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“Invisible Dangers”: Unconscious processing of angry vs fearful faces and its relationship to subjective anger

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ABSTRACT

Traditional paradigms for studying the unconscious processing of threatening facial expressions face methodological limitations and have predominantly focused on fear, leaving gaps in our understanding of anger. Additionally, it is unclear how the unconscious perception of anger influences subjective anger experiences. To address this, the current study employed Continuous Flash Suppression (CFS), a robust method for studying unconscious processing, to assess suppression times for angry, fearful and happy facial expressions. Following the administration of CFS, participants underwent an anger induction paradigm, and state anger symptoms were assessed at multiple timepoints. Suppression times for angry faces were compared to those for happy and fearful faces, and their relationship with state anger symptoms post-induction was examined. Results revealed that fearful faces broke suppression significantly faster than happy faces. Anger was slower to break suppression compared to fear, but no significant differences emerged between anger and happiness. In addition, the faster emergence into awareness of fear compared to anger was linked to an increased state anger after the induction, indicating that differences in the unconscious processing of these two emotions can potentially influence symptoms of subjective anger. These findings provide new insights into how angry and fearful faces are processed unconsciously, with implications for understanding the cognitive mechanisms underlying subjective anger.

1. Introduction

As social beings, we rely on others’ facial expressions to interpret social cues and understand the intentions and emotions of those around us. Emerging evidence suggests that facial information can be processed without conscious awareness (Axelrod et al., 2015), including dynamic features like emotional states (Tamietto & de Gelder, 2010), gaze direction (Sato et al., 2007), as well as traits such as trustworthiness (Stewart et al., 2012) and dominance (Stein et al., 2018). Among these features, emotional states are particularly crucial for social interactions as they help guide appropriate responses vital for our protection and overall well-being (Jessen and Grossmann, 2020a). In particular, facial expressions of fear and anger convey critical information about potential threats, enabling us

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to respond appropriately to danger. Our sensory systems have evolved to prioritise these threatening cues over positive or neutral signals, ensuring rapid and effective responses to potential dangers in our environment (Kawai et al., 2016; Li & Keil, 2023; Ozturk et al., 2024; Zsido et al., 2019). This prioritisation of threatening facial stimuli may also occur before conscious awareness, potentially facilitating rapid and automatic responses essential for survival (Diano et al., 2017; March et al., 2022; Suslow et al., 2006; Tamietto & de Gelder, 2010; Troiani et al., 2012). Indeed, it is believed, from an evolutionary perspective, that emotionally significant stimuli have priority in capturing attention (e.g., Axelrod et al., 2015; Vuilleumier, 2005; Yang et al., 2007), because of the potential impact of such stimuli on the observer's safety or well-being (Diano et al., 2017; Ohman & Mineka, 2001; Suslow et al., 2006; Troiani et al., 2012). Such threatening stimuli are also thought to bypass cortical areas, engaging subcortical structures like the amygdala, insula, and hippocampus (Pessoa & Adolphs, 2010; Tamietto & de Gelder, 2010), hence facilitating rapid and appropriate responses in social contexts (Jessen and Grossmann, 2020b).

However, research on how different facial expressions depicting threat compete for selection and access to awareness presents several challenges (Hedger et al., 2016). Previous studies have predominantly focused on responses to fearful facial expressions, with less emphasis on angry expressions (Hedger et al., 2016). While both anger and fear have a threatening valence, they differ in the nature of the danger signalled and may evoke different behavioural and neural responses (such as approach versus avoidance) (Carver & Harmon-Jones, 2009). In addition, traditional paradigms used for assessing unconscious processing such as stimuli degradation, visual crowding, backward masking, and binocular rivalry, present methodological challenges and often fail to consistently keep stimuli outside of conscious awareness (Webb & Hibbard, 2020).

More specifically, techniques such as stimuli degradation – which include brief stimuli presentation and superimposing noise – can make objects invisible but are limited to specific conditions and may not manipulate awareness reliably due to subjective judgment criteria (Kim & Blake, 2005; Kouider & Dehaene, 2007). On the other hand, visual crowding – which occurs when a recognisable figure becomes unidentifiable due to adjacent stimuli (Whitney & Levi, 2011) – remains effective during prolonged viewing periods, but it predominantly affects peripheral vision and requires precise fixation to sustain the effect (Tanriverdi & Cornelissen, 2024). Therefore, while crowding may impair identification, it can still allow detection, complicating the distinction between awareness and unawareness (Kim & Blake, 2005). Visual backward masking (Morris et al., 1998; Whalen, 1998) involves briefly presenting a target stimulus followed by a masking stimulus (typically for less than 100 ms) which makes detection difficult. This technique effectively separates non-conscious processing from conscious awareness, but it relies on distinct physical conditions to differentiate between awareness (unmasked) and unawareness (masked), limiting its suitability for creating sustained periods of perceptual invisibility, as it is only effective when the stimulus duration does not exceed a few tens of milliseconds (Gelskov & Kouider, 2010; Kim & Blake, 2005). In some cases, masked targets may be detectable without being identifiable, further complicating the distinction between awareness and unawareness (Kim & Blake, 2005). Masking also does not always completely suppress the visual stimulus in every trial or for every individual (Pessoa et al., 2005). Recent research has explored alternative methods that provide longer durations of invisible stimulation, such as binocular rivalry (Blake, 2001; Blake & Logothetis, 2002; de Graaf et al., 2017; Moradi et al., 2005; Mudrik et al., 2011). For example, binocular rivalry presents two incompatible stimuli to each eye, causing perceptual dominance to alternate between them. While one percept is fully visible, the other is suppressed and remains invisible for several seconds (for reviews see Dubois & Faivre, 2014; Maier & Leopold, 2009). However, controlling the timing of perceptual switches is challenging, and large rival targets may produce mixed dominance, confounding binary judgments (Kim & Blake, 2005). In summary, while these methods have advanced the study of perception without awareness, each has limitations regarding the reliability and duration of stimulus invisibility, as well as in distinguishing between conscious and non-conscious processing.

