

Emotion

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Physiological Arousal Underlies Preferential Access to Visual Awareness of Fear-Conditioned (and Possibly Disgust-Conditioned) Stimuli

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Fear and disgust have been associated with opposite influences on visual processing, even though both constitute negative emotions that motivate avoidance behavior and entail increased arousal. In the current study, we hypothesized that (a) homeostatic relevance modulates early stages of visual processing, (b) through widespread physiological responses, and that (c) the direction of these modulations depends on whether an emotion calls for immediate regulatory behavior or not. Specifically, we expected that increased arousal should facilitate the detection of fear-related stimuli, and inhibit the detection of disgust-related stimuli. These hypotheses were tested in two preregistered experiments (data collected in 2022, total $N = 120$, ethnically homogeneous Polish sample). Using a novel, response bias-free version of the breaking continuous flash suppression paradigm, we examined localization and discrimination of fear- and disgust-conditioned stimuli at individually determined perceptual thresholds. Our first hypothesis was confirmed: fear-conditioned stimuli were detected and discriminated better than neutral stimuli, and the magnitude of conditioning-related perceptual preference was related to arousal during conditioning acquisition. In contrast with our second hypothesis, perceptual access to disgust-conditioned stimuli was not diminished. Exploratory analyses suggest that discrimination of disgust-conditioned stimuli was also enhanced, although these effects appeared weaker than those evoked by fear conditioning. The current study strengthens previous evidence for facilitated perception of threatening objects and shows for the first time that stimuli evoking disgust might also gain preferential access to awareness. The results imply that homeostatically relevant stimuli are prioritized by the visual system and that this preference is grounded in the underlying arousal levels.

Keywords: visual perception, fear, disgust, physiological arousal, breaking continuous flash suppression

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Fear signals external threats and promotes immediate allostatic behavior in response to impending danger (e.g., the fight-or-flight response). As such, it entails a sympathetic activation pattern characteristic of mobilization for action, resulting in increased heart rate, respiration rate, and electrodermal activity (Comtesse & Stemmler, 2017). Underlying physiological arousal is believed to be responsible for preferential visual processing of stimuli indicating threat (Mather & Sutherland, 2011). Fear facilitates attention to threatening objects (Öhman et al., 2001) and improves discrimination of fear-signaling stimuli, as if it was amplifying their contrast (Phelps

et al., 2006). To facilitate rapid regulatory behavior, fear-related arousal selectively enhances the processing of low spatial frequency visual information—that is, “coarse” features of perceived stimuli—while impeding the processing of visual details (Bocanegra & Zeelenberg, 2009; Borst & Kosslyn, 2010; Lee et al., 2014). Studies using the breaking continuous flash suppression (b-CFS) paradigm have shown that fear-conditioned stimuli enjoy preferential access to visual awareness compared to neutral stimuli (Gayet et al., 2016) and are more accurately localized, even in the absence of conscious awareness (Vieira et al., 2017). The magnitude of the

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All hypotheses as well as the data analysis plan had been preregistered at the Open Science Framework repository in a time-stamped document (<https://osf.io/dyw64/>) before the data collection started.

Piotr Litwin served as lead for conceptualization, formal analysis, funding

acquisition, investigation, methodology, project administration, validation, and writing—original draft and served in a supporting role for resources and visualization. Paweł Motyka served as lead for visualization and served in a supporting role for conceptualization and methodology. Surya Gayet served as lead for resources and supervision and contributed equally to methodology. Piotr Litwin and Paweł Motyka contributed equally to data curation. Piotr Litwin, Paweł Motyka, and Surya Gayet contributed equally to writing—review and editing. Piotr Litwin and Surya Gayet contributed equally to software.

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enhancement of detection accuracy correlates positively with the relative arousal associated with the presentation of threatening stimuli during the conditioning phase (Vieira et al., 2017). Thus, an emerging coherent picture suggests that fear-related effects on visual perception are prevalent and likely related to underlying arousal.

The proposed mechanism of these fear-related effects is based on unconscious rapid recognition of relevant features through subcortical pathways (e.g., the amygdala) and subsequent feedback modulation of object-related activity in the visual cortex (Gayet et al., 2016). While it has been argued that such perceptual facilitation is informed by object-associated arousal (Lee et al., 2014), it does not follow that arousal exclusively improves perceptual processing, as it may exert a variety of influences depending on other contextual factors, such as approach/avoidance motivation, valence or adaptive action regulation (Balci, 2016). Elevated arousal levels accompany a wide variety of emotions that may yield different perceptual effects. For example, percepts associated with monetary reward tend to break suppression faster (Lunghi & Pooresmaeili, 2023), whereas those associated with monetary loss tend to be suppressed (Wilbertz et al., 2014); arguably, both monetary gains and losses entail physiological arousal.

