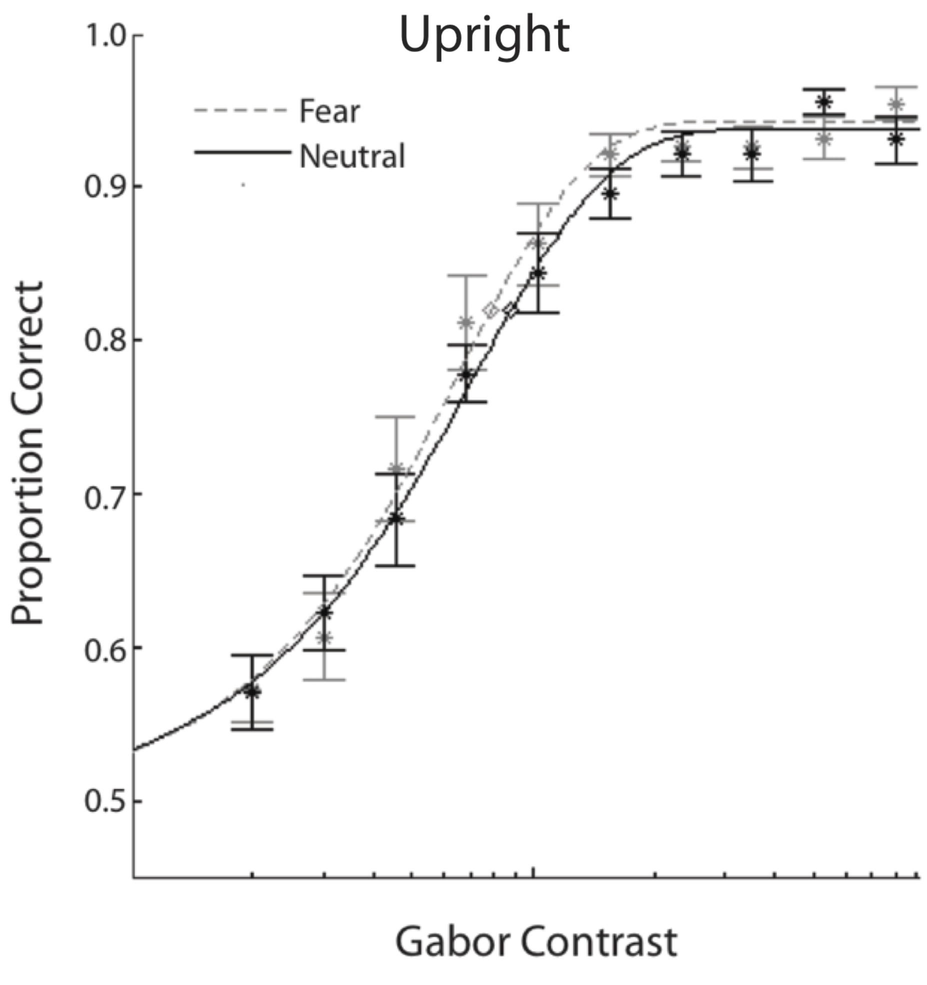

Figure 6.6. Averaged psychometric functions from Experiment 6. Observers' average accuracy for the orientation task as a function of whether the task was preceded by a fearful, or neutral upright face.

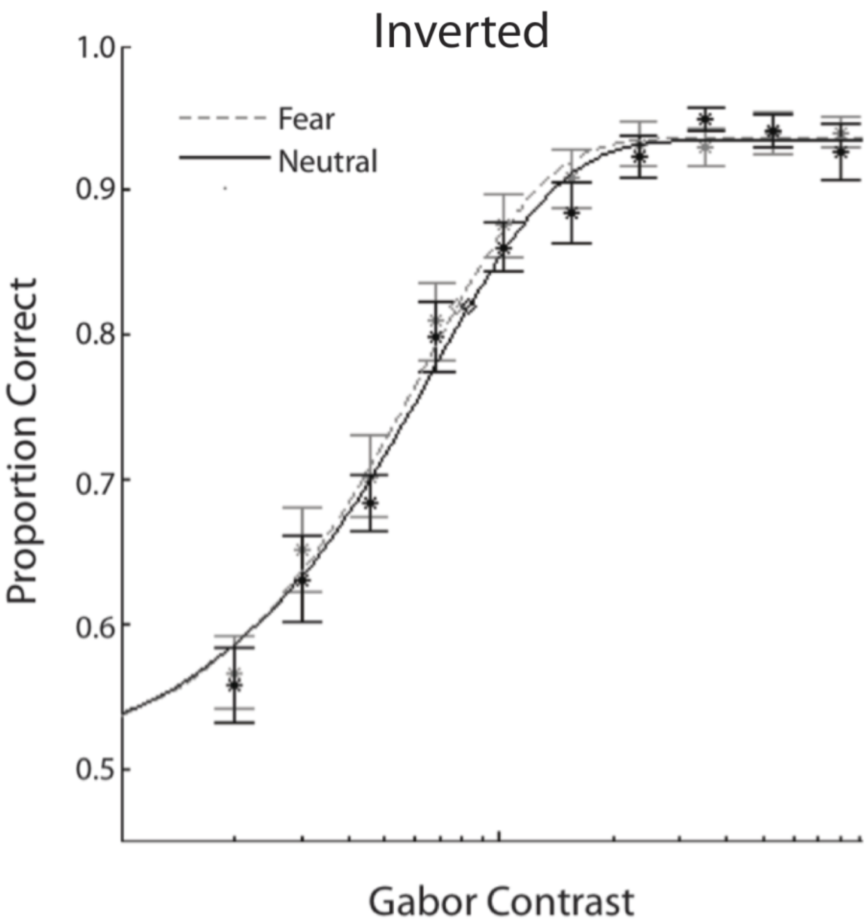

Figure 6.7. Averaged psychometric functions from Experiment 6. Observers' average accuracy for the orientation task as a function of whether the task was preceded by a fearful, or neutral inverted face.

To test this statistically, a 2 (emotion) x 2 (manipulation) repeated-measures ANOVA was run on the 82% threshold data[18] (see Figure 6.4). There was a main effect of emotion, $F(1,16) = 6.64$, $p<.05$, but no main effect of manipulation ($F(1,16) = 1.15$, $p=.30$) nor an interaction between emotion and manipulation ($F(1,16) = 1.17$, $p=.30$). Probe contrast thresholds were significantly lower following the presentation of a fearful face ($M=10.12$, $SD=6.37$) compared to a neutral face ($M=11.70$, $SD=7.74$). The interaction between emotion and manipulation was non-significant (see above). However, to explicitly compare Experiment 6 with Phelps et al., (2006), paired t-tests were conducted between the emotions within each manipulation condition. In the upright faces, fearful faces ($M=8.94$, $SD=5.84$) facilitated contrast performance (neutral:

[18] An identical analysis was performed on 75% thresholds; There was a marginal main effect of emotion, $F(1,16) = 4.17$, $p=.058$, and no effect of manipulation ($p>.9$), or emotion x manipulation interaction ($p>.7$).

M=11.27, *SD*=7.49; $t(16) = 3.54$, *p*=<01); whereas in the inverted faces, the effect was not significant (fear: *M*=11.30, *SD*=7.83; neutral: *M*=12.11, *SD*=9.76; $t(16) = .71$, *p*=.49). To explore whether this was caused by a facilitation following fear, or impairment following neutral, paired *t*-tests were also conducted to test the difference between manipulation conditions within each emotion. There was a marginal difference between upright fear and inverted fear ($t(16) = 1.83$, *p*=.09), and no difference between upright neutral and inverted neutral ($t(16) = .43$, *p*=.67). This suggests that the emotion effect may be driven by facilitated visual processing following the presentation of the fearful expression.

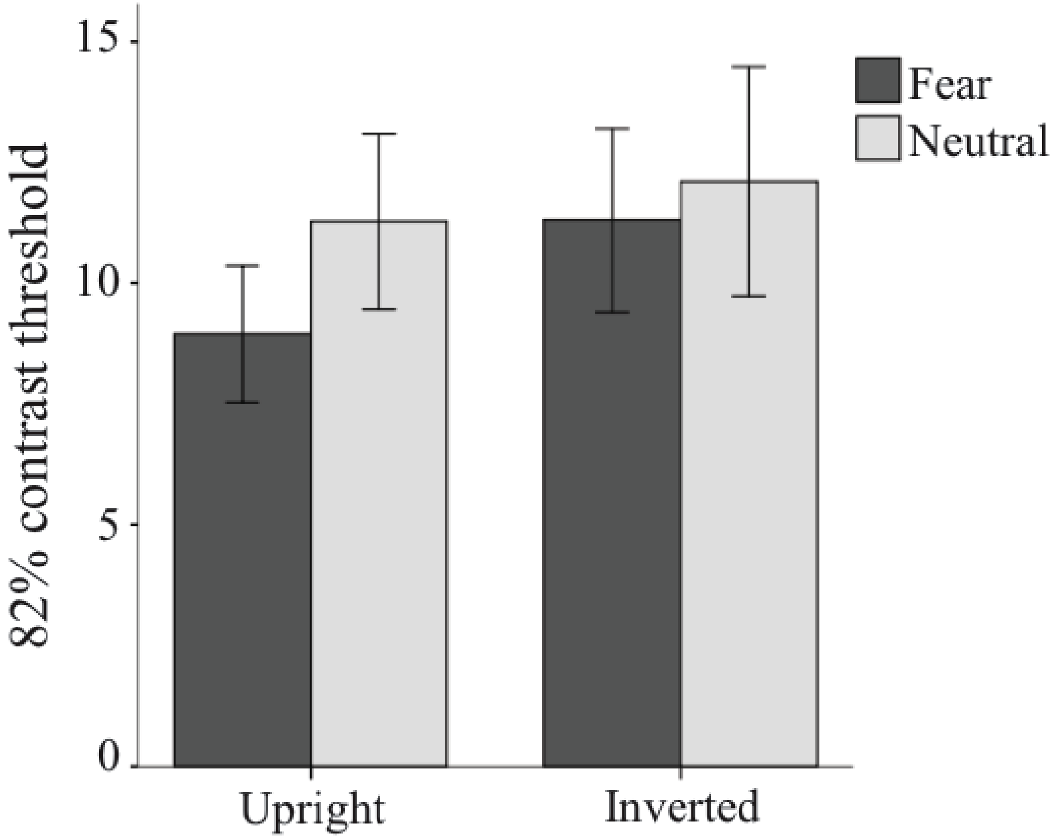

Figure 6.8. Average (±1 SE) 82% thresholds for each condition as a function of emotion.

6.8. Discussion

Experiment 6 was an exact replication of Phelps et al.'s (2006, Experiment 1) study. Results from Experiment 6 show that contrast sensitivity of a probe following a fearful face is higher than when the probe follows a neutral face. However, despite a near exact replication of Phelps et al.'s study, Experiment 6 failed to find the critical emotion by manipulation interaction. Given the pattern of results (Figure 6.8), paired comparisons were performed to provide additional insight. Although the results of these comparisons should be taken with caution, they suggest that the effect of emotion in the upright faces did not also exist on the inverted faces. This is consistent with Phelps et al.'s findings, although the effects found in the present experiment were far weaker (e.g. there was no significant interaction between emotion and manipulation). Additionally, the results from the present experiment tentatively suggest that shifts in contrast sensitivity is due to enhanced processing following fearful faces, rather than impaired processing following neutral expressions. This is contrary to the findings by Phelps et al., where their results seemed to be due to impaired sensitivity following the neutral face.

Despite the difference between emotions being significant only in the upright faces, the interaction between emotion and manipulation was not significant. This may be due to 1) inversion not being a good control for emotion (i.e. permits some processing of residual emotion); 2) low-level characteristics drive some of the 'emotion' effect; 3) the emotion effect not being particularly large in the upright faces. Results from Experiment 1 of this thesis showed that inversion is not a good control for emotion recognition; where although recognition was reduced from upright to inverted faces, the effect was relatively small and performance with inverted faces remained well above chance. Therefore, it is possible that the emotion effect found in the present experiment is due to the extraction of emotional meaning in both the upright and inverted conditions. On the other hand, results from Experiment 3 showed that an effect that has been previously attributed to the extraction of emotional expression (i.e. Yang et al., 2007), is the result of low-level visual characteristics.

The findings from Experiment 6 are dissimilar from those of Experiment 5, where there was no change in probe sensitivity following different expressions. The difference between results may be due to the various methodological alterations: although the same models were used, the faces in Experiment 5 were modified to help control for low-level characteristics (e.g. mean luminance and RMS contrast were equalised across stimuli). There was no effect of emotion in Experiment 5 (using well-controlled stimuli), and the facilitation by fear in Experiment 6 only tended to occur more in the upright than inverted faces (there was no significant emotion by manipulation interaction). It is possible that low-level characteristics were responsible for the emotion effect found in Experiment 6. However, this still would not account for why Phelps et al., (2006) found no difference in probe sensitivity between fearful and neutral faces when they were spatially inverted. The differences in findings between Experiments 5 and 6 could also have been caused by the inclusion of the happy face in Experiment 5, which lengthened the experiment, and may have caused carry-over effects. It is possible that Phelps et al. used a longer inter-trial interval to limit carry-over effects (this is unknown, given that they did not report an inter-trial interval).

A recent experiment, conducted by Phelps and colleagues (Ferneyhough, Stanley, Phelps & Carrasco, 2010) also failed to find any difference in probe contrast sensitivity when the probes followed fearful compared to neutral faces. Ferneyhough et al., investigated the effects of spatial attention on probe discrimination by presenting an emotional face cue on one side of fixation, or on both sides of fixation. Participants responded to both the location and orientation of a target Gabor, which was presented alongside a distractor Gabor (oriented vertically) at various contrasts. They found no effect of emotion; there was no difference in contrast sensitivity following fearful versus neutral faces for the valid, invalid or distributed cues (the distributed cue condition is the most similar to the procedure used in the present experiments).

It is possible that the SF of the Gabors that were used by Ferneyhough et al., (2010) to probe sensitivity were not likely to support emotional facilitation. They used Gabors with fairly high SF content (4cpd). Results from Bocanegra and Zeelenberg (2009) suggest that facilitation in response to fearful faces occurs in stimuli up to 3cpd. The same explanation cannot be levelled at Experiments 5 and 6 of this thesis, as 2cpd stimuli were used in both experiments. Indeed, facilitation of contrast sensitivity was found following the presentation of a fearful face (compared to neutral) in Experiment 6, suggesting that the probe SF was appropriate.

To date, only three studies have investigated emotional processing using the probe contrast sensitivity paradigm, and there does seem to be some controversy over which stimuli reliably elicit the effects (Bocanegra & Zeelenberg, 2009; Phelps et al., 2006; Ferneyhough et al., 2010). A recent meta-analysis of findings from (conscious) visual-probe studies suggest that a threat-related attentional bias is not observed in nonanxious individuals (Bar-Haim et al., 2007). There is some evidence of an effect of emotion on spatial attention using the visual-probe task in nonanxious individuals (Pourtois et al., 2004; Pourtois et al., 2006; Cooper & Langton, 2006; Holmes et al., 2009), but the extent to which these are explained by low-level characteristics is unclear given the absence of control stimuli.

The present Experiments were conducted in an attempt to find a dependent variable (in addition to response times) that would be sensitive to emotional face prioritisation outside of awareness. As the effects found in Experiments 5 and 6 are not robust (i.e. they are inconsistent with eachother), it was deemed inappropriate to explore this methodology in an unconscious version of the task. Indeed, given time constraints, no further attempts were made to discover a different methodology with which to explore unconscious emotional face processing. Instead the final experiment in this thesis returns to an intriguing effect found in the previous experiments that explored unconscious emotional face processing using CFS. In Experiments 3 and 4 of this thesis there was a robust ‘face’ effect, where normal faces were found to emerge faster from CFS than manipulated faces. In the next Chapter, this ‘face’ effect in unconscious vision will be explored further using a CFS paradigm in an individual who finds it difficult to use facial information.

In conclusion, findings from Experiments 5 and 6 suggest that the effect of emotion on subsequent probe contrast sensitivity is not robust. Despite finding an emotion effect using an exact replication of Phelps et al.’s (2006) study, the findings were weak and did not generalise to a modified version of the task that included better control stimuli and additional expressions.

Chapter 7

Investigating unconscious face processing in a case of prosopagnosia

7.1. Introduction

Experiment 3 of this thesis found that fearful faces emerge from suppression faster than other expressions due to their low-level characteristics, rather than the extraction of emotional content. However, an interesting 'face' effect was found in both Experiments 3 and 4, suggesting that high-level processing does occur during CFS suppression. Normal (upright positive) faces were found to emerge from suppression faster than less recognisable, manipulated (inverted negative) faces. These results concur with other studies that show upright faces break from suppression faster than inverted faces (Jiang et al., 2007; Yang et al., 2007). This advantage for familiar stimuli presented unconsciously using CFS has also been found for words (recognisable vs. unrecognisable words; Jiang et al., 2007).