Given the aforementioned limitations, it remains unclear whether the preferential awareness of threatening stimuli observed with these techniques truly reflects an advantage in unconscious processing, or if it stems from a methodological limitation in keeping the stimuli outside of conscious awareness (Hedger et al., 2016). It is also uncertain whether anger has privileged access to awareness compared to happiness, and whether it is processed similarly or differently to fear before reaching conscious perception. These are key questions that have significant implications for both cognitive and clinical research, influencing our understanding of how emotional biases affect behaviour and decision-making. Indeed, understanding whether certain emotions have prioritised access to awareness could help refine models of emotional processing and inform treatments for mood, anxiety and anger-related disorders, where misperceptions of emotional salience often play a central role (Fava et al., 2010; Stringaris et al., 2013). This is particularly relevant for the study of anger, an emotion that has been significantly neglected in previous research (DiGiuseppe & Tafrate, 2006).

Continuous Flash Suppression (CFS), an extension of binocular rivalry, has emerged as a robust technique for addressing the limitations of visual masking and traditional binocular rivalry (Tsuchiya & Koch, 2005). In CFS, contour-rich, high-contrast patterns are rapidly flashed to one eye, effectively and consistently suppressing salient visual information presented to the other eye (Tsuchiya et al., 2006). The suppressed image remains invisible until it "breaks through" suppression, allowing variables that facilitate detection to be interpreted as enhancing pre-conscious processing (Mudrik et al., 2011). CFS studies typically measure the time taken for a target stimulus to become visible, with shorter suppression times indicating stronger unconscious processing during interocular suppression (Sterzer et al., 2011; Yang et al., 2007).

CFS offers several advantages over traditional methods like backward masking and binocular rivalry. It provides precise control over timing and can suppress visual stimuli for considerably longer durations (Bachmann & Francis, 2013; Hedger et al., 2016). This allows for stronger and more prolonged non-conscious influences on human behaviour (Barbot & Kouider, 2012). Notably, suppression periods with CFS can last up to ten times longer than those induced by binocular rivalry (Tsuchiya & Koch, 2005). Another key advantage is CFS's reliability in inducing perceptual suppression from the onset of a trial, allowing for controlled, predictable, and extended manipulations of awareness compared to the conventional binocular rivalry paradigm (Hedger, 2016). The CFS paradigm also offers a key advantage by measuring breakthrough times, which estimate how long a stimulus takes to reach conscious perception.

This allows researchers to assess both when a stimulus gains access to awareness and whether it does so faster than others, making breaking CFS (bCFS) ideal for studying prioritised access to awareness (Lanfranco et al., 2023). Consequently, CFS is widely recognised as a robust measure of unconscious processing (Webb & Hibbard, 2020; Yang et al., 2007).

Using the CFS paradigm, previous research – including studies by our group – has demonstrated that fearful faces emerge from suppression more rapidly than happy expressions (e.g., Capitão et al., 2014; Yang et al., 2007; Jusyte et al., 2015). This suggests that threatening stimuli, such as fearful expressions, may receive prioritised encoding during the suppression phase, leading to enhanced unconscious processing and faster access to awareness. These findings align with theories proposing that threatening cues, like fear, possess a privileged pathway to conscious perception, an effect further amplified in individuals with heightened anxiety (Capitão et al., 2014). However, previous CFS studies have predominantly focused on fear as a threatening cue, with limited inclusion of anger as a stimulus (Hedger et al., 2016). Data from different tasks including anger is sparse and inconclusive, with some studies suggesting that anger may be prioritised at an unconscious level compared to positive cues (Honk et al., 2001), whilst others show non-significant or even negative effects (Hedger et al., 2016). Nonetheless, previous research has mostly relied on traditional paradigms such as backward masking, which present methodological limitations as described earlier. Of particular interest, preliminary evidence using CFS suggests that fear and anger may lead to different response profiles when presented unconsciously (Gray et al., 2013; Jiang & He, 2006; Zhan et al., 2015). Specifically, angry faces appear to take longer than fearful faces to reach conscious awareness (Gray et al., 2013), indicating that different threatening expressions may engage distinct cognitive and/or neural pathways, but more research is needed to clarify this effect. Exploring how anger is processed unconsciously, in contrast to other facial expressions (both positive and negative), can provide valuable insights into the cognitive mechanisms underlying this important yet often overlooked emotion (DiGiuseppe & Tafrate, 2006), both in healthy and clinical samples. Studying potential differences between anger and fear could also reveal how different individuals categorise and respond to different types of threats, thereby advancing research on emotional cognition more widely. In the current study, we therefore propose using CFS to measure how both fear and anger are processed at an unconscious level.

In addition, previous research on the cognitive perception of anger often lacks real-time measurements of the subjective experience of anger as it unfolds. For instance, some studies have studied the neural substrates underlying anger perception versus anger experience separately (Sorella et al., 2021), without exploring potential associations between how anger is perceived and subsequently experienced. Others have focused exclusively on the cognitive appraisal of anger without real-time assessments of participants' emotional states (see reviews by Cox & Harrison, 2008; Richard et al., 2023). Combining cognitive paradigms with measures that track changes in anger symptoms over time could therefore offer unique insights into the dynamic interplay between cognitive processes and emotional experiences. The way participants perceive anger may influence their subsequent experience of this emotion. Therefore, in this study we sought to integrate cognitive measures of unconscious anger perception with a protocol that induces anger in the laboratory, to assess how the unconscious processing of anger in others could influence the intensity of subjective anger experienced. One hypothesis is that some individuals may be predisposed to unconsciously detect anger in others, a bias that could be linked to more intense anger reactions in anger-inducing situations. However, to the best of our knowledge, this hypothesis has yet to be tested.

The current study therefore had two main goals. The first was to measure differences in suppression times of angry faces when compared to happy and fearful facial expressions in healthy volunteers using CFS as a robust measure of unconscious processing. By including angry faces, we aimed to elucidate distinctions between fear – the most commonly used threatening emotion in CFS paradigms – and anger, an emotion less frequently studied in this context. We hypothesized that both angry and fearful faces would break suppression faster than happy faces. Considering recent findings, we also predicted that angry faces would break suppression more slowly than fear. The second objective of this study was exploratory. For the first time, we sought to examine the relationship between suppression times for detecting angry faces (compared to other emotions) and the subjective experience of anger following an anger induction protocol. Investigating the association between these variables could offer valuable insights into the unconscious cognitive mechanisms that underpin the subjective experience of anger. We tentatively hypothesized that a faster emergence of angry faces into awareness (relative to happy faces) would be associated with heightened subjective anger symptoms post-induction.