Core disgust makes another case that increases in arousal might not be monotonically related to the access of visual information to awareness. Disgust is associated with a broader pattern of sympathetic-parasympathetic coactivation, resulting in increased heart rate and skin conductance response (de Jong et al., 2011) as well as increased heart rate variability and decreased cardiac output (Kreibig, 2010). This distinguishes disgust from other negative emotions, which increase cardiac output in order to mobilize for action (Kreibig, 2010, p. 403); disgust, as opposed to fear, serves long-term homeostatic control through inhibition of behavior and does not require immediate action (Cole et al., 2013; van Hooff et al., 2013). In other words, disgust “warns” that some objects should not be directly interacted with so one can avoid the transfer of toxins, but it does not usually entail the need for regulatory behavior orchestrated on a subsecond timescale (e.g., rapid withdrawal), given that most disgusting objects are inanimate or do not approach the observer. In this case, perceptual suppression may be more efficient in preventing acute internal responses associated with close yet indirect contact with an object of disgust (e.g., decreased normogastric activity causing nauseous feelings; Chapman & Anderson, 2012).

Accordingly, preliminary evidence shows that disgust may indeed involve perceptual suppression effects (Krusemark & Li, 2011). In a simple detection task, accuracy rates are lower and response times are longer for targets preceded by briefly presented disgusting images (van Hooff et al., 2013). Similarly, disgust-eliciting stimuli produce greater attentional blinks than neutral or fear-related stimuli, especially at short temporal intervals (Perone et al., 2021). Although these findings may be interpreted as increased inability for attentional disengagement, there is also the possibility that they reflect poorer detection following presentation of repellent objects (an analogous effect—although in the opposite direction—to the fear-induced “contrast amplification”; cf. Gayet et al., 2016, Phelps et al., 2006). A recent study using the b-CFS paradigm has also shown that disgusted faces break into visual awareness more slowly than do neutral faces, while fearful faces do so faster (Silva et al., 2020); however, it should be noted that differential processing of distinct emotional facial expressions may boil down to differences in their low-level visual properties (Gray et al., 2013; Stein et al., 2018; Webb & Hibbard, 2020).

In the current study, we intended to investigate the hypothesis that the perceptual effects of emotionally laden stimuli cannot be ascribed solely to arousal. Instead, we posited that arousal-related effects on perception are grounded in distinct (broader) physiological activation patterns attributable to specific emotions. The directionality of the effects could depend on whether the regulation of particular emotions requires an immediate regulatory response and, as such, should be irreducible to approach/avoidance motivation or emotional valence. Therefore, we chose to study the perceptual effects of fear and disgust, which represent two distinct ways in which emotions help preserve homeostatic stability: fear defends against external threat while disgust defends internal milieu from pollution (Toronchuk & Ellis, 2007). As such, fear and disgust constitute two examples of emotions matched in terms of the arousal (increased), valence (negative), and behavioral orientation they motivate (avoidance), but of which only fear normally promotes immediate regulatory behavior (i.e., evasion or fleeing). We expected that increased arousal should be positively related to increased performance in visual tasks for fear-conditioned stimuli, and negatively related to decreased performance for disgust-conditioned stimuli.

To examine our hypothesis, we used a nonspeeded, accuracy-based variant of the b-CFS paradigm (Jiang et al., 2007). In a series of two spatial two-alternative forced-choice (spatial 2AFC) experiments, we examined localization and discrimination performance for fear- and disgust-conditioned stimuli presented at individually titrated perceptual thresholds. We expected localization performance to be enhanced for fear-conditioned stimuli and worsened for disgust-conditioned stimuli as compared to similar stimuli that are not conditioned (neutral). Additionally, we expected the magnitude of these differences in performance to be correlated with physiological arousal (skin conductance response [SCR]) measured during the presentation of unconditioned stimuli in the conditioning phase. Separate studies were run for fear and disgust, since (a) we did not intend to compare fear- and disgust-related effects (our directional hypotheses pertained to differences between conditioned and neutral stimuli), and (b) we wanted to avoid problems with mixing multiple conditioning procedures in one study.