Do these results imply that binocular rivalry is resolved at high-level visual areas (such as FFA)? There have been inconsistent results regarding the site of binocular rivalry resolution. Some researchers have found that brain activation mirrors conscious perception at low-level visual areas, such as LGN and V1 (Tong & Engel, 2001; Polonsky et al., 2000; Lee & Blake, 2002; Wunderlich et al., 2005), whereas others have found that brain activation does not mirror perceptual alternations until higher visual sites, such as the inferotemporal cortex (Sheinberg & Logothetis, 1997; Tong et al., 1998). Recently it has been suggested that the resolution of binocular rivalry occurs over multiple stages (Freeman, 2005; Nguyen et al., 2003; Blake & Logothetis, 2002), thus validating both sets of neuroimaging findings. The advantage for normal faces over manipulated (inverted/ negative) faces suggests that some information from the suppressed stimulus reaches high-level visual areas (where face-specific processing occurs). Jiang et al. (2007) suggest two possible routes by which this may occur: either

1) some information from the suppressed stimulus is cortically processed to high-level visual areas, or 2) information from the suppressed stimulus does not persist at a cortical level, but is processed subcortically and projected to high-level cortical regions.

The present Chapter will investigate the unconscious processing of face stimuli by examining emergence times in an individual that cannot process face identity information due to cortical lesions. Prosopagnosia is a type of visual agnosia (loss of recognition ability) that is specific to faces (Hecaen & Angelergues, 1962). It can be acquired through brain injury, or stroke, with lesions typically affecting the occipital and temporal lobes (Rossion, Caldara, Seghier et al., 2003). It can also be congenital, and therefore not caused by neurological pathology, but evident for as long as the individual can remember (possibly from birth; Duchaine & Nakayama, 2006). The similarity between acquired (AP) and congenital (CP) prosopagnosia is unclear (Humphreys, Avidan & Behrman, 2007), therefore the present Chapter will focus on AP.

It has been proposed that prosopagnosic individuals suffer from an inability to process faces configurally (Levine & Calvanio, 1989; Ramon, Busigny & Rossion, 2010). Note that the definition of configural processing here encompasses all three 'types' defined by Maurer et al., 2002: first-order relations, holistic, and second-order relations (see Chapter 2, *Section 2.1.1*). Configural processing is the ability to process the face as whole, rather than simply as a collection of parts (Maurer et al., 2002). Comparing upright and inverted face processing has provided evidence for the absence of configural processing in prosopagnosia. Some studies have shown an absence of an inversion effect in prosopagnosia (equal performance for upright and inverted faces; McNeil & Warrington, 1991; Boutsen & Humphreys, 2002; Delvenne et al., 2004; Busigny & Rossion, 2009; occasionally, there have been reports of prosopagnosic individuals being better with inverted than upright faces; Farah et al., 1995; de Gelder et al., 1998), or a reduced inversion effect (reduced performance for inverted than upright faces, but the size of the effect is smaller than that found in control participants; Barton et al., 2003; Bukach et al., 2006). These results suggest that configural processing is disrupted in prosopagnosia.

As discussed in Chapter 2, identity and emotional expression may be processed somewhat separately (Bruce & Young, 1986; Hoffman & Haxby, 2000; Andrews & Ewbank, 2004; Adams, Gray et al., 2010), although are not completely distinct (see

Calder & Young, 2005). So, are prosopagnosic individuals able to process emotional facial expressions?

A number of studies suggest that emotional face processing is intact in prosopagnosia (Bentin, DeGutis, D'Esposito & Robertson, 2007; Duchaine, Parker & Nakayama, 2003; Humphreys et al., 2007; Riddoch, Johnston, Bracewell, Boutsen & Humphreys, 2008). However, the literature is full of controversies, with some finding disruption of emotional face recognition in CP (Bentin et al., 2007; Humphreys et al., 2007) but not AP (Humphreys et al., 2007), and others reporting significant emotional face recognition impairments in AP also (Riddoch et al., 2008, Stephan et al., 2006). These inconsistencies are likely to be driven by the different methods used, and participants tested across experiments. To summarise the evidence, it can be suggested that some prosopagnosic individuals show relatively unimpaired emotion recognition, whilst others show vast disruption to emotional face recognition. In addition, some prosopagnosic individuals show impairment only with specific emotions. For example, in a matching task, an AP observer showed normal recognition of happy expressions, but impairment for the other 5 basic expressions (surprise, fear, sad, disgust and anger; Stephan, Breen & Caine, 2006).

Interestingly, there is some indication that emotional expression can modulate face processing in prosopagnosia; the very presence of an emotional expression may facilitate identity processing. A study by de Gelder and colleagues (2003) showed that in a relatively large number of prosopagnosic individuals (N=7), emotional expression enhanced facial identity processing. When required to perform a matching task on the identity of a face (which of two faces matched a third), the prosopagnosic observers had very low accuracy. However, when the face displayed an emotional expression, accuracy increased. In this experiment, participants were given one whole face and asked to match which out of two face parts matched the whole face. The 'parts' were either the mouth or the eyes of a face. The faces were neutral or emotional (angry or happy), and were either upright or inverted (i.e. in the neutral upright condition, the neutral whole face was presented along with two neutral parts that were also upright). De Gelder et al. found that when matching neutral faces, none of the prosopagnosic participants displayed an inversion effect (similar RTs were found for the upright and inverted conditions), whereas a significant inversion effect was found in the control participants. However, when the faces displayed emotion, most participants, including each of the prosopagnosic individuals (with the exception of one) displayed a normal face inversion effect (i.e. faster responses to upright compared to inverted faces). These results suggest that emotional expression may modulate face processing in prosopagnosia.

To date, most research investigating emotional face processing in prosopagnosia has focused on whether recognition of facial emotional is impaired. However, a recent study has investigated whether emotional prioritisation is evident in AP. Peelen, Lucas, Mayer and Vuilleumier (2009) conducted several studies investigating emotional prioritisation in an individual with AP. In a visual search task, emotional (fearful/ happy) or neutral face targets were presented with neutral distractors. The target and distractors always had a different identity (thus when the target was neutral, it was a different identity to the neutral distractors). They found facilitated search in the AP case when the target was emotional, compared to when the target was neutral.

In the same paper Peelen et al. (2009) also used a change detection procedure. A face was presented on one side of fixation and a house on the other side of fixation for 250ms. After an interval, the face and house were presented again, but one, neither or both of the pictures could have changed. Participants were required to indicate which stimuli had changed on each trial. The expression of the face (fearful or neutral) was always constant over the change (only the identity of the face could differ). The prosopagnosic individual correctly identified the same number of changes in the house stimuli as controls, but was much worse for the faces (controls were better at detecting changes in the faces compared to houses, and slightly better for fearful than neutral expressions). However, the prosopagnosic observer detected changes more accurately when the face was fearful than when it was neutral. The authors suggest that this is because attention is directed towards the fearful faces due to their emotional content. Neither of Peelen et al's experiments included controls for low-level visual characteristics. Although the general impairment towards faces may have been driven by a lack of higher-level face processing in the prosopagnosic observer, the emotional effect may have been driven by low-level characteristics of the emotional face stimuli. Visual search experiments can be particularly affected by low-level characteristics of the stimuli (see Chapter 1, *Section 1.3.1*), therefore it is impossible to tell whether the apparent fear prioritisation in a case of AP was driven by the extraction of emotional meaning, or low-level characteristics.

Note that the exploration of face processing in prosopagnosia tends to be confined to individual case studies (Eimer & McCarthy, 1999). This is an obvious limitation, as it is unclear whether results can be generalised to the prosopagnosic population. However, prosopagnosia is relatively rare, and thus studies are limited to small sample sizes due to recruitment constraints. The present chapter will use a single case of AP to investigate whether a face prioritisation effect is present in the AP participant (as found in normal observers in Experiments 3 & 4 of the present thesis).

PHD is a 52 year-old man, who had a severe head injury in 1977 and has had severe (acquired) prosopagnosia since. There have been two previously published studies on PHD (Eimer & McCarthy, 1999; Eimer, 2000). Neurological scanning has revealed that PHD has a focused region of damage in the left temporal-parietal region (Eimer & McCarthy, 1999). However, PHD's lesion has been described as 'moderately diffuse' (p. 255, Eimer & McCarthy, 1999) and this may be reflected in his additional cognitive deficits, including visual agnosia (Eimer & McCarthy, 1999; Eimer, 2000).

Eimer and McCarthy (1999) tested PHD with a battery of face and object tests. They found his object recognition was within the normal range, yet he was unable to learn and recognise unfamiliar faces. He was also very poor at recognising famous people by their faces, but was within the normal range when describing them from their names. For detailed results on his performance on a range of tasks, see Eimer and McCarthy (1999). Eimer and McCarthy also investigated PHD's face processing with ERPs. As previously noted (see Chapter 2, *Section 2.1.1* of this thesis), normal individuals consistently display a negative deflection in ERP amplitude at around 170 ms post-stimulus in response to face stimuli (N170; Eimer, 1998). However, PHD did not display such an effect. This suggests that PHD has difficulties in encoding the structure of a face, prior to identification (Eimer & McCarthy, 1999).

PHD's face processing was also investigated by Eimer (2000) using ERPs. ERPs were measured in response to pictures of familiar faces, unfamiliar faces and houses. A simple task was used to ensure PHD was attending, in which he had to detect infrequent 'target' pictures (pictures of hands). In concurrence with Eimer and McCarthy, there was no evidence of a face-specific N170 in PHD's ERP data, nor did PHD show any ERP effects of familiarity.

The primary aim of the present Chapter was to investigate the unconscious 'normal' (upright positive) face advantage found in Experiments 3 and 4 using an AP individual (PHD). Before using a CFS paradigm to investigate unconscious face processing in PHD, it is first necessary to establish his recognition of both normal (upright positive) and manipulated (inverted negative) emotional faces.

Experiment 7

7.2. Introduction

It is unclear whether emotion recognition is preserved in prosopagnosia, as the research to date has been inconsistent (e.g. Humphreys et al., 2007; Riddoch et al., 2008). Generally, the inconsistent results may be due to the diversity in lesion locations between prosopagnosic individuals, or differences between tasks.

Recently, there has been some limited research on PHD's emotion recognition (Mestry, Menner, Godwin, McCarthy & Donnelly, 2010). Mestry et al., (2010) used a matching task to investigate PHD's discrimination of emotional intensity (within each emotion). Morphs of emotional faces were presented alongside each other, and he was asked to discriminate which face was more emotional. Happy, fear, angry and disgust expressions were explored. PHD was found to have normal discrimination of happy and fear expressions (compared to 4 age-matched controls), but very poor discrimination of angry and disgust expressions. In an additional experiment, a categorisation task was conducted, where participants had to label the expression of a centrally presented face (given 2 choices). PHD's results were similarly sensitive to controls when categorising between positive and negative faces, but he was poor at categorising between expressions that were both negative (e.g. fear and angry).

A recent study investigated the effect of inversion on emotion recognition in a prosopagnosic individual. Baudouin and Humphreys (2006) presented upright and inverted emotional faces and asked participants to judge whether the face was happy or angry. The individual with AP was better than chance at discriminating emotion (happy vs. angry) in upright faces, but not with inverted faces, and his performance was generally lower than that of controls. This suggests that the information he used to classify emotional expression was disrupted with inversion.

Baudouin and Humphreys (2006) argue that the prosopagnosic individual's emotion processing may not be normal. Instead, they suggest that he may use "critical local features" (Baudouin & Humphreys, 2006, p. 1368) when making emotional classifications. Although there was no evidence of configural processing in their prosopagnosic observer (i.e. no composite effect), he did show a significant inversion effect when categorising emotion. This suggests that it is not simply configural processing that is disrupted by inversion, and inversion may also impact on the local features that are critical to emotion perception in prosopagnosia.

The primary aim of the present experiment was to find a good control for emotion processing for the prosopagnosic observer, PHD, so the unconscious face effect could be investigated. PHD's emotional face recognition to both normal and manipulated faces was explored using a version of Experiment 1. In Experiment 1, angry, happy and fearful faces were presented centrally, and participants categorised the faces (using a 3AFC) according to their emotional expression. In the present experiment, the faces are either: 1) 'normal' (upright and with positive luminance polarity), or 2) 'manipulated' (inverted with negative luminance polarity). Experiment 1 investigated emotion recognition in a normal undergraduate sample. The results indicated that both inversion and negation impaired emotion recognition, and importantly, the effects of inversion and negation were additive. Is this effect also likely to be found in an individual with AP? The effects of inversion and polarity negation on identity processing in prosopagnosia are unclear, as are their effects on emotion processing.

PHD's emotion recognition of the manipulated (inverted negated) faces may be 1) impaired, or 2) unaffected, relative to the upright positive faces. However, given the inversion effect found when making emotional classifications in an AP individual (Baudouin & Humphreys, 2006), it is predicted that PHD will also show impaired recognition of emotional faces when they are inverted and negative.

Key Hypotheses

1) Generally, PHD's emotion recognition will be worse than that of Controls
2) PHD's emotional recognition will be further impaired with the inverted negative faces
3) PHD will have good recognition of happy and fear faces, but his recognition of angry faces will be impaired
4) PHD and Controls will recognise emotional faces more accurately when they are presented in high emotional intensity, rather than low emotional intensity

7.3. Method

7.3.1. Participants

PHD: PHD (described in detail above) is a left-handed 52 year old AP with no visual field loss (Eimer & McCarthy, 1999) and corrected to normal visual acuity. He gave informed consent.

Control participants: Three male, age-matched controls were used. Control A: left-handed, 59 years old, Control B: left-handed, 52 years old, Control C: right-handed, 47 years old. All had normal or corrected-to-normal visual acuity and all gave informed consent.

7.3.2. Apparatus and Visual Stimuli

Face stimuli consisted of the same 4 male models that have been used previously in this thesis (in Experiments 1, 2, 3, and 4; taken from the NimStim face set; Tottenham et al., 2002), each displaying fear, happy, and angry expressions. The faces were either presented normally (upright positive) or manipulated (inverted negative). Both 50% and 100% emotional morph-strength faces were used (the morphs were prepared as in Experiment 1).

Stimuli were prepared and presented using Matlab (The MathWorks, USA), with PsychToolbox (Brainard, 1997; Pelli, 1997). As with the previous Experiments in this thesis (Experiments 1 and 2), the faces were scaled, cropped, displayed within a black elliptical mask and matched for mean luminance and RMS contrast. As with Experiment 1, the faces were presented at 3.5° x 2.5° of visual angle (viewing distance = 65cm).

7.3.3. Procedure

A fixation cross was presented for 500ms, followed by a centrally presented face. The face was displayed for 200ms for the Control participants; for PHD it was displayed until he made a response, or up to a maximum of 10 seconds. It was impossible to use the same timings for PHD and controls, as at shorter durations, PHD's performance would likely have been at chance levels, whereas at longer durations, control participants would have been at ceiling (pilot data from undergraduates suggest that with 500ms presentation duration, participants were uniformly good). Participants classified each face as one of three emotions (fear, happy or angry) in a 3AFC. All participants used arrow keys to toggle through the possible options and selected their response using the space bar. There were 384 trials, (2 stimulus manipulations x 3 emotions x 2 emotion strengths x 4 models x 8 repetitions) in a single session.

7.3.4. Data Analysis

Statistical tests were conducted on the frequency of correct responses using chi-square tests. PHD was considered as a single case, and data from the Control participants were averaged.

7.4. Results

7.4.1. Emotional categorisation

PHD: PHD was good at categorising emotional faces when they were upright positive (collapsed across emotion and morph: 90% correct; see Figure 7.1. and Appendix P). He was significantly worse at categorising expression when the faces were inverted negative (collapsed across emotion and morph: 42% correct; $\chi^2(1)=16.79$, $p<.001$). PHD had statistically equal recognition of the different expressions ($p>.1$), and morphs ($p>.1$). There was no difference in performance between PHD's accuracy and the mean Control accuracy ($p>.8$).

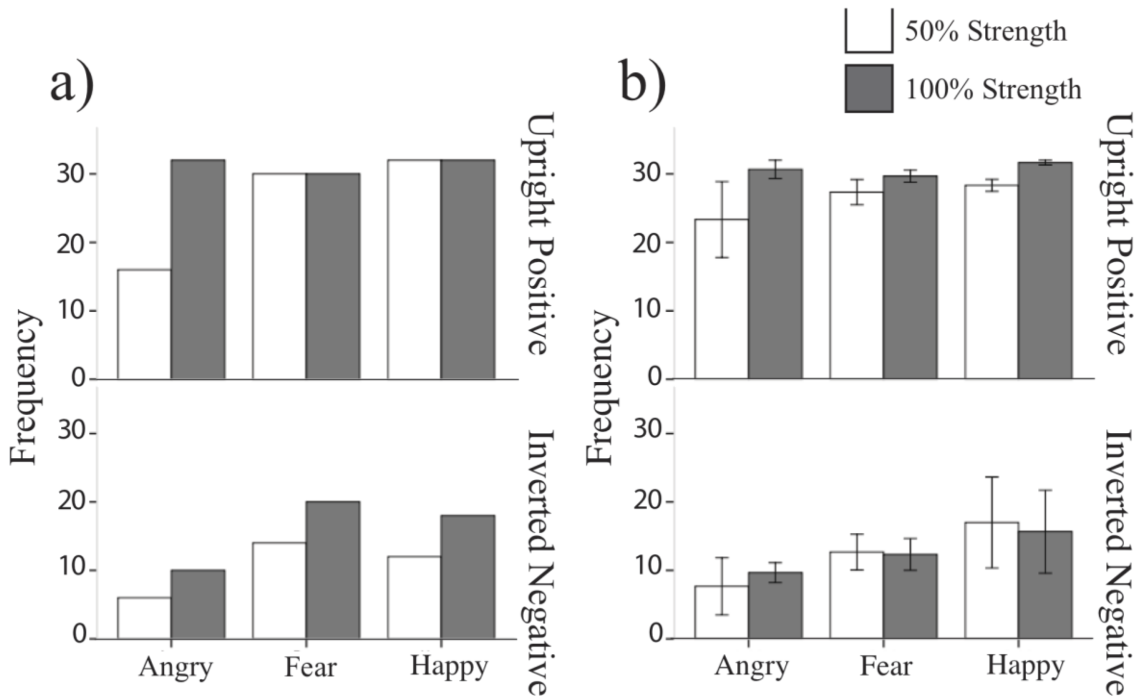

Figure 7.1. Frequency results for a) PHD and b) averaged Control (±1SE) as a function of manipulation condition, emotion and morph-level.