2. Materials and methods

2.1. Participants and experimental procedure

Thirty healthy volunteers (18–55 years) were recruited from the Oxfordshire community. This sample size was determined based on the previous study by Capitão et al. (2014). Specifically, to obtain a similar effect size of 0.45, a minimum of 14 participants would be needed to obtain a power calculation of 0.90 at α error probability of 0.05. The study received ethical approval (R68684/RE001) and participants were reimbursed for their time. Exclusion criteria included: insufficient fluency in English; current diagnosis of psychiatric or neurologic disorder; current use of psychotropic medication that could interfere with the results; history of cardiovascular disease or hypertension, or any other significant medical problem; previous participation in a study with similar tasks that could affect the results; pregnancy, and heavy smoking (>5 cigarettes/day). Eligible participants were asked to refrain from alcohol the night before testing and limit caffeine consumption to one cup on the testing day. Participants were advised to try to have a restful night of sleep before testing. Upon arrival, they were administered a series of questionnaires, followed by a battery of emotional processing tasks (details available on https://osf.io/862gc/), including the Continuous Flash Suppression (CFS) paradigm, and finally the anger recall protocol (ARP). Given the scope of the current paper, only data from the CFS and ARP are presented here. Of note, one participant did not complete the CFS paradigm and another was not administered the anger recall protocol due to technical problems.

2.2. Continuous flash suppression (CFS)

The CFS task was adapted from Yang et al. (2007) with the additional inclusion of anger. Stimuli consisted of grayscale faces displaying one of four different expressions (neutral, happy, fear and anger) and grayscale Mondrian-like patterns as the suppressor mask (Fig. 1a). The face stimuli (2 male and 2 female identities) were taken from the standard Ekman set of facial expressions (Ekman & Friesen, 1976). All images were cropped in a square shape to remove features outside of the faces and the edges were smoothed using a Gaussian filter. The suppressor mask consisted of random combinations of partly overlapping rectangles of varying sizes and luminance. To achieve an initial strong suppression, the faces were normalized to 20 % contrast (root mean square), whereas the Mondrian patterns were normalized to 60 % contrast (root mean square; Fig. 1b).

The selection of 20 % contrast for the face stimuli was guided by established protocols in CFS research, including Yang et al. (2007), where a lower target contrast ensures robust initial suppression and reduces the influence of baseline visual salience, enabling reliable measurement of suppression durations. Alternating eye presentation was chosen to mitigate potential biases from individual differences in ocular dominance, ensuring a more balanced and generalizable design by reducing systematic variance that could arise from consistently stimulating one eye.

Stimuli were generated with the Psychtoolbox (https://psychtoolbox.org/HomePage) for Matlab (Mathworks, Inc.) and presented at 60 Hz on an LCD display, resolution: 1280 x 1024 pixels, 37.5 width Dell monitor. Stimuli were viewed using a mirror stereoscope, which was positioned in front of the monitor and connected to a chin rest. All stimuli were surrounded by rectangular borders that served to promote stable binocular eye alignment. A black cardboard divider of matte material was placed between the participant's eyes, extending from the stereoscope midline towards the centre of the display to block the line of vision to the other eye's stimulus. The viewing distance was 49 cm.

The lights were switched off during the experiment. Before the task was initiated, the mirrors of the stereoscope were carefully adjusted so that the fusion contours surrounding the stimuli were combined to produce a square frame, which occurred only when the eyes were appropriately aligned. This stereoscope alignment also ensured accurate visual fusion for all participants, minimizing variability due to misalignment.

In the initial 1000 ms, one eye was presented with full contrast, dynamic Mondrian patterns (4° x 4°; refreshed at 10 Hz), whilst the other eye viewed a low contrast face image (1.7° x 1.7°). The contrast of the face was ramped up at a rate of 2 % every 20 ms, hence avoiding abrupt transients. When the face reached full contrast (1000 ms after presentation onset), the contrast of the Mondrian patterns linearly decreased at a rate of 2 %/100 ms for the next 5100 ms. The face remained in full contrast until a response was made. All stimuli, as well as the eye to which the Mondrian patterns or faces were presented, were randomised and counterbalanced across trials. Given the design of the paradigm, participants were unable to predict the emotional expression of the face on a given trial, which therefore prevented the occurrence of criterion biases in their responses.

The face stimuli were presented within one of four fixed quadrants of the display, corresponding to the upper-left, upper-right, lower-left, and lower-right regions of the visual field. Each face subtended 1.7° x 1.7° of visual angle and was centred at an eccentricity of 2.5° from the central fixation point. The exact positions were as follows: 2.5° left and 2.5° up for the upper-left quadrant, 2.5° right and 2.5° up for the upper-right quadrant, 2.5° left and 2.5° down for the lower-left quadrant, and 2.5° right and 2.5° down for the lower-right quadrant. These consistent locations were maintained throughout the experiment to ensure uniformity in visual field positioning. Participants were required to report its location via one of four corresponding buttons on a keyboard, as quickly and accurately as possible. Participants were instructed to press the button as soon as any part of the face (such as the eyes, mouth, etc.)