Finally, in each study, we examined the effects of conditioning on both stimulus localization and stimulus discrimination performance to determine which kind of information about a homeostatically relevant stimulus is affected and whether this depends on the specific emotion type. For example, fear-related effects should essentially pertain to the stimulus location (cf. Vieira et al., 2017), which is a crucial feature for successful regulatory action under time pressure. However, one may ask whether the visual system prioritizes the entire stimulus for further processing, including tangential visual features allowing its identification (cf. Gayet et al., 2016). On the other hand, perceptual suppression effects of disgust should mainly prevent visual recognition of the disgusting object’s identity. It follows that, in this case, one should perhaps expect worsened performance in discrimination tasks in particular. To examine possible dissociations between localization and discrimination performance, we had decided to include discrimination tasks in all b-CFS trials. Dissociations between localization and discrimination performance may occur in the b-CFS paradigm (Lanfranco et al., 2022; Stein, 2019; Stein & Peelen, 2021), since additional presentation time is typically needed for discrimination accuracy to match the localization performance, and the amount of additional time required largely depends on the stimulus salience (Kobyłka et al., 2017). Analyzing

both localization and discrimination accuracy allowed us to examine which stage of visual processing is primarily affected by the different types of conditioned emotions.

Method

Participants

To determine the appropriate sample size, we used the effect size estimates reported by Vieira et al. (2017). For the main comparison of interest (paired *t*-test: CS+ vs. CS−), we carried out a power analysis for the effect observed in the forced-choice localization task ($d = 0.55$) using the following formula (*pwr* package for R; Champely et al., 2018): *pwr.t.test* ($d = 0.55$, sig. level = .05, power = 0.9, type = “paired,” alternative = “greater”), which yielded $N = 30$. To calculate the sample size required for arousal-related analyses, we used the correlation between fear-related localization performance enhancement and relative SCR response to CS+ stimuli ($r = .36$). Using the formula proposed by Hulley et al. (2013), we determined $N = 63$ for such a one-sided correlation to be detected at 0.9 power. On that basis, we decided to include 60 participants in both experiments. This number, although slightly lower than our more conservative estimation, still provided sufficient statistical power, even for analyses with exclusions.

Taken together, 120 participants took part in the study: Experiment 1: $N = 60$ (17 male); Experiment 2: $N = 60$ (15 male). Participants were recruited through the recruitment platform of the University of Warsaw ($N = 51$ —Experiment 1: $N = 41$; Experiment 2: $N = 10$) and social media ($N = 69$ —Experiment 1: $N = 19$; Experiment 2: $N = 50$). Participants recruited through the University platform were mostly students of diverse majors; however, the group recruited through social media was more heterogeneous (e.g., in terms of age, educational background or socioeconomic status). The detailed data regarding age, gender identity, socioeconomic status, ethnicity, disability status, or sexual orientation were deemed irrelevant for the study purposes and thus not collected in accordance with incumbent data protection policies. We only recruited participants who had claimed to not have a diagnosis of psychiatric, neurological (with a particular emphasis on epilepsy), or ocular conditions (amblyopia and color blindness). All participants had normal or corrected-to-normal vision and gave written informed consent before taking part in the study. They received monetary compensation (40 PLN; ~8.5 €) for participation. The experiment complied with the ethical guidelines as specified in the Declaration of Helsinki and was approved by the ethics committee of the Faculty of Psychology of the University of Warsaw.

Stimuli and Apparatus

All stimuli were presented on a black screen (brand/model: BenQ GL2450-T; size: 24”; resolution: 1,920 × 1,200 px; refresh rate: 60 Hz; gamma corrected). With the use of a custom-built dichoptic mirror stereoscope, each eye was presented with a separate visual scene consisting of two nested rectangular presentation frames. The external frame, subtending an area of 11.24 by 6.32°, was filled with a Brownian noise frame to promote the fusion of images. A uniform gray presentation area of 10.71° × 6.02°, with a fixation cross (0.2° × 0.2°) in the center, was encapsulated within the larger rectangle.