It is possible that PHD resolved the emotion task using a speed/ accuracy trade-off. Therefore as an additional check, RTs were analysed for PHD as he was given up to

10 seconds to respond to the emotion of a face. PHD's mean RT data are presented in Figure 7.2.

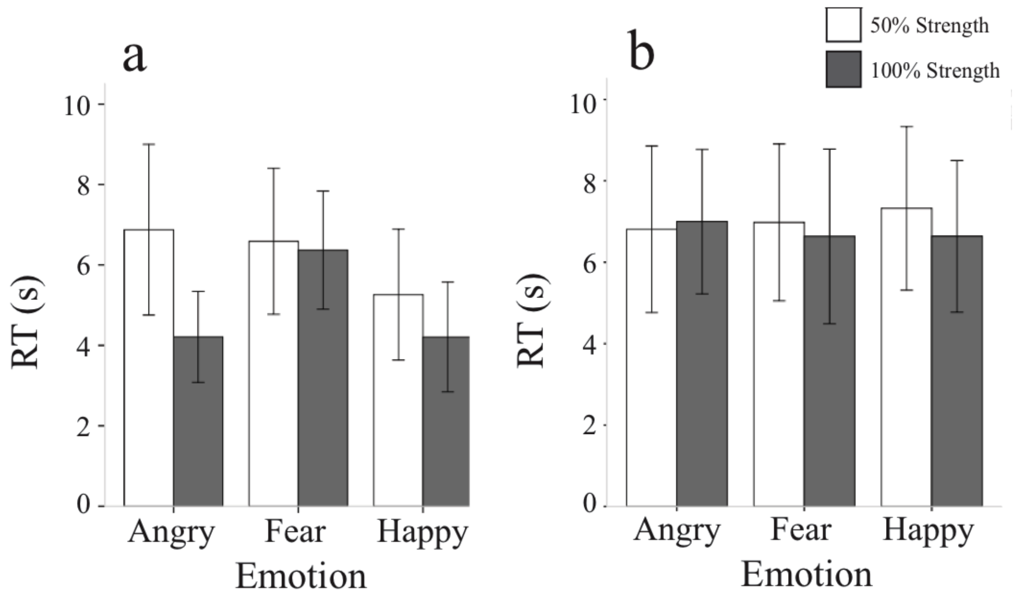

Figure 7.2. PHD's mean RTs (S) across emotion, and morph for a) Upright Positive and b) Inverted Negative faces (error-bars = ±1 SD).

PHD responded to most faces (90.63%) within the ten-second cut-off. He does not show a speed/accuracy trade-off; he tended to respond faster when he achieved very good emotion classification (r =-0.77, p<.01; R^2=0.59).

Controls: The mean Control data suggest that Controls correctly identified more expressions when they were upright positive than inverted negative (see Figure 7.1; collapsed across emotion and morph; 89.1% vs. 36.1%, $\chi^2(1)$= 36.54, p<.001). There was no effect of morph (p>.3), or emotion (p>.2).

7.4.2. Sensitivity and Bias

Given the possible role of bias in a 3AFC experiment, the data were also converted into A′ scores, as in Experiment 1 (see *Section 2.2.6* for the formulae used). Although these data could not be analysed statistically, the pattern of sensitivity found for PHD (Figure 7.3) and Controls (Figure 7.4) can be seen. As previously suggested, when considering sensitivity it can also be useful to examine bias. Given the interest in the present experiment in the strategies used by PHD to resolve emotion recognition, bias (B′′) is also presented.

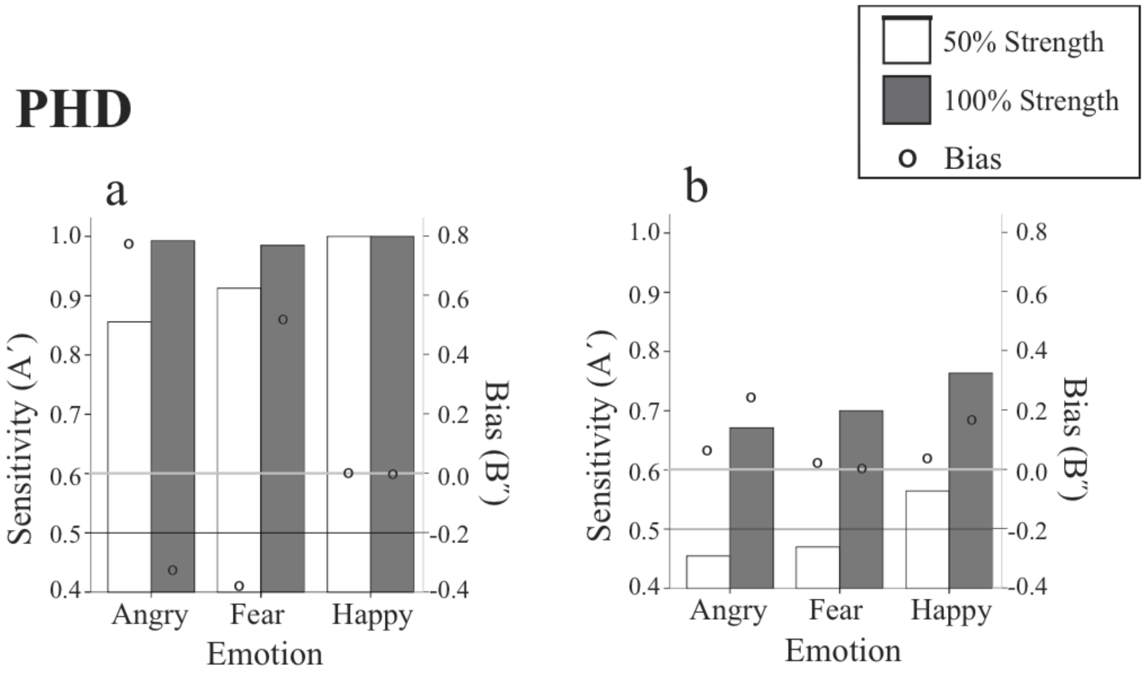

Figure 7.3. PHD's sensitivity and bias as a function of emotional expression and emotion strength for a) Upright Positive, and b) Inverted Negative faces. The black line represents chance performance on sensitivity, and the grey line represents a bias of 0.

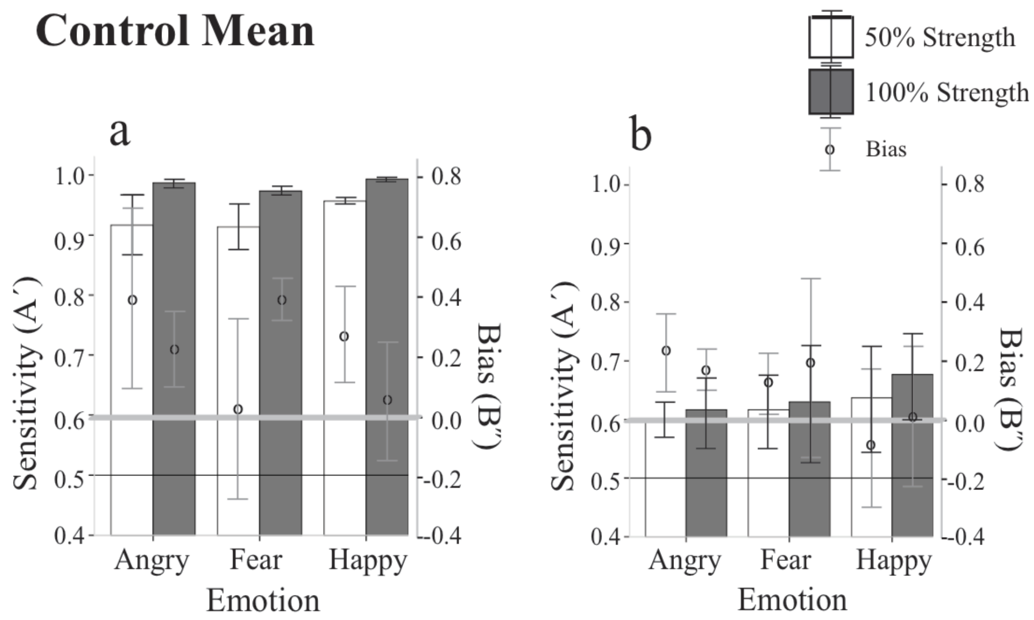

Figure 7.4. Sensitivity and bias as a function of emotional expression and emotion strength for a) Upright Positive, and b) Inverted Negative faces for the mean Control data (errorbars=±1SD). The black line represents chance performance on sensitivity, and the grey line represents a bias of 0.

PHD was more accurate with upright positive faces than inverted negative faces, even when biases were accounted for. PHD tended to respond conservatively towards upright positive angry faces when they were low in intensity, but liberally when they were high in intensity. Additionally he tended to respond conservatively towards upright positive fearful faces when they were high in intensity, but liberally when they were low in intensity. This differential effect of bias in the negative emotions across emotional intensity was unexpected, but may be caused by a strategy he was using to decode the low-morph strength emotional faces. He showed little effect of bias in the inverted negative faces.

The Controls had higher recognition of upright positive compared to inverted negative faces. The general pattern of sensitivity found from the Control participants follows the pattern found in the mean undergraduate sample in Experiment 1 (see Figure 2.3). There were individual differences in bias across the Control participants (indexed by the large error-bars).

7.5. Discussion

PHD was more accurate when categorising the emotional expression in normal (upright positive) faces than manipulated (inverted negative) faces. Generally, his pattern of results was similar to the control participants (which followed the expected pattern given results from Experiment 1). PHD's response time data suggest that his results were not based on a speed-accuracy trade-off. Both PHD and Controls were biased in their responses, and there were differences across individuals in the amount and direction of bias.

The impairment of PHD's emotion classification with inversion and negation was predicted given the findings of an inversion effect for emotional stimuli in AP (Baudouin & Humphreys, 2006). However, in identity processing research, some experimenters report a lack of inversion effect in AP (Boutsen & Humphreys, 2002; Delvenne et al., 2004; Busigny & Rossion, 2010). PHD's emotion processing in inverted faces was not tested directly here. However, he did show that when emotional faces were both inverted and negated, he was worse at classifying emotional expression. This is critically important for the proposed investigation of the unconscious 'face effect' in PHD. Generally, the pattern of results for PHD was very similar to the controls. However, he was considerably slower, so it cannot be said that he has normal emotional face processing.

There was no statistical difference between PHD's recognition of happy and fear/angry expressions found in the present experiment. However, he did tend to show good recognition of happy expressions, and worse recognition of low-intensity angry faces, thus concurring with Mestry et al.'s (2010) findings with PHD, using a different experimental paradigm.

It is important to note that although the tasks were comparable for PHD and the control participants, PHD was given up to 10 seconds to view the faces, whilst Controls were limited to 200ms. Thus PHD's results are not equivalent to Controls. Given that PHD had up to 10 seconds of viewing time on each trial, it is possible that he was using analytic strategies (for example, judging a happy face by its white teeth) to resolve the task. There is some evidence to suggest that prosopagnosics use analytic strategies to match/ discriminate faces (Davidoff & Landis, 1990; Farah, 1990). If PHD was using analytic strategies, the strategies cannot have been particularly useful in the manipulated faces (as PHD had fairly poor recognition of inverted negative emotions). It is possible that he could have been using cognitive strategies that may have been developed over a number of years, and thus may not have been directly transferrable to the manipulated images. Nevertheless, PHD was not at chance in recognising emotion in the 100% intensity manipulated faces; this suggests that he is able to adapt his strategy according to the task and stimuli presented.

To conclude, results from this emotional recognition experiment suggest that inversion and luminance polarity negation impair emotional face categorisation in PHD, an individual with AP. Therefore emotional faces with these manipulations will be used as a control to investigate unconscious emotional face processing in PHD.

Experiment 8

7.5. Introduction

In the present Experiment, the processes responsible for the unconscious face effect (found in Experiments 3 and 4) will be explored. In addition to findings from CFS (e.g. Jiang et al., 2007; Yang et al., 2007), other paradigms have also provided evidence that faces can be processed outside of awareness. Using a backward masking procedure, it has been found that neurological and behavioural priming towards facial identity can occur when the prime faces are presented unconsciously (Kouider, Eger, Dolan & Henson, 2008; Henson, Mouchlianitis, Matthews & Kouider, 2008).

The extent to which activity in face-selective brain regions (i.e. FFA) is correlated with awareness has been investigated extensively. Using a binocular rivalry paradigm, some have found that that activation is not induced in the FFA in response to unconsciously presented faces (Pasley et al., 2004; Williams et al., 2004, Tong et al., 2006). Jiang and He, (2006) presented faces unconsciously using CFS whilst recording brain activation using fMRI. Contrary to results with binocular rivalry (e.g. Pasley et al., 2004), although activation in the FFA was reduced in response to invisible faces, it was still reliably observed. Activation in FFA in response to faces rendered unconscious using CFS (Jiang & He, 2006) may be responsible for the unconscious face effect found in previous experiments of this thesis (Experiments 3 and 4).

The present experiment will investigate the unconscious face effect in PHD: an individual with AP. It is known that PHD finds it very difficult to use information from faces (Eimer & McCarthy, 1999). So, will faces still be granted preferential access to awareness in this individual? Critically, in this paradigm, the participants are not required to recognise the face (or categorise the face in any way). Recall that emergence time from CFS is proposed to be an index of image saliency. There is evidence that this includes the saliency of low-level properties of an image, such as contrast (Tsuchiya & Koch, 2004), and high-level salience, like meaning or familiarity (Jiang et al., 2007). Experiments 3 and 4 of this thesis (along with evidence from two separate research groups; Jiang et al., 2007; Yang et al., 2007) have found strong evidence that normal faces are afforded preferential access to awareness, compared to manipulated controls. If the effect found in normal samples is caused by the meaning of the face stimuli, then this effect would be unlikely to be evident in PHD (there is no evidence that faces are particularly salient for him; Eimer & McCarthy, 1999).

As discussed previously, de Gelder et al., (2003) found a modulatory role of emotion in identity processing for a number of prosopagnosic individuals. Given these findings, PHD may show a ‘face’ effect in the emotional, but not neutral expressions (i.e. upright positive faces may emerge faster than inverted negative faces when they display happy, fear or angry expressions, but no difference between manipulation conditions in the neutral faces).

In addition to investigating the unconscious face effect, the present experiment will also explore the effect of emotion on unconscious face processing in PHD. A recent experiment investigated the effect of emotion on attention in individuals with AP. Peelen et al., (2009) conducted a series of experiments to investigate whether emotionally expressive faces guide attention in prosopagnosia. They found that emotion did guide attention in AP, replicating the effect found in normal populations, although they did not control for low-level characteristics. Given their findings, emotion may modulate unconscious processing of faces in AP. Experiment 3 (present thesis) showed that, in normal samples, CFS emotion effects (e.g.'fear prioritisation') are driven by the low-level characteristics of the stimuli. Thus, it is likely that any emotion effects found for PHD would also be driven by low-level properties, and not the extraction of emotional meaning. However, it is unclear whether PHD will show any unconscious emotion effects, such as the fear enhancement found in normal populations (Experiment 3).

In this experiment, a CFS paradigm will be used to discover whether normal (upright positive) emotional faces emerge from suppression faster than manipulated (inverted negative) emotional faces in a prosopagnosic individual. The procedure used was similar to that used in Experiment 3, with one significant difference. In the present experiment, in order to ascertain whether any effects are specific to face processing, an additional 'house' condition is used. As PHD has displayed normal recognition of buildings (McCarthy, Evans & Hodges, 1996), in this extra condition, houses were displayed in a CFS procedure. The houses were either normal (upright and positive luminance polarity) or manipulated (inverted with negative luminance polarity).

Again, a control condition was included in which response biases were measured. There are limitations associated with this control condition (see Chapter 4, *Section 4.4*.), however it is included as it does provide some information on the biases that may affect the CFS data. This control condition consisted of both the face/house and the dynamic noise being presented to both eyes (i.e. not suppressed), and the contrast of the face/house slowly increased (as in Jiang et al., 2007).

Key hypotheses:

1. PHD will not show a 'face effect' (there will be no difference in emergence between upright positive and inverted negative faces).