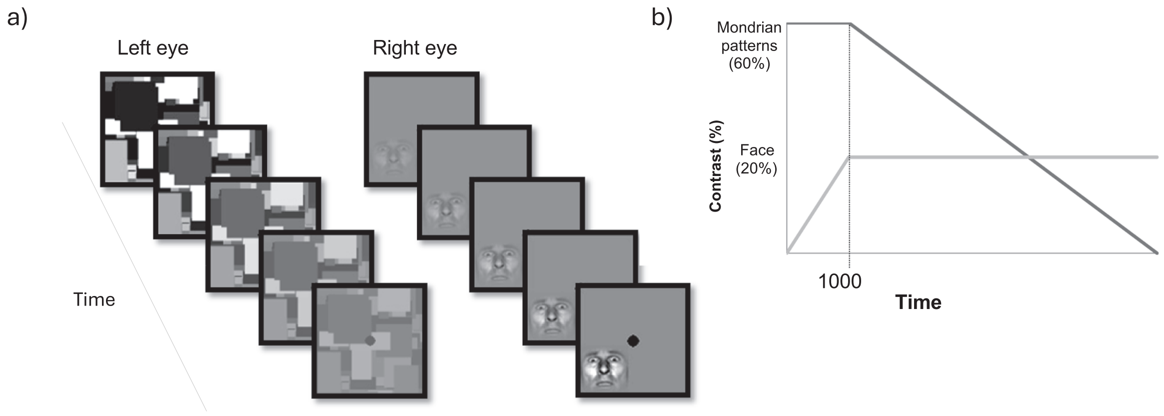

Fig. 1. Example of a trial presentation in CFS. a) One eye was presented with flashing Mondrian-like pattern images, while the other viewed a facial image of 1 of 4 expressions (fearful, happy, neutral or angry). **b)** The contrast of the face was ramped up to 20 % by the end of the first 1,000 ms, the point at which the contrast of the Mondrian patterns started decreasing from 60 % until the observer indicated the location of the face via button press. **Note:** Figure used with permission of the American Psychological Association, from "Anxiety increases breakthrough of threat stimuli in Continuous Flash Suppression", by Capitão, LP, Underdown, SJV, Vile, S, Yang, E., Harmer, CJ & Murphy, SE, Emotion, 14(6), 1027-1036 (2014); permission conveyed through Copyright Clearance Centre, Inc. Face reprinted with permission from the Paul Ekman Group.

emerged. Trials (n = 240) terminated upon response and there was a self-timed break every ten trials. Visual and auditory feedback was given for incorrect responses. The outcome measure was reaction times (RT) to detect each of the emotional expressions.

2.3. *Anger recall paradigm (ARP)*

Participants underwent an anger recall paradigm (ARP) (adapted from Burg et al., 2011; Why & Johnston, 2008). This protocol is a form of anger induction designed to elicit an intense anger reaction by asking the participant to recall and verbally describe an event in which they had become very angry or lost their temper in the past year, and which remained upsetting. The ARP consisted of a 5-min baseline period, 7-min anger recall task (including 2 min of imagery), and 5-min recovery period. During baseline, participants were instructed to clear their minds and relax as much as possible. During the anger recall, participants were initially asked to mentally place themselves back in the situation and recall, as vividly as possible, the sequence of events experienced, as well as any associated thoughts, feelings, and physical sensations. Participants were also prompted to imagine that the situation was happening again, in the present. At the end of these 2 min of imagery, participants were asked to verbally describe the incident in detail for 5 min, trying to recreate it as best they could, and – if comfortable – with their eyes closed. To enhance the reliving of the incident during recall, the experimenter provided prompts, such as paraphrasing the subject's statements or directing their attention to the emotions experienced by asking questions such as "How did that make you feel?", particularly when pauses exceeded 3 s. At the end, there was a 5-minute recovery period with identical instructions as for the initial baseline. Following each of these timepoints, participants were asked to complete the state scale from the State-Trait Anger Expression Inventory (STAXI-S; Spielberger, 1988) to measure variations in state anger. The full protocol for the ARP is openly available (https://osf.io/pt9fw). Electrocardiogram responses were recorded during the ARP but the presentation of this data is beyond the scope of the current article (additional information available here: https://osf.io/862gc/).

2.4. *Statistical analyses*

A repeated measures ANOVA (rmANOVA) was used to analyse differences in reaction times (RTs) to detect angry, fearful, happy and neutral faces in the CFS, as well as to analyse STAXI-S scores collected following each of the timepoints (baseline, anger recall and recovery). Any significant main effects were further explored using Bonferroni-corrected pairwise comparisons. Two-tailed bi-variate correlations were used to explore associations between the detection of the different facial expressions in the CFS and STAXI-S symptoms post anger induction. Relevant difference scores between the various emotions were also computed and correlated with STAXI-S post-induction. Specifically, subtraction scores were calculated as the difference between suppression scores for emotions that showed a significant difference in the rmANOVA. These scores were used to quantify differences in the relative speed at which each emotion broke suppression and emerged into awareness compared to the other. These differences in scores were then correlated with state anger symptoms experienced following the anger recall. This approach has been well-documented in psychological research, including in previous research involving CFS (Jusyte et al., 2015), and allowed us to quantify participants' differential response to these emotions (Trafimow, 2015). Due to STAXI-S post-induction not following a normal distribution, Spearman correlations were used. A *p*-value lower than 0.05 is considered statistically significant. Partial eta squared is used to report effect sizes.

3. Results

3.1. *Participants*

Participants were aged between 19 and 50 (mean = 26.76, SD = 7.38) (see Table 1) and had normal or corrected-to-normal acuity. All participants provided written informed consent and were naïve to the purpose of the study.

Table 1
Sample demographics.

	Mean (SD)	**Relevant Range**
Age (years)	26.76 (7.38)	19 – 50
Gender (%)		
Female	21 (70 %)	
Male	9 (30 %)	
Ethnicity (%)		
White	18 (60 %)	
Non-white	12 (40 %)	
Handedness (%)		
Right-handed	28 (93 %)	
Left-handed	2 (7 %)	
Occupation		
Student	17 (56 %)	
PhD student	5 (16 %)	
Non-student	8 (26 %)	
Alcohol units per week	4.5 (6.61)	0 – 27

3.2. *Continuous flash suppression (CFS)*

There was a significant main effect of emotion on RTs [$F(3, 84) = 11.751 p < 0.001$, $\eta p^2 = 0.296$]. Bonferroni-corrected pairwise comparisons showed that angry faces broke suppression significantly more slowly than fearful (means: 2.863 vs. 2.725 s; $p < 0.001$) and neutral faces (means: 2.863 vs. 2.748 s; $p < 0.032$). Fearful faces broke suppression significantly faster than happy faces (means: 2.725 vs. 2.953 s respectively; $p < 0.001$). There were no significant differences between detection times for angry and happy faces (means: 2.863 vs 2.953 s; $p = 0.522$). Additionally, neutral faces were faster than happy faces to break suppression (means: 2.748 vs. means: 2.953 s respectively; $p < 0.001$), but no significant differences were found between suppression times for fearful vs neutral faces (means: 2.725 vs. 2.748 s; $p = 1.000$) (Fig. 2).