In addition:

2. PHD may show a face effect in the emotional faces, but not in the neutral faces (upright positive faces emerge faster than inverted negative faces when they are emotional)

3. PHD may display an effect of emotion that is based on low-level characteristics (any effect of emotion found in the upright positive faces will be evident to the same extent in the inverted negative faces)

7.6. Method

7.6.1. Participants

PHD and the same three control participants were used as Experiment 7.

7.6.2. Apparatus and Visual Stimuli

The same 100% emotional faces were used as in Experiment 3; each of the 4 male models taken from the Nimstim face set (Tottenham et al., 2002) displayed angry, fear, happy, and neutral facial expressions. The dynamic noise was created the same way as in Experiments 3 and 4. The house stimuli used in the present experiment consisted of 4 photographs of different houses (independently sourced). They were based in a rectangular frame and matched for mean luminance and RMS contrast. They were presented either spatially upright with positive luminance polarity, or spatially inverted with negative luminance polarity.

7.6.3. Procedure

The faces and houses were presented in CFS (Figure 7.5) and in the control condition following the procedure from Experiment 3. The experiment was blocked by stimulus type (face/house). There were 256 trials with the face stimulus, (2 suppression conditions x 2 stimulus manipulations x 4 emotions x 4 models x 4 repetitions) and 64 trials with the house stimulus (2 suppression conditions x 2 stimulus manipulations x 4 models x 4 repetitions). Blocks were counterbalanced between participants: PHD and Control B completed the face block first, whereas Controls A and C completed the house block first.

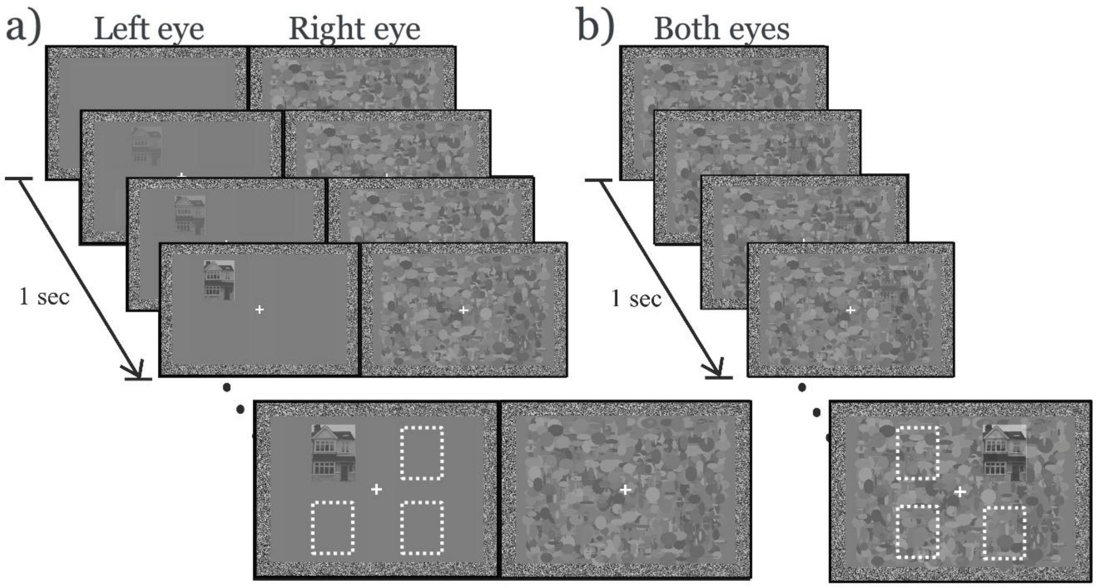

Figure 7.5. Schematic of the procedure used in Experiment 8, for the house stimulus, including a) the CFS condition, and b) the control condition. Dashed circles represent the (other) possible locations the houses could appear.

7.6.4. Data Analysis

RTs were computed on correct responses only. PHD's error rate was 4.4%, whilst the mean error rate for the Controls was 0.52% (*SD*=0.48%). The data were prepared and normalised using the same method at in Experiments 3 and 4. RTs below 250ms were removed, the reciprocal (1/RT) of the data was taken, and outliers were removed (scores > mean ±3*SD* within participant and condition). The removed scores accounted for less than 2% of PHD's data, and less than 1% of the Control participant data. Removed scores were replaced by the mean of the condition.

PHD's RTs were analysed using an independent ANOVA (as used by a number of researchers performing statistical tests on single case studies; Williams, Savage & Halmagyi, 2006; Striemer et al., 2009; Bate et al., 2009). Conducting an ANOVA with only one subject, and using individual trials as the experimental unit, has associated problems. As the data are not independent, the degrees of freedom are inflated, which will overestimate the significance of any differences (Type 1 error). However, there is a lack of a suitable alternative. Control participant data were prepared in the same way as PHD's, and were then averaged, before being submitted to an independent ANOVA.

7.7. Results

7.7.1. CFS condition

The mean transformed scores from the CFS condition for PHD and Controls are displayed in Figure 7.6.

PHD: In the CFS face condition, PHD had significantly faster responses to upright positive faces (*M*=.127, *SD*=.038) than inverted negative faces (*M*=.094, *SD*=.049; indexed by a main effect of manipulation; $F(1,120)=17.95$, $p<.001$)[19]. In other words, ‘normal’ faces are responded to faster than ‘manipulated’ faces when presented unconsciously in a prosopagnosic individual. PHD did not show faster responses to any particular emotional expression (main effect of emotion; $p>.05$), and this was true in both the upright positive and inverted negative faces (no emotion x manipulation interaction; $p>.05$). However, with the house stimulus, PHD’s responses did not differ between upright positive and inverted negative (indexed by a non-significant effect of manipulation in the house condition: $t(30) = 1.34$, $p=.19$).

Controls: The mean control data displayed a significant effect of manipulation, whereby upright positive (*M*=.129, *SD*=.027) faces were responded to faster than inverted negative faces (*M*=.100, *SD*=.034; $F(1,120)= 37.14$, $p<.001$). This ‘face facilitation’ effect replicates that found in Experiments 3 and 4 with an undergraduate sample, and is comparable to the effect found in PHD. The mean control data was modulated by emotion, ($F(3,120) = 8.43$, $p<.001$), and there was a significant emotion x manipulation interaction ($F(3,120) = 5.60$, $p=.001$). Exploration of the interaction suggested that there was not an effect of emotion in the positive upright faces ($p>.05$), but there was in the inverted negative faces ($F(3,60) = 10.79$, $p<.001$). The emotion effect in the inverted negative faces was due to slowed responses to angry faces (Bonferroni corrected *t*-tests between angry and other emotions: fear, $t(30)=5.25$, $p<.001$; happy, $t(30) = 3.19$, $p<.05$; neutral, $t(30) = 4.44$, $p<.001$). This slowed response to angry faces was also seen in the mean RT data from undergraduates in Experiment 3. That it was only found in the inverted negative stimuli (and not also in the upright positive stimuli) was unexpected, but consistent with the effect being driven by low-level characteristics.

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[19] This effect was also significant when tested with the more conservative Mann-Whiney U test, $Z=3.68$, $p<.001$.

There was no effect of manipulation for the house stimulus in the Controls ($t(30) = .66, p>.05$). Thus, there are comparable findings for PHD and Controls in the house condition. Overall, these results suggest that the effect of inversion and luminance polarity negation on unconscious house processing is less pronounced than in face processing. There are two possible reasons for this; either there is something special about faces and words (Jiang et al., 2007) that makes them unconsciously salient; or familiar objects in general are more salient, but that the houses still looked familiar when they were manipulated. In reference to this second point, the house stimuli that were used in this experiment are presented in Figure 7.7.

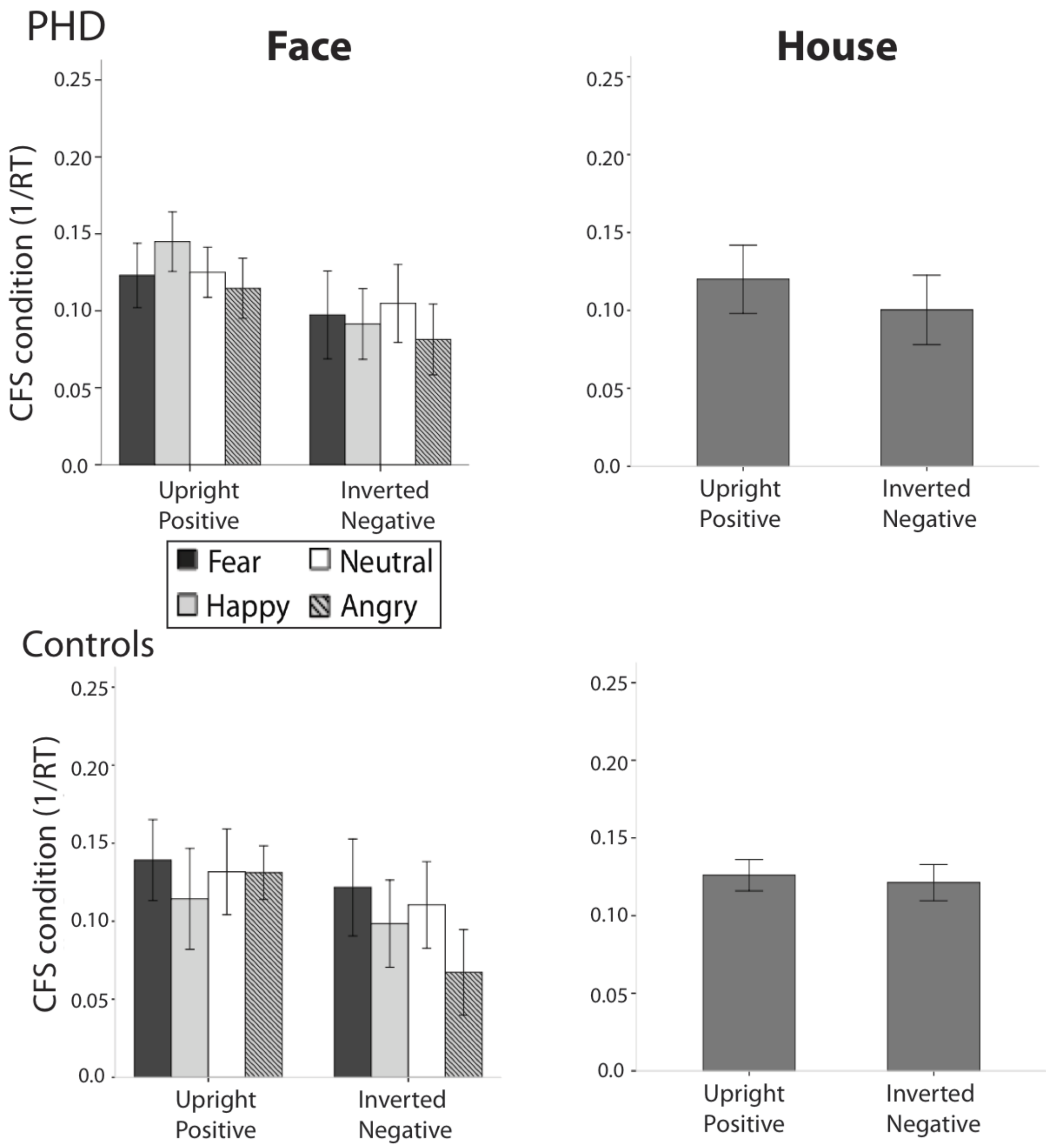

Figure 7.6. Mean reciprocal RTs (±95% CI) for the face CFS condition for PHD and the mean Control data as a function of emotion and manipulation condition.

Figure 7.7. Upright positive and inverted negative house stimuli

7.7.2. Control condition

The mean transformed scores from the control condition for PHD and the mean Control data are displayed in Figure 7.8. As in Experiments 3 and 4, response biases may have affected the CFS data. It is unclear the extent to which the control condition adequately measures these biases (see Chapter 4, *Section 4.4*), although it may provide some approximation.

PHD: PHD did show condition-specific effects in the control condition. PHD detected upright positive faces (M=.154, SD=.025) faster than inverted negative faces (M=.108, SD=.033; main effect of manipulation, $F(3,120) = 80.14$, $p<.001$). In addition, PHD's detection speed was modulated by the expression of the face (main effect of emotion, $F(3,120) = 4.05$, $p<.01$), whereby happy faces were detected faster than neutral faces, $t(62) = 2.77$, $p<.01$. There was no difference in PHD's detection times across manipulation condition in the house stimuli, $t(30) = .17$, $p=.87$.

Controls: The mean Control data showed that upright positive faces (M=.190, SD=.015) were detected faster than inverted negative faces (M=.167, SD=.018; $F(1,120) = 72.57$, $p<.001$). There was also a main effect of emotion ($F(3,120) = 8.99$, $p<.001$), where fear and happy expressions were detected faster than angry expressions (Bonferroni corrected t-tests between angry and fear, $t(62) = 3.40$, $p<.01$; and happy, $t(62)=3.13$, $p<.05$). This effect of slowed detection of angry is in line with the slowed responses to angry found in the CFS condition. The Control participants detected the upright positive and the inverted negative houses at similar speeds ($t(30)$ =.82, p=.42).

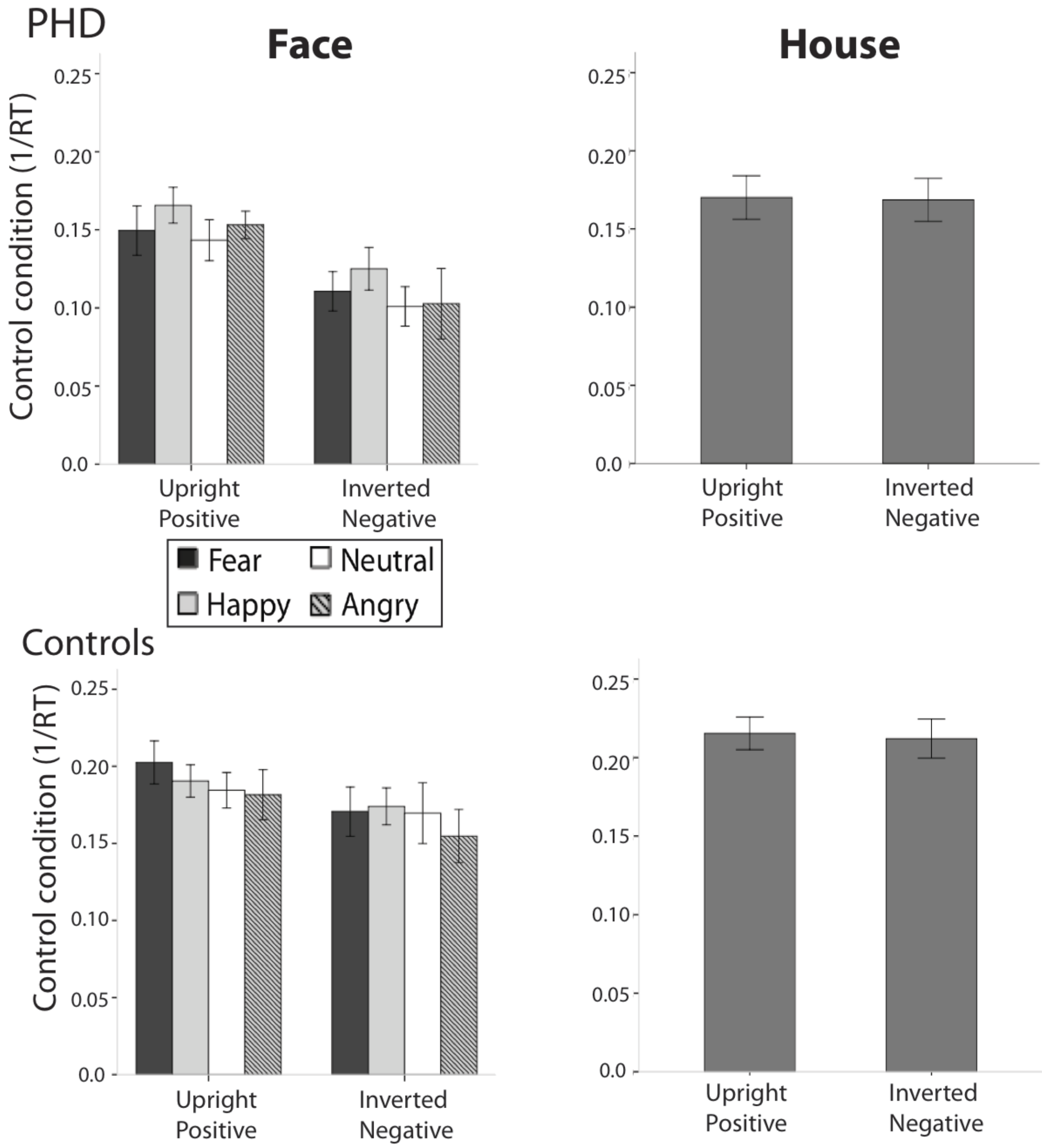

Figure 7.8. Mean reciprocal score (±1SD) from the face Control condition for PHD and the mean Control data as a function of emotion and manipulation condition.

Assuming that the CFS and control conditions were subject to the same response biases, they can be combined to estimate unbiased emergence times. The unbiased measure of emergence time was calculated in the same way as in Experiments 3 and 4; as variability across conditions was slightly higher in the CFS than the control data, each data set was first normalised using a zscore transformation. Thus the emergence time for each emotion and stimulus manipulation was given by CFS zscores – control zscores[20].

7.7.3. Unbiased measure of emergence

Emergence scores for PHD and the Control participants are displayed in Figure 7.9.

PHD: For PHD, in emergence time data, there was a significant interaction between emotion and manipulation ($F(3,120) = 7.02$, $p<.001$). The interaction was caused by there being an effect of emotion in the upright positive faces ($F(3,60) = 8.78$, $p<.001$), but not in the inverted negative faces ($F(3,60) = 1.31$, $p=.28$). In the positive faces, angry emerged slower than fear ($t(30) = 3.04$, $p<.01$), happy ($t(30) = 4.35$, $p<.001$) and neutral ($t(30) = 3.49$, $p<.01$). PHD showed a significant effect of manipulation in the angry faces (inverted negative faster than upright positive, $t(30) = 2.37$, $p=.025$). There was also an effect of manipulation in the happy expression (upright positive faster than inverted negative ($t(30) = 3.81$, $p<.001$), suggesting face-related processing in the happy expression that cannot be explained by low-level characteristics. Additionally, PHD's data showed no difference across manipulation condition for the house stimuli, $t(30) = .77$, $p=.45$ (as would be expected, given there was no difference in the CFS or Control conditions).

Controls: In the mean Control data, there was a main effect of emotion, $F(1,120) = 7.39$, $p<.001$, but no other effects were significant ($p>.05$). The main effect of emotion was due to fear expressions emerging faster than happy ($t(62) = 3.91$, $p<.001$), and angry ($t(62)= 3.73$, $p<.001$), expressions, and also, happy expressions emerging slower than neutral expressions ($t(62) = 2.73$, $p<.05$). Again, there was no difference in emergence times between upright positive and inverted negative houses for control participants ($t(30) = .16$, $p=.91$).

[20] Parallel analyses using the difference between the raw scores, rather than z-scores produced almost identical results.

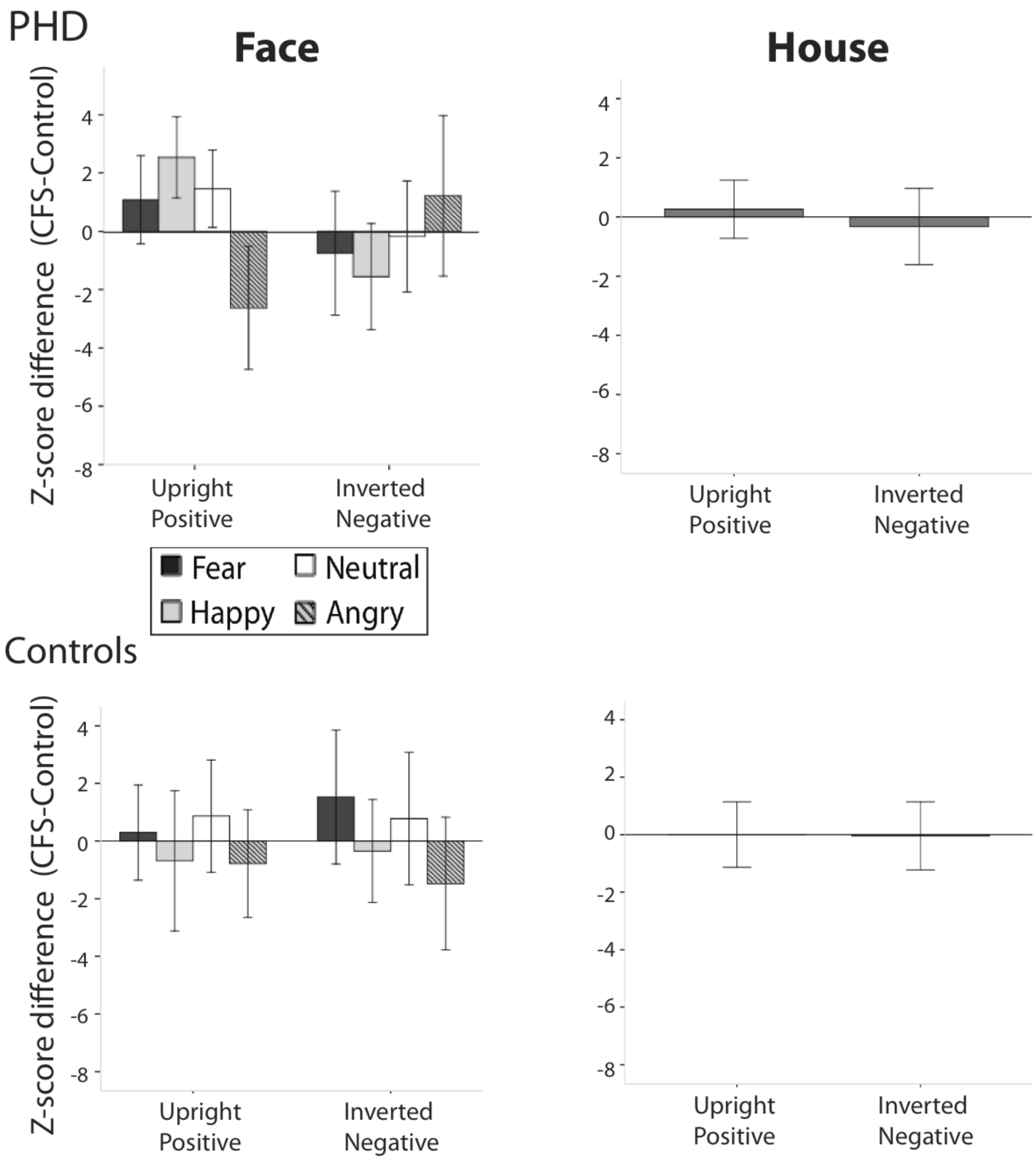

Figure 7.9. Mean CFS corrected by control data (CFS-control; ±95% CI) for PHD and Control mean as a function of emotion and manipulation condition.

7.8. Discussion

The present experiment used a CFS paradigm to investigate unconscious emotional face processing in the prosopagnosic individual, PHD. Results from the CFS condition in the present experiment indicate that the same general face prioritisation effect found in Experiments 3 and 4 of this thesis is replicated in a case of prosopagnosia (PHD responded faster to upright positive faces than inverted negative faces). This was unexpected, given that the 'face-effect' was hypothesised to be driven by the meaningfulness of the stimuli. PHD is an individual who finds it very difficult to use information from faces, and does not find them particularly salient; indeed, he does not show the classic, robust, early electrophysiological response to faces (N170, Eimer & McCarthy, 1999). However, he still displays a convincing 'face' prioritisation effect in CFS. This suggests that it may not be the assessed meaningfulness of the stimuli that drives preferential access to awareness in this paradigm. It is possible that even in an individual who finds it very difficult to extract information from faces, it is the familiarity of the stimulus that is responsible for the effect. Thus, even though faces seem to hold little meaning for PHD, he (and his visual system) is used to seeing faces as upright and positive, rather than inverted and negative.

PHD was better at categorising emotional faces when they were presented normally, compared to when they were manipulated (Experiment 7). Is it possible that PHD's accurate overt recognition of the normal faces drove their faster emergence from suppression? It is unclear whether PHD's emotion recognition (as found in Experiment 7) is based on analytic/cognitive strategies. These cognitive strategies are unlikely to have affected responses in the CFS paradigm; participants were instructed to record the location of the stimulus as soon as they saw anything emerge from the noise – they did not need to recognise the identity or emotion of a stimulus before responding.

De Gelder et al. (2003) suggested a modulatory role for emotion on identity processing. They found that prosopagnosics performed better on a face-matching task when the faces displayed an emotional expression, compared to neutral. The neurological process by which this may occur was also investigated. In response to emotional faces, prosopagnosics (with damage to areas typically associated with face identification), showed brain activation in emotion-sensitive pathways (e.g. the SCS and amygdala). A modulation of face processing by emotion in the present study would have been evidenced by a face prioritisation effect (faster responses to upright positive faces than inverted negative faces) found in the happy, angry and fear expressions, but not in the neutral faces. PHD showed no such emotion-contingent effects, emotion did not appear to modulate face processing in PHD when the faces were presented unconsciously.

Peelen et al., (2009) used visual search and change-blindness tasks to explore whether emotional faces are prioritised in prosopagnosia. They found that an AP individual showed attentional capture with consciously presented fearful and happy expressions (over neutral faces). This was explained by the emotion processing systems used to preferentially process emotional information functioning normally in AP. In the present experiment, no evidence for unconscious emotional prioritisation was found in PHD. It would be interesting to replicate Peelen et al.'s method in PHD for conscious attentional prioritisation with good control stimuli, to determine the role of low-level visual characteristics in these 'emotion' effects.

Note that although the CFS data give an overall measure of the time it takes for unconscious stimuli to reach awareness, it may include different 'conscious' detection times (variation in times to respond to the stimuli after they emerge from suppression). Our control data suggest that these conscious detection times did vary across the stimuli used in the present experiment for both PHD and Controls. As discussed previously, (Chapters 4, *Section 4.4*), the correct interpretation and implementation of these control data is not entirely clear. Not withstanding these reservations, in the present experiment, when these conscious detection times were eliminated from the CFS data, the only significant effect of manipulation in PHD's data (where upright positive faces emerged faster than inverted negative faces) was in the happy expression. This is interesting and may suggest there is something special about PHD's processing of happy expressions (i.e. the processing of happy expressions may have been less disrupted by his lesions). This concurs with findings from Experiment 7, and Mestry et al. (2010), and results from another prosopagnosic individual (Stephan et al., 2006).

In the present experiment, the controls showed a face effect in the CFS condition, thus replicating findings from Experiments 3 and 4 with an older sample. Emotion also modulated response time in the control participants. As the emotion effect was found in the inverted negative faces, it is likely to be caused by the low-level characteristics of the stimuli.

Neither PHD nor the controls showed any effect of manipulation in the house condition. No preliminary test was used to explore how recognisable the houses were when normal (upright positive) versus manipulated (inverted negative). It is possible that the manipulations do not impair recognition of a house to the same degree as they impair face perception. Alternatively, it is possible that faces can be processed (and prioritised) when they are unconsciously presented, whereas houses are not. Jiang et al., (2007) found that upright faces emerged from suppression faster than inverted faces, and that recognisable words emerged from suppression faster than unrecognisable words. Jiang et al.'s study is the only experiment to date that has explored unconscious processing of meaningful stimuli – other than faces – under CFS. In order to ascertain why there is a lack of manipulation effect in the house condition, it would be necessary to investigate recognition of the house stimulus with the inversion/polarity manipulations.

In summary, the present experiment has found that a prosopagnosic individual does display prioritised processing of faces when they are presented unconsciously. Further investigations on PHD and other prosopagnosic individuals would be necessary to explore this effect further and delineate the processes by which this face effect is preserved in an individual with very poor face recognition. To conclude, the unconscious face effect found in previous Experiments using a CFS paradigm cannot be explained in terms of the 'meaningfulness' of the stimuli. The results found here warrant additional investigation, and suggest that the use of prosopagnosia is valuable in investigating face and emotional face processing, both inside and outside of awareness.

Chapter 8

General Discussion

8.1. Summary

Theories of emotion processing with an evolutionary perspective highlight the adaptive nature of fast and efficient processing of emotional information (e.g. Ohman & Mineka, 2001). This has lead to a large number of studies designed to investigate whether emotional stimuli are granted prioritised access to attention and awareness.

There is some evidence that emotional information is preferentially attended; experiments have shown attentional prioritisation of emotional over neutral stimuli (e.g. Koster et al., 2004; Pourtois et al., 2004; Vuilleumier & Schwartz, 2001). Importantly though, the vast majority of the studies investigating attentional prioritisation of emotional information have failed to use control stimuli. Thus, they are unable to differentiate between the extraction of emotional content, or low-level characteristics.

Evidence from visual search does not indicate that faces can be processed *without* attention, as there is no robust evidence for a ‘pop-out’ effect (e.g. Fox et al., 2000; Ohman et al., 2001; Horstmann, 2007). Although some studies have reported a more efficient search with threatening rather than positive or neutral faces (e.g. Fox et al., 2000), others have found faster search for happy expressions (Calvo & Marrero, 2009; Juth et al., 2005). However, both sets of results may be due to the low-level characteristics of the stimuli (Calvo & Marrero, 2009; Coelho et al., 2010; Calvo & Nummenmaa, 2008). Specifically, it seems that with pictorial faces, happy expressions have particularly salient low-level characteristics (e.g. Calvo & Nummenmaa, 2008), and with schematic emotional face stimuli, angry expressions have particularly salient low-level characteristics (e.g. Coelho et al., 2010).

Neuroimaging studies indicate that emotional faces can be processed with limited attention. When attention is distracted away from emotion stimuli, amygdala activation elicited by fearful expressions is increased compared to that in response to neutral expressions (Vuilleumier et al., 2001; Anderson et al., 2003). This suggests that emotional faces can differentially activate emotion-specific brain areas when they are not the focus of attention. However, when attention is fully distracted, there is no difference in amygdala activation in response to fearful versus neutral faces (Pessoa et al., 2004). None of these high-impact neuroimaging studies (cited above) used control stimuli. Therefore, it is possible that these results are not caused by the extraction of emotional meaning.

The prioritisation of emotional faces outside awareness has been investigated using a number of methods, with varying success. Backward masking has been used considerably (see Chapter 1, *Section 1.4.1*), but most of the research using this paradigm has not used objective awareness tests; thus the effects may be conditional on conscious processing (Pessoa et al., 2004).

The experiments that have used binocular rivalry as a behavioural tool to investigate the relative predominance of emotional over neutral faces have shown that emotional faces (both threatening and positive) are prioritised; however, some suffer from major experimental flaws (Alpers & Gerdes, 2007; Bannerman et al., 2008; Yoon et al., 2009). In these studies, it was unclear whether the stimuli were in fact rivalling (due to large stimuli, and overall similarity in the stimuli presented to each eye), or whether predominance of the emotional stimulus was caused by the suppressed, or the dominant image (see Chapter 1, *Section 1.4.3*). My recent study controlled for both issues, but could not distinguish whether the results were caused by high-level or low-level factors (Gray et al., 2009). Continuous flash suppression (CFS) has also been used to discover whether emotional faces are prioritised when presented outside of awareness (Yang et al., 2007). Despite a conclusive fear prioritisation effect, again, results from Yang et al.'s study were ambiguous regarding the origin of the effect (high- vs. low-level characteristics).

Finally, neuroimaging techniques have been used to monitor brain activation in response to unconsciously presented emotional faces. These studies have suggested that fear-specific brain activation can occur outside of awareness (Pasely et al., 2004; Williams et al., 2004; Jiang & He, 2006); as amygdala activation is increased in response to fearful compared to neutral faces, even when the faces are unconsciously perceived (i.e. suppressed in rivalry or CFS).

Generally, few studies that have investigated emotional face processing have controlled for low-level visual characteristics of the stimuli. Within emotion processing research, researchers have typically investigated differences between emotional and neutral faces. The neutral face does act as a control for emotion (as it has none). However, the low-level characteristics vary a great deal between a neutral and an expressive face, meaning that there are many reasons why responses might differ. Low-level visual characteristics are critically important in attentional allocation. Indeed, in visual search experiments, 'pop-out' occurs when the target has a visual feature that is unique (e.g. colour, luminance contrast, or orientation) and not shared with the distractors (Triesman & Gelade, 1980). Salient visual information (i.e. stimuli with high contrast) is also prioritised when presented outside of awareness (Tsuchiya & Koch, 2005). Therefore, there is danger that without adequate controls, the emotional face literature is simply confirming low-level effects that are well-documented with simple stimuli. The use of control stimuli in emotional face processing research is therefore critically important in the interpretation of any emotion effects.

The work presented in this thesis represents a well-controlled, thorough investigation of the unconscious processing of emotional expressions. An overview of the major results of each experiment are summarised below, including a discussion of the limitations of each study, and ideas for further research.

8.1.1. Experiments 1 & 2: Emotion categorisation of normal and manipulated broad, high and low spatial frequency faces

This thesis first addressed the issue of what makes a good control for low-level characteristics in emotional face processing. Generally, studies investigating emotional face processing have not used controls. In the rare instances that low-level controls are used, inverted faces have been chosen (Phelps et al., 2006; Yang et al., 2007; Bannerman et al., 2008; Gray et al., 2009; Holmes et al., 2005). Previous research has shown a limited effect of inversion on emotion recognition (Prkachin, 2003; McKelvie, 1995), despite a large effect on identity recognition (Valentine, 1989; Freire et al., 2000). With this in mind, stimuli were created that retain most low-level characteristics but are more difficult to recognise than normally presented faces, and inverted faces. Spatial inversion and luminance polarity negation are two manipulations that do not affect critical low-level features, such as contrast, luminance, spatial frequency. When combined, these manipulations significantly impair identity processing (e.g. Kemp et al., 1990; McMullen et al., 2000). However, there has not been a systematic study of both manipulations on emotion recognition. In Chapters 2 & 3 it was shown that orientation and luminance polarity manipulations disrupted emotion processing with additive effects. Therefore the best control was given when both manipulations were used: low-level properties were vastly similar to the original images, but the extraction of emotional information was severely disrupted. This was true for BSF (Experiment 1; Experiment 2), HSF and LSF (Experiment 2) faces.