3.3. *Anger recall paradigm (ARP)*

A rmANOVA with STAXI-S measures for each participant and timepoint (baseline, anger recall, recovery) as within-subjects factors, revealed a significant main effect of timepoint [$F\ (2, 56) = 15.254$; $p < 0.001$, $\eta p^2 = 0.353$] (Fig. 3a). Bonferroni-corrected pairwise comparisons showed a significant increase in the mean STAXI-S score from baseline to anger recall (means: 11.276 vs. 14.103 scores; $p < 0.01$) and a significant decrease from anger recall to recovery (means: 14.103 vs. 11.103 scores; $p < 0.01$). The difference between the baseline and recovery is not significant (means: 11.276 vs. 11.103 scores; $p = 1.000$), showing that STAXI-S returned to pre-existing levels after the recovery period. Together, this data suggests that the ARP was effective at eliciting subjective symptoms of anger.

3.4. *Correlations between CFS task performance and subjective symptoms of anger*

In contrast to our hypothesis, there was no significant association between RTs to detect anger and symptoms of STAXI-S after anger recall ($p > 0.3$). For exploratory purposes, we computed additional correlations between several computed mean differences (anger-neutral, anger-fear and fear-happy) and STAXI-S following anger recall. Interestingly, there was a significant moderate to large correlation between the computed mean difference between anger and fear RTs and the STAXI-S completed immediately after anger recall

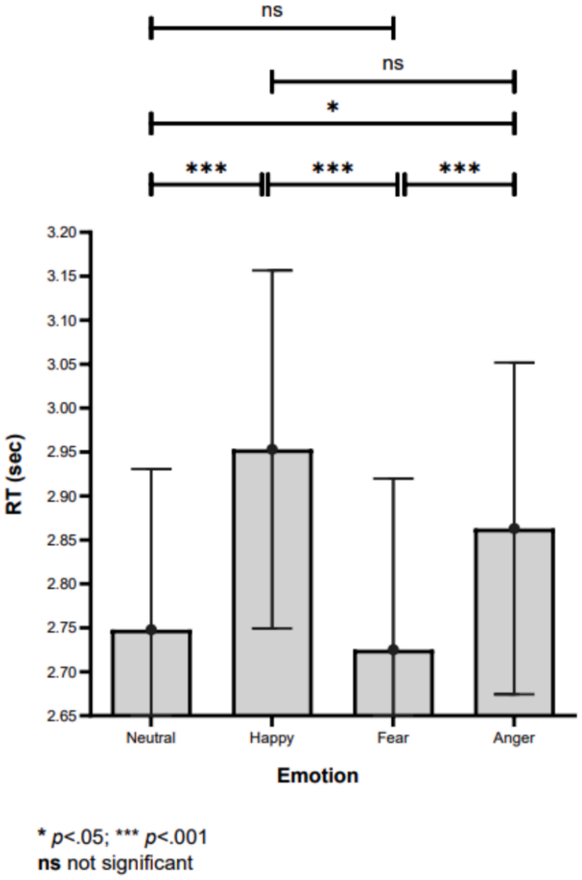

Fig. 2. ***Average reaction times (RTs) for each of the facial expressions in the CFS paradigm.*** *Reaction times represent the time it took to detect a face in the display. Error bars represent the standard error of the mean (SEM).*

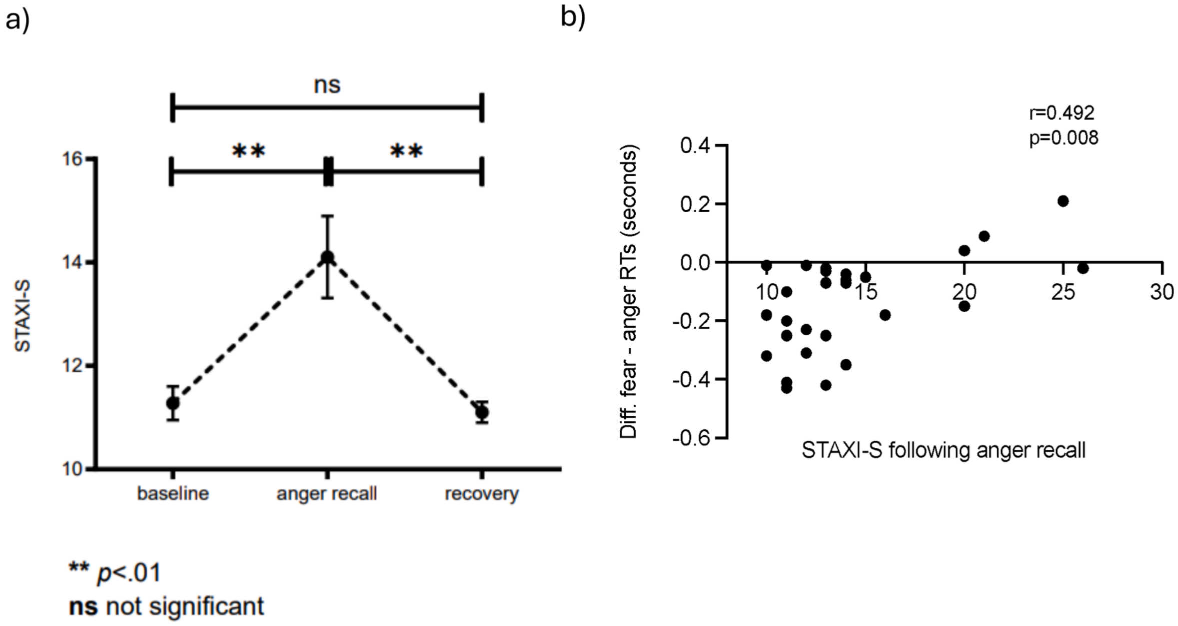

Fig. 3. ***a) Anger recall paradigm.*** Average STAXI-S ratings for each of the anger recall conditions (baseline, recall and recovery). Values represent average and standard error of the mean (SEM). There was a significant increase in the mean STAXI-S-recall score from baseline to anger recall and a significant reduction from anger recall to recovery, showing that the paradigm was effective at eliciting subjective feelings of anger. ***b) Scatterplot of anger-fear RTs difference against STAXI-S scores following anger recall.*** A relatively faster speed to detect fear in comparison to anger was associated with increased STAXI-S symptoms following the anger recall protocol ($r = 0.492$, $p = 0.008$).