The interpretation of the data from latter studies in this thesis is reliant on the inversion and negation manipulations severely disrupting the extraction of emotional meaning from the faces. Experiments 1 and 2 indicated that the emotional content of the manipulated stimuli was significantly harder to recognise than the normal face stimuli. However, it is possible that residual emotion processing may exist, even in faces with these manipulations. For example, it is arguable that even though emotions are very difficult to classify, participants may be able to discern that the manipulated faces are generally positive or generally negative. This is unlikely, as participants would have been above chance at classifying emotion (performance did not differ from chance for the inverted negative expressions in Experiment 1, although with increased presentation time, performance was significantly better than chance in Experiment 2). It is also possible that although observers cannot overtly classify the emotions, that they have some physiological reaction (i.e. increased skin conductance responses) to the threat-related manipulated stimuli. Neither of these possibilities was addressed in this thesis, providing an obvious development for future research.

8.1.2. Experiment 3: Unconscious processing of threat

There has been some indication that emotional faces can be processed outside of awareness (Yang et al., 2007; Williams et al., 2006). A number of studies have reported sub-cortical, amygdala-based activation in response to fearful faces that are presented unconsciously (Williams et al., 2004; Pasley et al., 2004, Jiang & He, 2006). However, it is unclear whether this is paralleled in behavioural measures (due to methodological issues with the behavioural tasks employed; see above). To be adaptive (i.e. increase chances of survival; Ohman & Mineka, 2001), it is critical that the emotional prioritisation impacts on behaviour (e.g. by directing attention towards emotional stimuli, or granting them prioritise access to awareness).

Recall that an interesting behavioural study investigated the unconscious processing of emotional faces and found a fear prioritisation effect (Yang et al., 2007). However, the design of this study could not differentiate whether the fear prioritisation was driven by the extraction of emotional meaning (in both the upright and inverted faces) or low-level characteristics. Therefore, in Experiment 3, using the control stimuli validated in Experiment 1, the origin of the unconscious fear prioritisation effect previously found with CFS (Yang et al., 2007) was explored. Results from Experiment 3 indicated that all the variability in prioritisation across emotional expressions was explained by the low-level visual characteristics of the stimuli, as the same emotion effect was found in both the normal (upright positive) and the manipulated (inverted negative) faces.

The control condition used in Experiment 3 was derived from a similar control condition used by Jiang et al. (2007). It attempted to measure the bias in conscious detection times that might have been influencing the CFS data. For example, if a manipulated face is generally less recognisable, observers may respond more conservatively / slowly to it. Therefore, the CFS response times may consist of unconscious detection time plus conscious bias. The control condition was used to measure conscious bias, enabling it to be extracted from the CFS data to produce an 'unbiased' emergence from suppression time. However, there are several problems (that have been raised earlier in this thesis, Chapter 4, *Section 4.4*.) with this approach. Firstly, the rate of contrast increase chosen for the control trials was arbitrary (although based on that used by Jiang et al.). Secondly, it is not clear whether the same detection mechanisms are being tapped in the CFS and Control conditions. In the CFS condition, the stimuli do not appear to slowly emerge into awareness, as if their contrast is being increased. Instead, they tend to either be perceived or not perceived (suggesting a minimal effect for conscious biases in the detection times of stimuli in CFS). Given these limitations, the control data and unbiased emergence data are interesting, while main conclusions should be drawn from the CFS data.

It would be interesting to discover whether the low-level explanation of emotion effects found in Experiment 3 can also explain emotion effects found across different types of emotional stimuli. There is some indication that emotional scenes are preferentially processed (e.g. Calvo & Lang, 2004). To investigate this possibility, a good control for low-level characteristics for emotional scenes would first need to be verified. Similar manipulations to those used in this thesis (i.e. inversion and luminance polarity negation) would offer a good starting point.

8.1.3. Experiment 4: Investigating the visual characteristics that contribute to unconscious emotion processing: spatial frequency

To ascertain which visual characteristics are involved in the unconscious processing of emotional faces, the influence of spatial frequency (SF) was investigated in Experiment 4. The low-spatial frequency (LSF) information contained in an emotional face has been suggested to account for the prioritisation of emotional stimuli (Vuilleumier et al., 2003). This proposition has been supported by the suggested involvement of the largely magno-cell dominated, sub-cortical processing pathway, in rapid emotion processing (LeDoux, 1996). Holmes, Green and Vuilleumier, (2005) found that LSF fearful faces were selectively attended in a dot probe technique; this effect was not found with high-spatial frequency (HSF) faces. In Experiment 4, little effect of emotion was found in any of the SF categories (HSF, LSF, or broad spatial frequency; BSF). Certainly, there was no greater effect of emotion in the LSF faces than the faces in the other SF bands. Holmes et al. used conscious presentation, whereas Experiment 4 used a CFS method to present the faces unconsciously. Taking these data together, it is possible that the LSF prioritisation of emotional faces is only observable in conscious vision.

The effect found in Experiment 3 for the BSF faces was not replicated in Experiment 4. It could be that the there was not enough power to detect the emotion effect (less participants were tested). However, the ‘face’ effect (with a statistically similar effect size to the emotion effect in Experiment 3) was found in Experiment 4. There were methodological differences between Experiments 3 and 4. Place-holders were used in Experiment 4 to control for the suggested contour-confound in the HSF faces. The use of hybrid SF faces (a face containing an expression in one SF band, and a neutral face in the other SF band) would also have controlled for the HSF contour confound. Hybrid SF faces have been used by other researchers when investigating emotion effects (Winston et al., 2003; Pourtois et al., 2005). It would be interesting to compare the results found in Experiment 4 with a study that used these hybrid SF faces in CFS. Additionally, observers’ search strategies may have changed between Experiments 3 and 4, as the stimuli were, on average, less face-like in Experiment 4

(HSF, LSF and BSF faces were interleaved). Blocking the design by SF may reduce this effect.

Further studies could extend the investigation into which low-level characteristics are responsible for the fear-prioritisation effects found in Experiment 3. Results from Experiment 4 suggest that SF is not a critical variable. However, given the pattern of results from Experiment 3, low-level characteristics are responsible for the fear effect. As discussed in Chapter 4 (*Section 4.4*), it is possible that local luminance contrast in the eye region may lead to preferential processing of fear. A previous experiment found that the amygdala shows increased activation in response to just the eye region of a fear face (compared to the eye region of a neutral face) when presented unconsciously (Whalen et al., 2004). In addition, fearful eyes were found to emerge faster than neutral eyes when just the eye area of an emotional face was presented under CFS (Yang et al., 2007). Therefore, the fear prioritisation effect found in Experiment 3 is likely to have been driven by high-contrast in the eye region, although this was not tested directly in the present thesis.

8.1.4. Experiments 5 & 6: Investigating the effect of a previously presented emotional face on probe contrast discrimination

The use of a different dependent measure (than reaction times) was investigated in Experiments 5 and 6. Some have measured contrast discrimination of a visual probe to investigate emotional facilitation (Phelps et al., 2006; Bocanegra & Zeelenberg, 2009). Despite the limited research using this method, Phelps et al.'s (2006) study has been cited over 80 times (source: Web of Science). However, to date, only fearful expression facilitation (cf. neutral expressions) has been investigated using this paradigm (Phelps et al., 2006; Bocanegra & Zeelenberg, 2009). There is some ambiguity in the direction of the emotion effect, and whether fearful faces enhance, or neutral faces impair contrast sensitivity for a subsequently presented probe (Phelps et al., 2006).

A number of studies that have investigated emotional prioritisation have only done so for fearful (vs. neutral) faces (e.g. Phelps et al., 2006; Holmes et al., 2005; Whalen et al., 1998). Neuroimaging data has tended to suggest robust activation in subcortical brain structures in response to fearful faces (Breiter et al., 1996; Morris et al., 1996), whereas activation in response to other expressions is mixed (Morris et al., 1996; Whalen et al., 1998). It is possible that fear expressions alone tend to be explored in this research due to an issue of power (the power to find a significant effect is reduced when more comparisons are being made). However, there does not seem to be any reason why the same emotion effects (enhancement or attentional/ unconscious prioritisation) would not also be predicted to occur in response to angry expressions as well as fear expressions. Indeed, some of the visual search literature has focussed on angry expressions (Ohman, et al., 2001; White, 1995; Fox et al., 2000; Horstmann, 2007); it is possible that this is because fear expressions are difficult to represent in a schematic (which have been used extensively to limit low-level effects). There has been some suggestion that the amygdala specialises in threat processing (Whalen et al., 1998). However, theoretically, if the emotional face effects are driven by a threat-prioritisation, then they should generalise to other threatening (like angry) expressions. In turn, they should not generalise to happy expressions (although in the literature a happy' effect has also been found, Calvo & Marrero, 2009). It is difficult to get a complete picture of what is happening in emotional face processing when only fear and neutral expressions are tested.

All experiments reported in this thesis presented fear, neutral, happy and angry expressions, with the exception of Experiments 5 and 6. In Experiment 5, fear, neutral and happy faces were presented, and the expressions were limited to just fear and neutral in Experiment 6 (to exactly replicate Phelps et al., 2006). The results of Experiments 5 and 6 were somewhat surprising. Overall, the probe contrast discrimination was not robustly affected by the expression of a previously presented face. The effect found by Phelps et al., (2006) was not evident at all in Experiment 5, where subtle changes in the design of the study, including the addition of a happy face, seemed to nullify the effects. Using a near exact replication of Phelps et al.'s study in Experiment 6, a significant 'fear' effect was found, but there was not a convincing emotion by manipulation interaction.

It would be interesting to explore the role of low-level characteristics in other conscious attentional prioritisation paradigms. For example, the classic visual-probe task, or exogenous cuing task (that index visuo-spatial attention) could be investigated using manipulated faces as a control for low-level characteristics.

8.1.5. Experiments 7 & 8: Investigating unconscious face processing in a case of prosopagnosia

Motivated by the findings from Experiments 3 and 4 (and those found by Yang et al., 2007 and Jiang et al., 2007), the present thesis also investigated the face prioritisation effect. Upright positive faces consistently emerged from suppression faster than inverted negative faces (Experiments 3 and 4), and this tended to be a stronger effect than that of emotion (Experiment 4). Experiments 7 and 8 attempted to investigate this effect in an individual with acquired prosopagnosia. Experiment 7 investigated the suitability of using manipulated faces as controls for emotional faces in the prosopagnosic individual. Unconscious face processing in the prosopagnosic individual was explored in Experiment 8. Critically, he did show the same unconscious face effect, whereby normal faces emerged faster than manipulated faces. This suggests that the processing required for the unconscious face effect may not be dependent on intact cortical face processing, or being able to extract information from a face easily. There were constraints in the number of trials/duration of the experiment, as the prosopagnosic observer tested tended to find it difficult to concentrate for a long period of time. Thus, collecting data over a succession of days would be a good way to collect a larger number of trials, which would help to reduce the confidence limits on the mean RT scores.

8.2. General comments

In every experiment in this thesis (with exception of Experiments 7 & 8, with the prosopagnosic individual), anxiety measures were taken. A considerable volume of research suggests that individual differences in anxiety significantly impact threat-related processing. Indeed, leading models of anxiety propose that threatening information can be processed before conscious appraisal, and is granted prioritised access to attention and awareness to a greater extent in anxious than non-anxious individuals (Mogg & Bradley, 1998). There is even some indication that the attentional effects found in the visual-probe task are not reliably found in normal samples, but are robustly found in anxious individuals (Bar-Haim et al., 2007). No effect of anxiety was found on the dependent measures of any of the experiments in the present thesis.

The experimental designs used in this thesis were not optimised to discover an effect of anxiety: participants were not pre-selected for anxiety levels; clinically anxious participants were not tested; and samples did not tend to include a large number of participants. However, individual differences in anxiety were not the main focus of this thesis. Anxiety measures were taken to check that anxiety was not a confounding factor across experiments.

It is possible that emotional faces are unconsciously prioritised based on a combination of both high-level and low-level factors. In the present Experiments, all of the variance can be explained by low-level visual characterisics. However, there may be individual differences in the magnitude of an additional high-level (i.e. emotional content) effect. In anxious individuals, high-level factors may add to the effect of low-level characteristics, increasing the emotion effect by further prioritising fear, and perhaps anger in the emergence from suppression. This is a possibility that would help explain the vast emotional face prioritisation literature in anxious participants (see *Section 1.5*).

It would therefore be interesting to conduct an experiment based on Experiment 3 on clinically anxious participants (given the above hypothesis, clinically anxious participants should demonstrate the largest high-level emotional effect). It is predicted that in a clinically anxious population, the emergence of emotional faces into awareness may be modulated by the basic low-level features (as found in the normal population), with an additional effect of higher-level emotional meaning. In other words, it is predicted that the effects of fear prioritisation will be greater in anxious participants, in line with findings from previous experiments probing attentional prioritisation (Bar-Haim et al., 2007).

The present thesis concentrated exclusively on emotional face stimuli. Emotional faces may be somewhat ecologically valid, as facial expressions inform us about the environment and potential threats (Ohman, 2002). The emotions displayed by models used in the experiments of the present thesis were selected on the basis of their validity (from the NimStim face set, Tottenham et al., 2009). However, static faces are very rarely seen, and some research has suggested that dynamic faces are much more ecologically valid (Kilts, Egan, Gideon, Ely & Hoffman, 2003). The low-level characteristics of faces are relatively easy to control, but emotional faces are not particularly arousing stimuli (compared to images of negative and positive scenes; Lang et al., 1993, or dynamic faces; Kilts et al., 2003). It would be interesting to investigate the effects found here for more arousing stimuli.

Finally, it is possible that the distinction between the extraction of emotional content and low-level characteristics in the prioritisation of emotional information may be considered unimportant. The fact that the fear prioritisation effect (found in Experiment 3) was driven entirely by low-level characteristics does not negate the fact that the fear-prioritisation effect was found. Theories of emotion processing suggest that the threat content of a stimulus drives its prioritisation (e.g. Ohman & Mineka, 2001; Mogg & Bradley, 1998). However, data from the present thesis suggests that one should be careful when interpreting data from emotional face studies. Findings from the present thesis suggest that the apparent threat biases can be explained without threat-specific processing, or the extraction of meaning from threatening stimuli from sub-cortical pathways. Instead, it may also suggest that our facial expressions have developed to be salient to our visual systems.

8.3 Concluding remarks

The main points from this collection of experiments are that 1) emotional expression may facilitate emergence into awareness; 2) when emotion is prioritised it is due to low-level visual characteristics, not the extraction of emotional meaning; 3) It is unclear whether the emotion prioritisation is driven by a particular SF band; 4) Face specific processing occurs during unconscious vision; 5) unconscious high-level face processing may not be dependent on intact cortical face processing.

A number of researchers have started questioning the basic emotion-prioritisation effects, and are investigating them using well-controlled paradigms (e.g. Coelho et al., 2010; Calvo & Nummenmaa, 2008). Indeed, Pessoa and Adolphs, (2010) provide a review that challenges the traditional idea that sub-cortical brain regions drive rapid processing of emotional information (note that this traditional idea receives significant support; see review by Tamietto & de Gelder, 2010). Instead, Pessoa and Adolphs emphasise the involvement of more general-purpose cortical regions in threat detection. Thus, the question of whether emotional face prioritisation is driven by the extraction of emotional meaning, or low-level visual characteristics, is being considered widely. This thesis is timely in its exploration of this question, and contributes to the resolution of this high profile debate, and theoretical tension.

Appendices

Appendix A

Experiment 1: Bias data

A.1. Data analysis

The hits (H) and false alarms (FA) were converted into proportions, and then into B″ a non-parametric measure of bias (Grier, 1971), which is given as

$$B'' = \left[\frac{H(1-H) - FA(1-FA)}{H(1-H) + FA(1-FA)}\right] \qquad \text{(A1)}$$

If the proportion of hits were lower than the proportion of false alarms, a different formula was used (Snodgrass & Corwin, 1988), where

$$B'' = \left[\frac{FA(1-FA) - H(1-H)}{H(1-H) + FA(1-FA)}\right] \qquad \text{(A2)}$$

Bias scores range from 1 to -1, with values less than 0 indicating a bias towards the ‘yes’ response (i.e. the happy response when the face is happy), and values greater than 0 indicating bias towards the ‘no’ response (i.e. the fear or angry response when the face is happy). A value of 0 represents no bias.

A.2. Design

The B″ scores were entered into a 3 x 2 x 2 x 2 repeated measures ANOVA, with emotional face (angry, happy, fear), orientation (upright, inverted), polarity (positive, negative), and morph strength (low, high) as within subject IVs.

A.3. Results

There was a significant main effect of polarity ($F(1,20) = 17.22$, $p = .001$), and significant interactions between polarity and emotion ($F(2,40) = 4.32$, $p < .05$), orientation and morph ($F(1, 20) = 5.37$, $p < .05$), emotion and morph ($F(2,40) = 7.89$, $p = .001$), and a significant three-way interaction between orientation, polarity and morph ($F(1, 20) = 10.70$, $p = .01$).