[$r_s = 0.492$; $p = 0.008$] [95 % CI (0.16, 0.72)] (Fig. 3b). Specifically, a relatively faster speed to detect fear in comparison to anger was associated with increased symptoms of subjective state anger following the anger induction. This association with STAXI-S following recall was not seen when including fearful or angry reaction times only, or the difference between fear-happy or anger-neutral (all $ps > 0.4$).

4. Discussion

The aim of this study was to measure differences in suppression times (taken as an index of unconscious processing) of angry faces when compared to happy and fearful expressions in healthy volunteers using CFS. Additionally, we investigated, for the first time, the relationship between individual differences in suppression times of angry faces (against other emotions) and the subjective experience of anger following an anger induction protocol (ARP), as an exploratory analysis. Results showed that angry faces broke awareness significantly more slowly than fearful faces. There were no significant differences between detection of angry vs happy facial expressions. Fearful faces broke suppression significantly faster than happy faces. In addition, RTs to detect angry faces were not significantly associated with the subjective experience of anger following an anger induction. Interestingly, the relative difference in RTs to detect anger vs fear was associated with an increased subjective experience of anger following the ARP. This association was not seen with fear or anger only or with other differences in RTs scores (such as fear-happy or anger-neutral), suggesting that this relationship is specific to the fear-anger RTs difference.

4.1. Angry faces are slower to reach awareness than fearful faces

The CFS task revealed a significant effect of emotion on reaction times (RTs), with fearful faces breaking suppression faster than happy faces. This finding replicates previous research (e.g., Capitão et al., 2014; Yang et al., 2007; Jusyte et al., 2015) and reinforces the notion that fearful faces are prioritised over positive stimuli under conditions of strong perceptual suppression (for a review see Hedger et al., 2016). Although suppression times for angry faces were faster than for happy faces, this difference did not reach statistical significance after applying the Bonferroni correction. This may appear counterintuitive given prior theories claiming the superiority of anger in "face-in the-crowd" tasks (Hansen & Hansen, 1988). However, not all findings are consistent with this hypothesis (e.g., Becker et al., 2011; Coelho et al., 2010), and there is emerging evidence suggesting that angry faces take longer than happy to break through CFS (Stein & Sterzer, 2012; Stewart et al., 2012). This suggests that, while both anger and fear share a threatening quality, these emotions may be processed differently when compared to positive cues, particularly in the context of CFS. It is possible that fear, possibly due to its more universally recognised survival relevance, is more consistently prioritised over anger in such contexts.

Consistent with this, when directly comparing anger with fear, we found that angry faces were significantly slower than fearful faces to break suppression. Although these results align with previous preliminary studies using CFS (e.g., Gray et al., 2013; Jiang & He, 2006; Zhan et al., 2015), the differences in perception between fear and anger remain relatively underexplored, as prior research has predominantly included fear as a threat stimulus rather than anger (Hedger et al., 2016). There is nonetheless a growing body of evidence suggesting that these two emotions serve a different purpose. Indeed, angry and fearful faces convey different types of threat, appear to evoke separate neural circuits, and often elicit distinguishable attentional and behavioural responses. Fearful faces indicate the presence of a potential threat in the environment without indicating the source of the threat, hence signalling that more information is needed to determine the safety of the situation (Davis et al., 2011). This ambiguity leads to increased amygdala activation and prompts participants to direct their attention towards fearful faces (Whalen, 1998; Whalen et al., 2001). Angry faces, on the other hand, indicate a direct threat, i.e., the person with the angry expression looking directly at the observer which may lead to avoidance (Marsh et al., 2005; Schmidt et al., 2012) or freezing responses (Roelofs et al., 2010; Roelofs, 2017). In line with this, Zhan and colleagues (2015) found that participants looked towards fearful faces but averted their gaze away from angry faces made invisible using CFS.

The distinct behavioural responses to angry and fearful facial expressions are likely attributed to different underlying mechanisms. Fearful faces signal an indirect or ambiguous threat, heightening the sensitivity of the visual system to detect potential threats in the environment, thereby triggering fight-or-flight responses and increasing cortical arousal. In contrast, direct threats signalled by angry faces may elicit more passive reactions, such as freezing behaviours and reduced cortical arousal, potentially prolonging the suppression of threat (Stewart et al., 2012). This freezing response to social threat cues, characterized by reduced body motion and decreased heart rate, mirrors animal defence mechanisms and has been observed in humans exposed to angry faces (Roelofs et al., 2010; Roelofs, 2017). Additionally, angry faces engage a broader network of brain regions beyond the amygdala, including areas in the prefrontal cortex such as the orbitofrontal cortex, anterior cingulate cortex and the ventromedial prefrontal cortex (e.g., Gilam and Hendler, 2015a; Pichon et al., 2009; Williams et al., 2005). This involvement of higher-level processing regions suggests that the pathway for processing angry facial expressions may require more complex cognitive evaluation, potentially resulting in longer times to enter conscious awareness compared to the more automatic detection of fearful expressions. However, this hypothesis remains speculative and warrants further investigation. More research is needed to better understand how fear and anger are processed cognitively, including at an unconscious level.

Neutral faces broke suppression significantly faster than happy and angry faces, suggesting they may hold unique salience in the context of the CFS paradigm. The faster detection of neutral faces may be attributable to their ambiguous nature, as they lack clear emotional cues, especially when compared to happy and angry faces, which convey distinct and recognizable emotions. Indeed, rather than being always perceived as neutral, neutral faces are emotionally ambiguous (Rollins et al., 2021). Such ambiguity in facial expressions often demands increased cognitive effort or heightened attention, potentially explaining their salience in the suppression-breaking task (Kaminska et al., 2020). On the other hand, neutral faces can also be perceived with a negativity bias in certain populations (Rollins et al., 2021). Indeed, prior research has shown that individuals in certain emotional or cognitive states, such as anxiety or heightened vigilance, are more likely to interpret neutral faces as threatening or negative (e.g., Peschard & Philippot, 2017; Yoon & Zinbarg, 2008). Interestingly, no significant differences were found when directly comparing suppression times for neutral and fearful faces, consistent with previous findings (Capitão et al., 2014). Although fearful faces are inherently threatening, they also convey ambiguity by signalling danger without specifying its source (Whalen, 2007), as discussed earlier. This shared ambiguity in both neutral and fearful faces may have contributed to the lack of a detectable difference when directly comparing their suppression times.

4.2. *Association between unconscious processing of angry vs fearful faces and subjective symptoms of anger*

The second objective of the study had an exploratory nature and aimed to examine the relationship between suppression times for detecting angry faces (compared to other emotions) and the subjective experience of anger following an anger induction protocol. In contrast with our hypothesis, the RTs to detect angry faces made invisible by CFS were not significantly correlated with levels of subjective anger experienced following the ARP. Further correlations were computed between the difference scores for suppression times to the facial expressions that showed significant differences in the rmANOVA and state anger symptoms post-induction. This approach offers the advantage of isolating emotion-specific effects that may influence psychological symptoms (Jusyte et al., 2015; Trafimow, 2015) and aligns with theories that highlight the importance of relative differences, rather than absolute values, in understanding emotional processing (Diener & Larsen, 1984; Scherer, 2009).

Using this difference scores approach, we found a positive significant correlation between the difference in reaction times (RTs) for detecting fear versus anger and STAXI-S ratings following the anger induction. In other words, those participants who detected fearful faces more quickly than angry faces experienced more symptoms of anger immediately after the induction. This effect did not appear when considering RTs for detecting anger or fear alone, nor in comparisons between anger-neutral or fear-happy conditions, suggesting that it was specific to the difference in detecting fear vs anger. This difference in perception between fearful and angry faces may therefore predispose subjects to experience anger more intensely. This finding is nonetheless preliminary, requiring further replication, and should therefore be interpreted with caution. Notwithstanding, previous research by Carlson et al. (2010) have found that an increased amygdala response to masked fearful faces was positively associated with a predisposition to experience anger. This suggests that a neural bias to detect fear at an early stage of information processing could potentially reflect a mechanism that triggers anger-related responses. Nevertheless, the study by Carlson et al. (2010) did not include angry faces – which is a common limitation of previous studies –, hence making comparisons with our study more difficult.

The reasons for the differences in RTs when detecting fear vs anger in the CFS are not fully understood and have been sparsely explored. As noted previously, the neural pathways for processing these emotions are different and the CFS paradigm may detect such differences at an unconscious stage of information processing. Indeed, fearful faces are known to elicit stronger activation in the amygdala compared to other negative emotions, including anger (Whalen et al., 2001), and this mechanism is likely responsible for the preferential processing of this emotion into awareness. On the other hand, because angry faces seem to evoke a wider network of brain regions, including areas involved in higher cognitive functions (Gilam & Hendler, 2015b; Pichon et al., 2009; Williams et al., 2005), this emotion may take longer to reach conscious perception. Differences in the unconscious processing of these emotions at a cognitive level – preferential detection of fearful vs slower detection of angry faces – could be relevant to the subsequent subjective experience of anger. It is noteworthy that this association did not emerge when comparing fear with happy or anger with happy, suggesting that the relationship between reaction times and subsequent feelings of anger may be particularly tied to the differential transition from suppression to awareness of fearful vs. angry faces. This finding is particularly intriguing given previous research indicating that, while both fear and anger convey threat, they often evoke distinct attentional and behavioural responses (e.g., Schmidt et al., 2012; Whalen et al., 2001). Perhaps the faster detection of fear when contrasted with the slower detection of anger specifically reflects a bias to detect ambiguous threatening information in the environment and a simultaneous difficulty in coping with the angry facial expressions of others, resulting in longer suppression from conscious awareness and a longer time to determine the appropriate behavioural response (see Pichon et al., 2009). This difference could be associated with a higher predisposition to experience anger at a subjective level following an anger-inducing event, but future research is needed to fully tease apart the effects of fear vs anger perception on this association.

More studies are also needed to better understand the role of individual differences in conscious and non-conscious detection of fear versus anger perception. Previous studies have demonstrated variability in sensitivity to both fearful (Doty et al., 2014) and angry expressions (Honk and colleagues, 2001). Therefore, replicating this study with a larger sample that includes variability in traits like trait anxiety and trait anger would be particularly valuable, given their relevance to the perception of emotional cues. Finally, it would also be relevant to repeat this experience with a design in which the CFS paradigm is administered after the anger induction. This would help clarify whether the induction of anger alters unconscious processing as measured by CFS, thereby providing further insight into the relationship between the perception of fearful versus angry faces and the subjective experience of anger.

5. Study limitations

While this study provides valuable insights into the unconscious processing of fearful versus angry faces, the findings reported here should be considered in light of certain limitations. The study was adequately powered to investigate differences in RTs when processing different facial expressions made unconscious by CFS, as confirmed by our sample size calculation and replication of previously observed effects using this task (Capitão et al., 2014; Yang et al., 2007), with the added inclusion of anger as an additional facial expression. However, the absence of prior studies investigating the relationship between unconscious facial expression processing and subjective emotional experiences prevented us from conducting a separate sample size calculation specifically for this purpose. It would therefore be important to replicate this effect with a larger sample. In addition, we did not perform statistical correlations for multiple comparisons in the correlations reported, given that this analysis had an exploratory nature. However, there has been debate on the risks and advantages associated with multiple corrections. As García-Pérez (2023) recently recommended, applying lower alpha levels as a result of statistical corrections increases the risk of Type II errors (false negatives) without necessarily reducing Type I errors (false positives). The author also states that overly stringent significance criteria may obscure meaningful effects, particularly in smaller samples, as in our study. The author therefore recommends the use of effect sizes and confidence intervals − which we have reported − rather than inherently arbitrary significance thresholds. As the significant correlation observed here shows a moderate-to-large effect size, we believe it offers valuable insights for developing future hypotheses about differences in the unconscious perception of fear versus anger in relation to subjective anger. Notwithstanding, this finding should be treated as exploratory and subject to future replication.