Generally, a liberal criterion was adopted when the stimuli were ambiguous. Participants were more conservative when the faces were positive polarity than negative polarity (positive: $M = .17$, $SD = .01$; negative: $M = 0.11$, $SD = 0.11$). In the positive faces, there was no difference between the emotions ($p > .05$). However, in the negative faces, fear ($M = .02$, $SD = .10$) was responded to more liberally than happy ($M = .18$, $SD = .13$; $t(20) = 3.98$, $p = .001$) or angry expressions ($M = .13$, $SD = .14$; $t(20) = 2.14$, $p < .05$). This suggests that when the stimuli were ambiguous, fearful faces were responded to more liberally than angry or happy expressions. This may be the result of fearful faces being slightly more ambiguous than angry or happy expressions, and generally a little harder to categorise.

Another example of a more liberal criterion used with ambiguous stimuli is that in the 50% morph strength condition, upright faces ($M = .17$, $SD = .05$) were responded to more conservatively than inverted faces ($M = .12$, $SD = .10$), $t(20) = 5.03$, $p < .001$. Whereas in the 100% morphs, there was no difference in bias between the two orientations ($p > .05$).

In the 50% morph, fear ($M = .02$, $SD = .15$) was responded to more liberally than happy ($M = .22$, $SD = .11$; $t(20) = 4.05$, $p = .001$) and angry ($M = .19$, $SD = .15$; $t(20) = 3.14$, $p < .01$). Whereas in the 100% morph there was no difference between the emotions ($p > .05$). Again, this suggests that when stimuli are ambiguous, participants become more liberal in answering ‘fear’ than ‘happy’ or ‘angry’.

In the 50% morph, there was a main effect of orientation ($F(1,20) = 25.30$, $p < .001$), polarity ($F(1,20) = 24.10$, $p < .001$) and a significant interaction ($F(1,20) = 18.69$, $p < .001$). The interaction shows that upright faces were responded to more conservatively than inverted faces when they were presented in positive polarity ($t(20) = 6.47$, $p < .001$), but not negative polarity ($p > .05$). And also positive faces were responded to more conservatively than negative faces when they were upright ($t(20) = 6.32$, $p < .001$), but not inverted ($p > .05$). In the 100% morph, there was no significant effect of orientation or polarity on bias ($p > .05$).

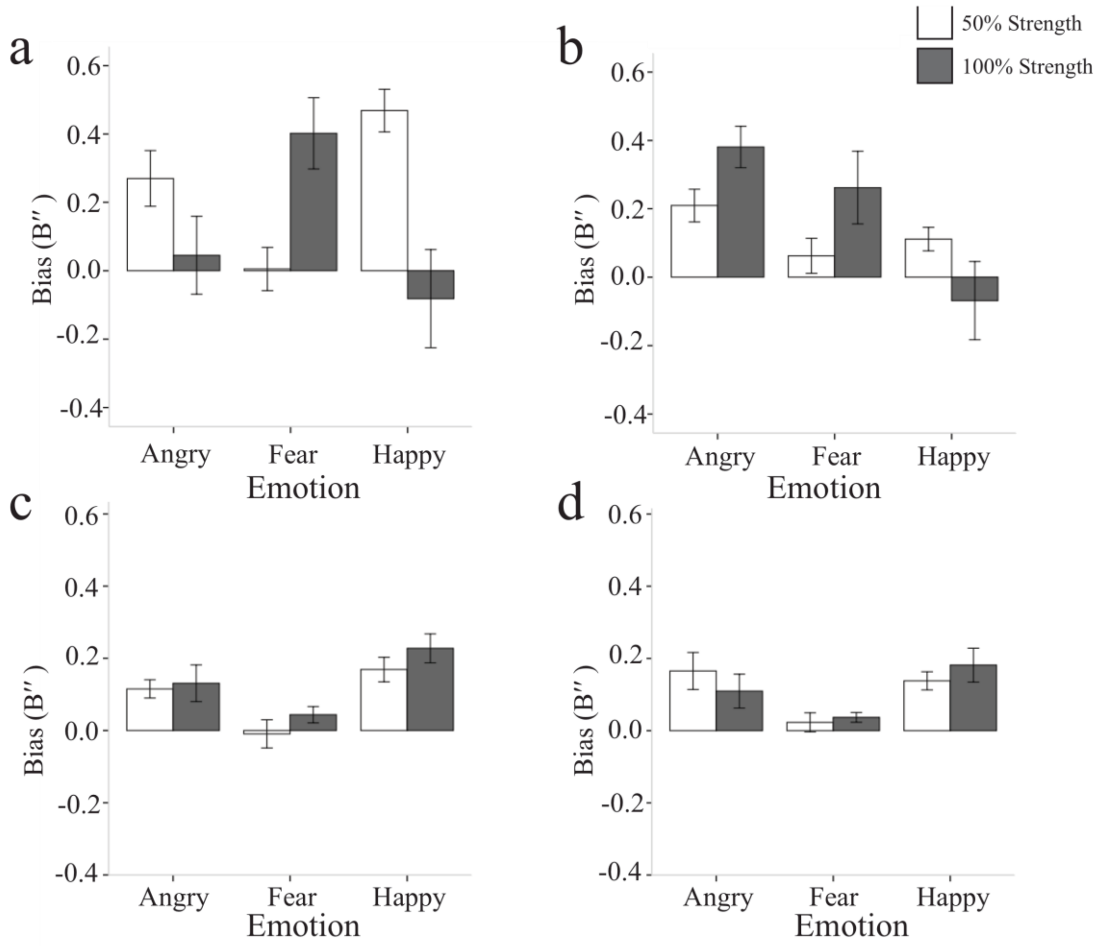

Figure A1. Bias as a function of emotional expression and emotion strength for a) Upright Positive, b) Inverted Positive, c) Upright Negative, and d) Inverted Negative faces.

Appendix B

Experiment 1: Sample Characteristics

Table B1.

Sample characteristics: Experiment 1

Anxiety Questionnaires	*M* (*SD*)	Min	Max
STAI-T	39.71(*12.97*)	20	74
FNE	15.43 (*9.09*)	0	30
SADS	4.48(*5.64*)	0	23
SDS	3.24 (*1.67*)	0	8
STAI-S	35.67 (*13.82*)	20	75

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

Appendix C

Experiment 1:

Correlations between performance and anxiety measures

Table C1. Correlations between sensitivity and questionnaire measures

			STAIT	STAIS	FNE	SADS	SDS
Upright	Angry	1	0.03	0.12	0.27	0.14	-0.07
Positive		2	-0.09	-0.05	0.04	-0.08	-0.12
	Fear	1	-0.22	-0.14	0.01	-0.14	0.03
		2	-0.06	0.00	0.17	-0.05	-0.19
	Happy	1	-0.22	-0.10	-0.19	-0.34	0.26
		2	-0.17	-0.06	0.04	-0.21	-0.09
Upright	Angry	1	-0.53*	-0.49*	-0.22	-0.20	0.27
Negative		2	-0.46*	-0.51*	-0.15	-0.15	-0.16
	Fear	1	-0.33	-0.39	-0.19	-0.28	0.21
		2	-0.24	-0.27	0.06	-0.16	-0.00
	Happy	1	-0.37	-0.33	-0.26	-0.40	0.14
		2	-0.56**	-0.65**	-0.35	-0.47	0.17
Inverted	Angry	1	-0.01	0.05	0.17	0.19	-0.07
Positive		2	-0.07	0.07	0.03	-0.08	0.03
	Fear	1	-0.22	-0.11	-0.01	-0.06	-0.11
		2	-0.20	-0.08	-0.01	-0.09	-0.03
	Happy	1	-0.11	-0.00	-0.17	0.00	0.13
		2	-0.25	-0.16	-0.08	-0.25	0.05
Inverted	Angry	1	-0.23	-0.13	0.05	0.03	-0.15
Negative		2	-0.17	-0.09	0.23	-0.06	0.13
	Fear	1	0.00	0.02	-0.22	-0.14	0.17
		2	-0.20	-0.04	-0.20	-0.06	0.24
	Happy	1	-0.13	-0.15	-0.20	-0.15	-0.15
		2	-0.07	0.02	0.02	-0.23	0.35

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version. 1=50% morph-level; 2=100% morph-level.

*=p<.05; **=p<.001

Appendix D

Experiment 2: Bias data

Bias data were calculated and analysed in the same way as Appendix A.

Design

The B′′ scores were entered into a 3 x 2 x 2 x 3 x 2 repeated measures ANOVA, with emotional face (angry, happy, fear), orientation (upright, inverted), polarity (positive, negative), spatial frequency (broad, high, low) and morph strength (low, high) as within subject IVs.

Results

Due to the main effect of spatial frequency, and the number of unpredicted interactions that contain the spatial frequency variable[21], it was deemed appropriate to split the remaining analyses by spatial frequency (data entered into three separate 3 (emotion) x2 (orientation) x2 (polarity) x2 (morph) repeated-measures ANOVAs).

BSF: There were main effects of orientation ($F(1,18) = 8.16$, $p=.01$), polarity ($F(1,18) = 4.84$, $p<.05$), and emotion ($F(1.4,25.5) = 7.89$, $p<.01$. There were significant interactions between polarity and emotion ($F(2,36) = 12.23$, $p<.001$), emotion and morph ($F(2,36) = 11.71$, $p<.001$), and a three-way significant interaction between polarity, emotion and morph ($F(2,36) = 14.59$, $p<.001$).

In agreement with the bias data from Experiment 1, participants were more conservative to upright ($M=.18$, $SD=.01$) that inverted faces ($M=.13$, $SD=.01$). However, in this experiment participants were more conservative to negated ($M=.18$, $SD=.01$) than positive faces ($M=.13$, $SD=.02$). Responses to happy ($M=.32$, $SD=.03$) were more conservative than fear ($M=.02$, $SD=.05$; $t(18) = 4.78$, $p<.001$), and angry ($t(18) = 2.98$, $p<.01$).

When presented in positive polarity, angry faces were responded to more liberally when they were high than low morph strength ($t(18) = 4.68$, $p<.001$), whereas fear faces were the opposite: they were responded to more liberally when they were low than high morph strength ($t(18) = 5.38$, $p<.001$). There was no difference in bias between the morph strengths in the happy face ($p>.4$). This agrees with bias data from

[21] Including: a significant main effect of SF, $F(2,36) =8.18$, $p=.001$; Orientation x SF interaction, $F(2,36) = 5.97$, $p<.01$; Emotion x SF interaction, $F(4,72) = 7.65$, $p<.001$; Polarity x emotion x SF interaction, $F(4,72)=4.51$, $p<.01$; SF x morph interaction, $F(2,36) = 5.33$, $p<.01$; Orientation x SF x morph interaction, $F(2,36) = 5.52$, $p<.01$; Polarity x emotion x SF x morph interaction, $F(4,72) =7.39$, $p<.001$.

Experiment 1, and suggests when fear faces are ambiguous, they are likely to be responded to more liberally.

When presented in negative polarity there was no difference in bias between morph strengths for any of the emotions (p>.05).

HSF: In the HSF faces, there was a main effect of emotion (F(2,36) =7.32, p<.01), an orientation x morph interaction (F(1,18) = 13.90, p<.01), and a emotion x morph interaction (F(2,36) = 32.24, p<.001).

Angry faces (M=.03, SD=.19) were responded to more liberally than happy (M=.24, SD=.18; t(18) = 2.80, p=.012) or fear faces (M=.26, SD=.15; t(18) = 3.83, p=.001). There was no difference between happy and fear (p>.8). This shows that when presented in HSF, and a liberal criterion was set for angry expressions.

In the 50% morph level, happy was responded to more conservatively than fear (t(18) =4.63, p<.001) and marginally more conservatively than angry (t(18) =2.56, p=.20). There was no difference between angry and fear (p>.05).

In the 100% morph strength, fear was responded to more conservatively than happy (t(18) = 5.26, p<.001) and angry (t(18) = 9.21, p<.001). There was no difference between angry and happy (p>.05).

LSF: There were main effects of orientation (F(1,18) = 6.29, p<.05) and morph (F(1,18) = 14.68, p=.001). There were also significant orientation x emotion (F(2,36) = 7.92, p=.001), and polarity x emotion (F(2,36) = 3.68, p<.05) interactions. These were subsumed under an orientation x polarity x emotion interaction (F(2,36) = 4.01, p<.05).

In the LSF faces, inverted faces were responded to more liberally than upright faces, and the 50% morph level was responded to more liberally that the 100% morph level. These results suggest that when the stimuli were more ambiguous (i.e. had lower morph strength or were manipulated), a more liberal criterion was set.

The three-way interaction was explored by investigating each emotion separately. In the angry expression, there was a main effect of orientation (F(1,18) = 11.62, p<.01), and of polarity (F(1,18) = 7.08, p<.05), where inverted and negative faces were responded to more liberally than upright and positive faces. In the fear expression there was a main effect of polarity (positive more conservative than negative), F(1,18) = 5.34, p<.05. In the happy expression there was a main effect of orientation (upright more conservative than inverted), F(1,18) = 5.24, p<.05.

Appendix E

Experiment 2: Sample Characteristics

Table E1.

Sample Characteristics

Anxiety Questionnaires	*M* (*SD*)	Minimum	Maximum
STAI-T	41.35 (8.85)	26	55
FNE	17.65 (8.98)	2	30
SADS	7.47 (7.19)	0	23
SDS	4.00 (1.97)	0	7
STAI-S	34.41 (8.85)	21	54

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

Appendix F

Experiment 2:

Correlations between performance and anxiety measures

Table F1. Correlations between sensitivity of broad spatial frequency faces and questionnaire measures

			STAIT	STAIS	FNE	SADS	SDS
Upright	Angry	1	0.08	-0.08	-0.17	0.33	0.12
Positive		2	0.04	-0.16	-0.17	0.08	-0.31
	Fear	1	0.04	-0.27	-0.15	0.16	0.11
		2	0.03	-0.15	-0.05	-0.06	-0.13
	Happy	1	0.16	-0.01	-0.12	0.26	0.01
		2	0.24	0.16	0.44	0.00	0.05
Upright	Angry	1	0.01	-0.11	0.06	-0.04	0.21
Negative		2	-0.10	-0.31	0.09	-0.15	0.44
	Fear	1	-0.16	-0.22	-0.31	0.01	0.03
		2	-0.23	-0.48	-0.20	-0.20	0.30
	Happy	1	0.05	-0.15	-0.15	0.14	-0.07
		2	0.03	-0.38	0.26	-0.46	0.65**
Inverted	Angry	1	0.13	0.04	0.04	0.24	0.41
Positive		2	0.11	0.09	-0.16	0.34	-0.42
	Fear	1	0.24	0.08	0.08	0.19	0.19
		2	-0.09	-0.25	-0.17	0.16	-0.12
	Happy	1	-0.12	-0.13	-0.25	-0.04	0.43
		2	0.06	-0.08	-0.32	0.17	-0.31
Inverted	Angry	1	-0.23	-0.10	0.05	-0.21	0.29
Negative		2	0.07	-0.20	-0.30	0.02	-0.07
	Fear	1	-0.34	-0.40	-0.16	-0.40	0.24
		2	0.06	-0.27	-0.17	-0.05	0.16
	Happy	1	-0.11	0.04	-0.31	-0.18	-0.12
		2	0.13	-0.14	-0.20	0.15	-0.24

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version. 1=50% morph-level; 2=100% morph-level.

*=p<.05; **=p<.001

Table F2. Correlations between sensitivity of high spatial frequency faces and questionnaire measures

			STAIT	STAIS	FNE	SADS	SDS
Upright	Angry	1	-0.46	-0.44	-0.18	-0.23	0.24
Positive		2	0.11	0.06	0.14	0.01	-0.21
	Fear	1	-0.28	-0.30	0.04	-0.45	0.01
		2	0.20	0.06	0.20	0.12	-0.08
	Happy	1	-0.22	-0.25	-0.12	-0.27	-0.16
		2	0.27	0.14	0.24	0.04	-0.35
Upright	Angry	1	0.18	0.05	0.18	-0.05	-0.08
Negative		2	0.29	0.01	0.01	0.20	-0.03
	Fear	1	-0.12	-0.29	0.03	-0.25	0.31
		2	0.31	0.12	0.02	0.24	-0.06
	Happy	1	0.10	-0.14	0.08	-0.10	0.07
		2	0.06	-0.08	-0.30	-0.00	-0.22
Inverted	Angry	1	-0.03	-0.12	-0.17	0.10	-0.21
Positive		2	-0.05	-0.16	-0.23	0.00	0.06
	Fear	1	-0.19	-0.35	-0.26	0.06	0.25
		2	-0.04	-0.17	0.17	-0.23	0.31
	Happy	1	0.09	0.04	-0.15	0.06	-0.18
		2	0.01	-0.09	-0.21	0.00	0.00
Inverted	Angry	1	0.16	0.10	0.16	0.17	-0.13
Negative		2	0.06	-0.20	-0.08	-0.06	-0.08
	Fear	1	-0.03	-0.12	0.13	-0.21	0.30
		2	0.11	-0.14	-0.19	0.10	0.09
	Happy	1	0.14	-0.02	-0.07	0.07	0.09
		2	0.18	-0.05	-0.12	-0.01	-0.06

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version. 1=50% morph-level; 2=100% morph-level.