Additionally, despite being a robust paradigm for studying unconscious processing, the CFS task presents some methodological limitations. Firstly, the lack of a staircase procedure may introduce variability in suppression effectiveness across participants. Furthermore, while the stimuli in our CFS experiment were fully equated for overall contrast and mean luminance, they were not controlled for other low-level spatial features, such as focal contrast around the eye region and spatial frequency content. It has been argued that the advantage of emotional faces in breaking suppression in CFS may stem from these differences in stimulus characteristics rather than purely from emotional content (Comfort et al., 2013; Gray et al., 2013; Lanfranco et al., 2023). These factors could influence reaction times (RTs), making it difficult to distinguish whether our findings are driven by high-level cognitive processes, such as facial recognition and emotional expression, or by low-level visual properties. Although differences in low-level features cannot be entirely ruled out, existing evidence suggests they alone may not fully account for our findings or those of previous studies. First, this effect may be influenced by the mammalian predisposition to rapidly detect low spatial frequency information to identify potential threats (Geisler, 2008). Additionally, the observation that the detection of fear relative to anger was linked to subjective anger following an anger induction—an effect independent of the physical properties of the facial stimuli—suggests a deeper association between CFS detection and psychological processes. Similar links between CFS detection times and psychological constructs have been observed in other populations, such as individuals with antisocial behavior (e.g., Jusyte et al., 2015). Regardless of whether this effect arises from low- or high-level mechanisms, our findings indicate a meaningful relationship between the speed of detecting fearful versus angry faces in CFS and subjective anger. To address low-level confounds, future studies should carefully control stimuli by equating luminance, contrast, size, and spatial frequency and use validation studies to ensure consistent stimulus selection for each emotional expression (Lanfranco et al., 2023). Further research should also investigate the interplay between low- and high-level visual features in detecting anger and fear, ultimately clarifying the precise mechanisms underlying the perception of these emotional expressions (Gray et al., 2013; Stein & Sterzer, 2012).

Another limitation of CFS is that RTs might reflect both detection and identification processes, rather than detection alone (Lanfranco et al., 2023). This conflation can confound RT interpretation, as it becomes difficult to determine whether faster RTs result from actual prioritization in awareness or post-detection identification differences, such as response bias (a preference for a particular response) or decision criterion (the willingness to report a signal). Recent research has proposed adaptations the CFS paradigm, such as incorporating a conscious control condition, employing a separate task orthogonal to the experimental manipulation, or using non-speeded tasks where experimenters control stimulus presentation durations and include both detection and identification components (Lanfranco et al., 2023). However, even these adaptations have inherent limitations, making the CFS paradigm particularly challenging to implement. Nonetheless, future research should incorporate these recent recommendations (Lanfranco and colleagues, 2023), to ensure that findings reflect unconscious processing rather than artefacts stemming from differences in stimuli.

6. Conclusion

Our findings suggest that fearful faces are processed faster than happy faces, a finding that is consistent with prior research. In contrast, there were no significant differences between suppression times for angry versus happy faces. Notably, angry faces were detected more slowly than fearful faces, suggesting that fear may have preferential processing over anger when entering awareness. Moreover, the difference between the detection of fearful versus angry faces was found to be significantly associated with increased subjective anger symptoms post-anger induction. This may suggest that that the faster detection of fear when contrasted with the slower detection of anger specifically reflects a bias to detect ambiguous threatening information in the environment and a difficulty in coping with the angry facial expressions of others, a pattern of response which, in turn, could be associated with an increased predisposition to feel angry in response to an anger-triggering event. Overall, these findings contribute to our understanding of how fearful and angry faces are processed at an unconscious level, and how the difference in detection times between these two emotions may contribute to the subjective experience of anger, hence shedding light on the early cognitive mechanisms influencing subjective emotional experiences.

CRediT authorship contribution statement

Anna Pelliet: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Formal analysis, Data curation. **Marlene Nogueira:** Writing – review & editing, Project administration, Formal analysis, Data curation. **Catarina Fagundes:** Writing – review & editing, Visualization, Validation, Project administration, Formal analysis. **Susana Capela:** Writing – review & editing, Visualization, Validation, Project administration, Formal analysis. **Fátima Saraiva:** Writing – review & editing, Project administration, Formal analysis. **Erdem Pulcu:** Writing – review & editing, Visualization, Validation, Software, Resources. **Catherine J. Harmer:** Writing – review & editing, Validation, Resources, Methodology. **Susannah E. Murphy:** Writing – review & editing, Visualization, Validation, Resources, Methodology. **Liliana P. Capitão:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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Open Practices

The anger recall paradigm is publicly available via the Open Science Framework (https://osf.io/pt9fw). Primary data and corresponding analysis scripts are also publicly available via the same platform (https://osf.io/862gc/). The authors are open to any requests regarding the measures used and analysis process.

Declaration of competing interest

CJH has received consultancy fees from P1vital Ltd., Janssen Pharmaceuticals, Sage Therapeutics, Pfizer, Zogenix, Compass Pathways and Lundbeck. SEM has received consultancy fees from Zogenix, Sumitomo Dainippon Pharma, P1vital Ltd. and Janssen Pharmaceuticals. CJH and SEM hold grant income from Zogenix, UCB Pharma, Syndesi and Janssen Pharmaceuticals. CJH hosts grant income from a collaborative research project with Pfizer and the MRC. The rest of the authors have no conflicts of interest to declare.

The rest of the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is available on https://osf.io/862gc/.

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