*=p<.05; **=p<.001

Table F3. Correlations between sensitivity of low spatial frequency faces and questionnaire measures

			STAIT	STAIS	FNE	SADS	SDS
Upright Positive	Angry	1	-0.15	-0.41	-0.30	-0.18	0.52*
		2	-0.06	-0.05	-0.36	-0.08	0.36
	Fear	1	-0.19	-0.53*	-0.23	-0.16	0.31
		2	0.14	-0.29	-0.23	0.03	0.38
	Happy	1	-0.12	-0.49*	-0.07	-0.42	0.22
		2	-0.07	-0.42	-0.36	0.17	0.18
Upright Negative	Angry	1	0.11	0.20	0.48	0.05	0.26
		2	-0.35	-0.09	-0.34	0.10	-0.47*
	Fear	1	-0.05	0.00	-0.03	0.20	0.23
		2	-0.14	-0.30	-0.25	0.23	-0.12
	Happy	1	0.42	0.33	0.15	0.13	0.05
		2	-0.19	-0.50*	-0.42	0.21	0.51*
Inverted Positive	Angry	1	0.02	-0.25	-0.16	-0.02	0.39
		2	0.05	-0.39	-0.28	0.11	0.42
	Fear	1	-0.09	-0.00	0.09	0.23	0.23
		2	-0.28	-0.05	-0.20	-0.04	0.30
	Happy	1	-0.06	-0.36	-0.25	-0.05	0.08
		2	-0.28	-0.05	-0.12	-0.06	0.03
Inverted Negative	Angry	1	-0.02	-0.12	0.23	-0.33	-0.13
		2	0.22	0.09	-0.28	0.07	-0.33
	Fear	1	-0.15	-0.13	0.32	-0.25	0.04
		2	-0.18	-0.33	0.26	-0.06	-0.03
	Happy	1	-0.27	0.05	-0.56*	0.04	-0.05
		2	-0.06	0.04	-0.25	0.24	0.25

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version. 1=50% morph-level; 2=100% morph-level.

*=p<.05; **=p<.001

Appendix G

Experiment 3: Box plot of incorrect responses

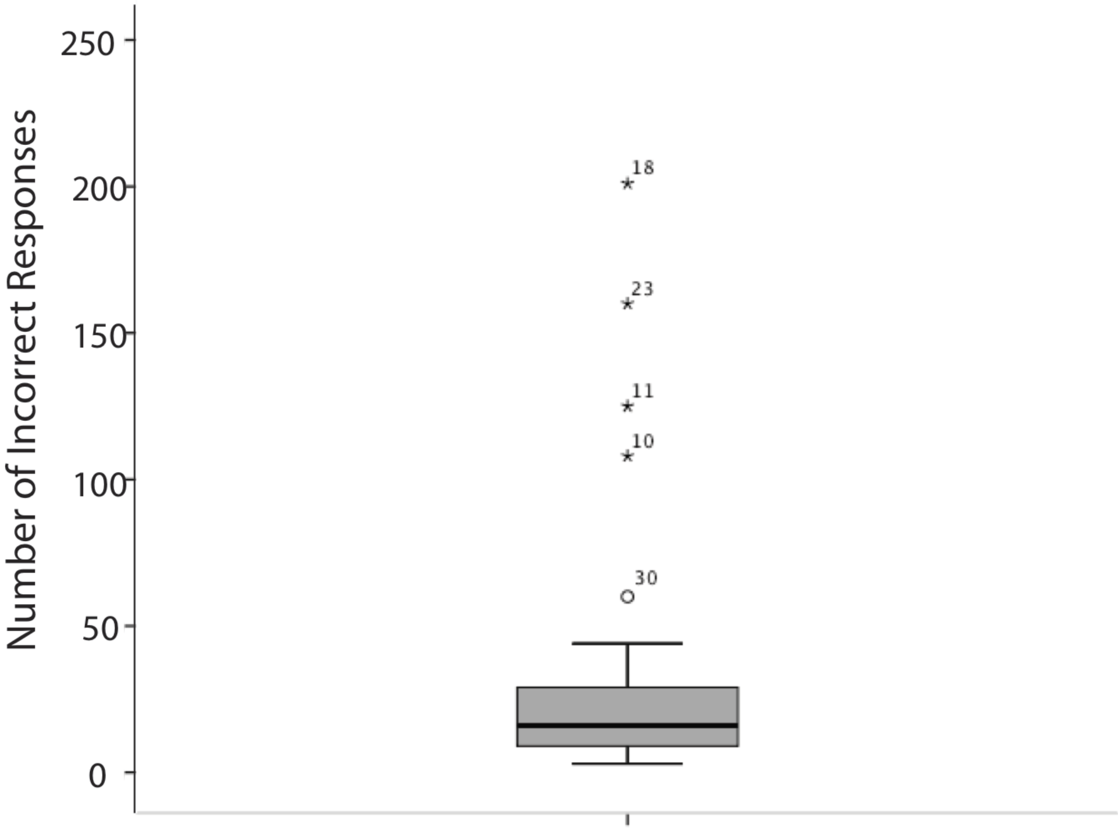

*Figure G1. Distribution of the incorrect responses in Experiment 4. *= the scores of the four participants that were removed.*

Appendix H

Experiment 3: Sample Characteristics

Table H1.

Sample Characteristics

Anxiety Questionnaires	*M* (*SD*)	Minimum	Maximum
STAI-T	41.20 (10.02)	23	59
FNE	15.69 (9.44)	0	30
SADS	6.69 (7.05)	0	27
SDS	3.77 (1.88)	1	7
STAI-S	35.91 (9.37)	21	59

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

Appendix I

Experiment 3:

Correlations between performance and anxiety measures

Table I1. Correlations between CFS data and questionnaire measures

		STAIT	STAIS	FNE	SADS	SDS
Upright	Angry	0.05	0.15	0.01	0.17	-0.17
Positive	Fear	-0.01	0.12	-0.04	0.21	-0.08
	Happy	-0.00	0.13	-0.10	0.14	-0.06
	Neutral	0.00	0.14	-0.05	0.12	-0.16
Upright	Angry	0.10	0.08	0.07	0.09	-0.07
Negative	Fear	0.09	0.12	-0.02	0.14	-0.15
	Happy	0.05	0.09	-0.05	0.04	-0.15
	Neutral	0.03	0.05	0.04	0.18	0.03
Inverted	Angry	0.03	0.05	0.11	0.17	-0.17
Positive	Fear	0.09	0.17	0.05	0.18	-0.07
	Happy	-0.06	-0.36	-0.25	-0.05	0.08
	Neutral	0.05	0.12	-0.03	0.18	-0.15
Inverted	Angry	0.03	0.07	0.04	0.14	0.09
Negative	Fear	0.04	0.07	-0.03	0.10	-0.12
	Happy	0.10	0.03	0.07	0.08	-0.17
	Neutral	0.07	0.08	0.05	0.14	0.04

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

*=p<.05; **=p<.001

Table I2. Correlations between Control data and questionnaire measures

		STAIT	STAIS	FNE	SADS	SDS
Upright	Angry	0.02	-0.02	-0.09	0.07	0.18
Positive	Fear	-0.04	-0.10	-0.13	0.08	0.04
	Happy	-0.04	-0.14	-0.11	0.02	-0.09
	Neutral	0.02	-0.12	-0.11	0.00	-0.08
Upright	Angry	-0.07	-0.14	-0.10	0.09	0.16
Negative	Fear	-0.05	-0.11	-0.13	0.03	0.15
	Happy	-0.06	-0.19	-0.12	0.01	-0.08
	Neutral	-0.05	-0.11	-0.13	0.04	0.01
Inverted	Angry	-0.00	-0.08	-0.06	0.06	0.11
Positive	Fear	-0.01	-0.11	-0.10	0.06	-0.02
	Happy	-0.06	-0.20	-0.11	0.04	0.15
	Neutral	-0.01	-0.09	-0.09	0.06	-0.03
Inverted	Angry	-0.07	-0.14	-0.10	0.70	0.24
Negative	Fear	0.02	-0.10	-0.12	0.05	-0.06
	Happy	0.10	0.03	0.07	0.08	-0.17
	Neutral	-0.09	-0.15	-0.17	-0.03	0.20

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

*=p<.05; **=p<.001

Table I3. Correlations between unbiased emergence data and questionnaire measures

		STAIT	STAIS	FNE	SADS	SDS
Upright	Angry	0.02	0.13	0.08	0.08	-0.44
Positive	Fear	0.02	0.19	0.09	0.10	-0.20
	Happy	0.03	0.22	0.02	0.09	-0.00
	Neutral	-0.01	0.23	0.05	0.11	-0.23
Upright	Angry	0.13	0.15	0.11	0.02	-0.38
Negative	Fear	0.11	0.18	0.08	0.08	-0.42
	Happy	0.08	0.21	0.06	0.02	-0.36
	Neutral	0.06	0.12	0.13	0.10	0.04
Inverted	Angry	0.03	0.10	0.13	0.10	-0.27
Positive	Fear	0.04	0.20	0.08	0.12	-0.26
	Happy	0.12	0.28	0.11	0.12	-0.23
	Neutral	0.05	0.08	0.05	0.09	-0.24
Inverted	Angry	0.07	0.14	0.10	0.08	-0.06
Negative	Fear	0.02	0.14	0.08	0.03	-0.13
	Happy	0.16	0.11	0.11	0.02	-0.24
	Neutral	0.11	0.16	0.16	0.12	-0.19

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

*=p<.05; **=p<.001

Appendix J

Experiment 4: Sample Characteristics

Table J1.

Sample Characteristics

Anxiety Questionnaires	*M* (*SD*)	Minimum	Maximum
STAI-T	40.11 (8.33)	29	57
FNE	17.28 (7.29)	3	28
SADS	6.94 (8.93)	0	28
SDS	3.17 (2.23)	0	7
STAI-S	35.61 (9.80)	25	62

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

Appendix K

Experiment 4:

Correlations between performance and anxiety measures

Table K1. Correlations between CFS data and questionnaire measures

			STAIT	STAIS	FNE	SADS	SDS
BSF	Upright	Angry	0.17	0.03	0.29	-0.06	-0.06
	Positive	Fear	0.17	-0.01	0.25	-0.03	-0.16
		Happy	0.12	0.06	0.21	-0.06	0.36
		Neutral	0.19	-0.02	0.32	-0.04	0.22
	Inverted	Angry	0.14	-0.09	0.21	-0.06	0.23
	Negative	Fear	0.15	-0.03	0.21	-0.00	0.26
		Happy	0.12	-0.01	0.16	-0.05	0.31
		Neutral	0.19	-0.01	0.06	-0.02	0.36
HSF	Upright	Angry	0.10	-0.06	0.21	-0.08	0.02
	Positive	Fear	0.18	-0.04	0.20	-0.12	0.41
		Happy	0.15	-0.02	0.26	-0.08	0.30
		Neutral	0.14	-0.12	0.24	-0.05	0.19
	Inverted	Angry	0.19	-0.07	0.31	-0.05	0.10
	Negative	Fear	0.18	0.01	0.21	-0.01	0.22
		Happy	0.17	0.03	0.29	-0.05	0.32
		Neutral	0.14	-0.01	0.26	-0.04	0.26
LSF	Upright	Angry	0.22	0.02	0.32	-0.08	0.14
	Positive	Fear	0.19	0.10	0.25	-0.06	0.23
		Happy	0.16	0.06	0.24	-0.10	0.24
		Neutral	0.25	0.10	0.32	-0.08	0.11
	Inverted	Angry	0.15	0.04	0.30	-0.05	0.16
	Negative	Fear	0.14	-0.04	0.30	-0.12	-0.09
		Happy	0.25	0.10	0.32	-0.08	0.23
		Neutral	0.16	-0.01	0.30	-0.11	0.28

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

*=p<.05; **=p<.001

Table K2. Correlations between CFS data and questionnaire measures

			STAIT	STAIS	FNE	SADS	SDS
BSF	Upright	Angry	0.14	0.09	0.03	0.29	-0.19
	Positive	Fear	-0.06	-0.15	0.12	-0.02	-0.38
		Happy	0.01	-0.24	0.09	-0.01	-0.39
		Neutral	-0.17	-0.09	-0.17	0.06	-0.44
	Inverted	Angry	-0.06	-0.10	0.03	0.04	-0.46
	Negative	Fear	-0.04	-0.08	0.07	0.05	-0.32
		Happy	-0.05	-0.10	0.08	0.03	-0.44
		Neutral	-0.04	-0.08	0.04	0.07	-0.27
HSF	Upright	Angry	-0.07	-0.11	0.02	0.00	-0.27
	Positive	Fear	0.00	-0.12	0.05	0.07	-0.37
		Happy	0.00	-0.06	0.07	0.07	-0.11
		Neutral	0.03	-0.13	0.16	0.08	-0.27
	Inverted	Angry	-0.14	-0.17	0.04	-0.00	-0.38
	Negative	Fear	-0.01	-0.02	0.15	0.07	-0.25
		Happy	-0.06	-0.16	0.09	0.03	-0.41
		Neutral	-0.08	-0.18	0.05	0.02	-0.42
LSF	Upright	Angry	0.14	0.09	0.03	-0.29	-0.29
	Positive	Fear	-0.06	-0.15	0.12	-0.02	-0.38
		Happy	0.01	-0.24	0.09	-0.01	-0.39
		Neutral	-0.17	-0.09	-0.17	0.06	-0.44
	Inverted	Angry	-0.06	-0.10	0.31	0.04	-0.46
	Negative	Fear	-0.04	-0.08	0.07	0.05	-0.38
		Happy	-0.05	-0.11	0.08	0.03	-0.44
		Neutral	-0.04	-0.08	0.04	0.07	-0.27

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

*=p<.05; **=p<.001

Appendix L

Experiment 5: Sample Characteristics

Table L1.

Sample Characteristics

Anxiety Questionnaires	*M* (*SD*)	Minimum	Maximum
STAI-T	35.57 (11.86)	21	58
FNE	12.43 (8.08)	1	27
SADS	5.64 (7.07)	0	26
SDS	3.29 (2.43)	0	8
STAI-S	34.43 (8.92)	20	49

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

Appendix M

Experiment 5:

Correlations between performance and anxiety measures

Table C1. Correlations between sensitivity and questionnaire measures

		STAIT	STAIS	FNE	SADS	SDS
Upright	Fear	-0.21	0.39	0.21	-0.21	0.06
Positive	Happy	-0.37	0.23	0.17	-0.02	0.34
	Neutral	-0.35	0.41	0.13	-0.04	0.41
Inverted	Fear	-0.11	0.36	-0.10	-0.02	0.24
Negative	Happy	-0.08	.56*	-0.14	0.24	-0.17
	Neutral	-0.18	0.27	0.17	-0.11	0.33

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

*=*p*<.05; **=*p*<.001

Appendix N

Experiment 6: Sample Characteristics

Table N1.

Sample Characteristics

Anxiety Questionnaires	*M* (*SD*)	Minimum	Maximum
STAI-T	34.89 (10.98)	20	56
FNE	11.87 (7.87)	1	27
SADS	6.65 (6.92)	0	26
SDS	3.54 (2.13)	0	8
STAI-S	32.31 (10.42)	21	48

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version.

Appendix O

Experiment 6:

Correlations between performance and anxiety measures

Table M1. Correlations between sensitivity and questionnaire measures

		STAIT	STAIS	FNE	SADS	SDS
Upright	Fear	-0.24	0.29	0.23	0.13	0.21
	Neutral	-0.02	0.18	0.15	-0.08	0.04
Inverted	Fear	-0.17	0.25	0.02	-0.03	0.18
	Neutral	-0.11	0.31	-0.15	-0.09	0.31

Note. STAI-T= State Trait Anxiety Inventory trait version, FNE=Fear of Negative Evaluation, SADS = Social Avoidance and Distress Scale, SDS = Marlow-Crowne Social Desirability Scale, STAI-S= State Trait Anxiety Inventory state version. *=p<.05; **=p<.001

Appendix P

Experiment 7:

PHD and Control recognition of emotional expression

Table P1. PHD and Control accuracy to recognise emotional expressions at different morph-levels and manipulation conditions

			PHD	Control Mean
Angry	Normal	50%	16/32 (50)	23.3/32 (72.9)
		100%	32/32 (100)	30.7/32 (95.8)
	Manipulated	50%	6/32 (18.8)	7.7/32 (24.0)
		100%	10/32 (32.3)	9.7/32 (30.2)
Fear	Normal	50%	30/32 (93.8)	27.3/32 (85.4)
		100%	30/32 (93.8)	29.7/32 (92.7)
	Manipulated	50%	14/32 (43.8)	12.7/32 (39.6)
		100%	20/32 (62.5)	12.3/32 (38.5)
Happy	Normal	50%	32/32 (100)	28.3/32 (88.5)
		100%	32/32 (100)	31.7/32 (99.0)
	Manipulated	50%	12/32 (37.5)	17.0/32 (35.1)
		100%	18/32 (56.3)	15.7/32 (49.0)

Nb. Percentage correct in brackets

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