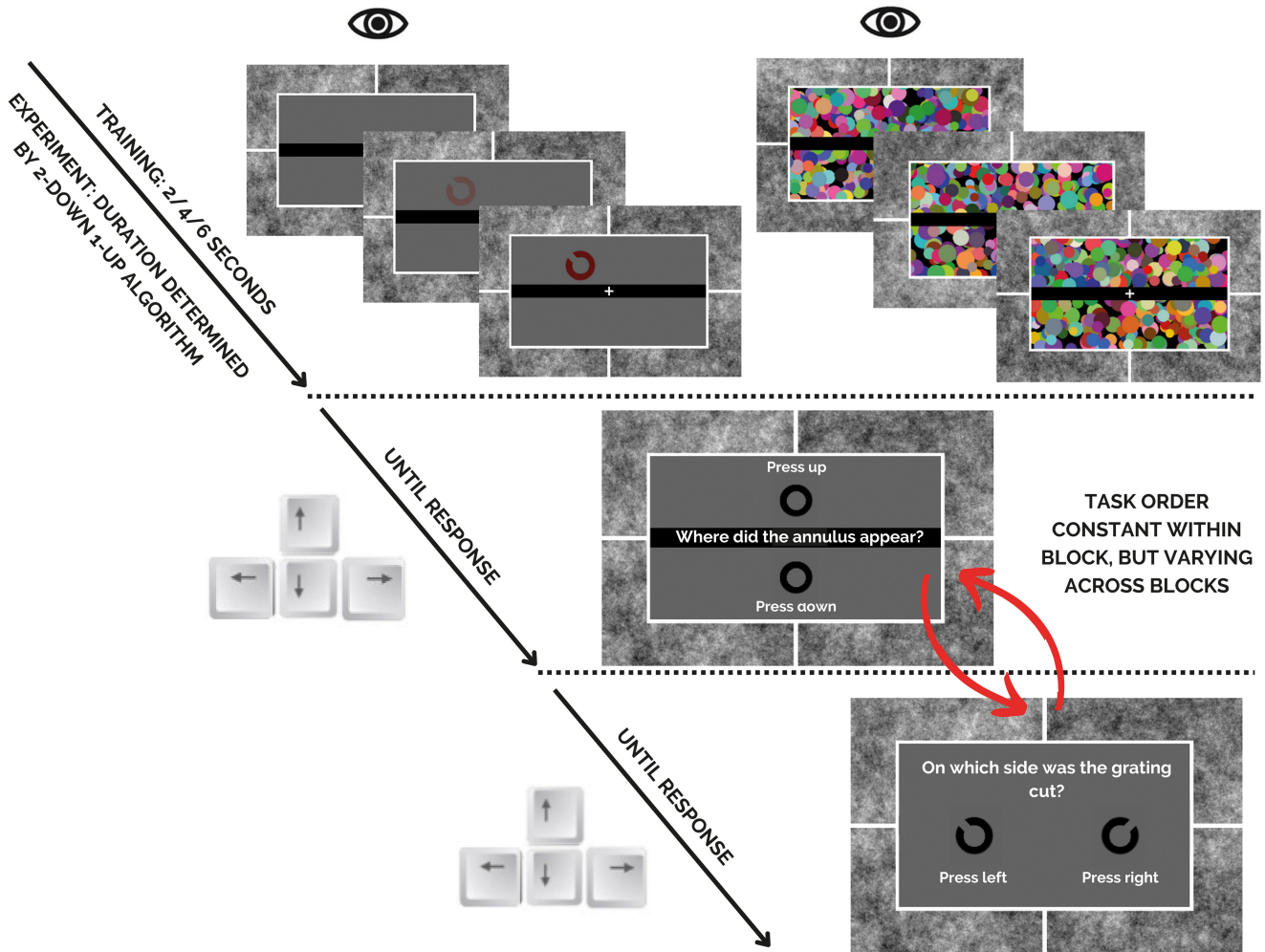
The masks consisted of overlapping colored, high-contrast circles (Figure 1, right eye). Unique 40 masks were pregenerated and loaded from images before each experiment. During each trial, masks were shuffled in a unique order at 6 Hz frequency which tends to provide the longest suppression durations (Drewes et al., 2018).

The target stimuli were modeled on those used previously by one of the authors (Gayet et al., 2016) and comprised colored annuli (outer radius: 1.2°; inner radius: 0.7°) cut either on the left or the right side (−45° or +45° rotation from vertical; Figure 1, left eye). For the presentation of stimuli, we used red and blue annuli. The exact RGB values of red annuli and gray background were individually determined using the flicker photometry method (Kaiser & Comerford, 1975) to perceptually equate the luminance of the colors with the uniform gray background of the presentation area. By doing so, we ensured that the annuli were predominantly defined by their chromatic contrast with the background, which is the feature dimension that carries the experimental manipulation. Each of the participants provided 10 RGB estimates for red and gray colors relative to the reference color—saturated blue. Individual estimates were then averaged for the respective colors and fed to the main experiment as perceptually isoluminant RGB values. Black annuli, which served as a prompt for a response, were predetermined and not subject to calibration based on flicker photometry.

We used two sets of unconditioned stimuli (US): white noise bursts (fear conditioning; Experiment 1) and disgusting video clips (disgust conditioning; Experiment 2). Along with electrocutaneous shocks, white noise bursts are the most reliable and widely used method in human fear conditioning (Lipp, 2006). However, noise bursts are more resilient to conditioning extinction effects (Sperl et al., 2016) and, as such, are better suited for procedures requiring larger numbers of trials (such as b-CFS). Noise bursts were delivered from a stereo speaker positioned directly in front of participants (under the display) at a volume of 95 dB (measured at the participants’ head position).

In the second experiment, we used short video excerpts as aversive US, because, in contrast to disgusting sounds (Köchel et al., 2013), film clips more reliably elicit an intense and specific disgust emotion (Bujarski et al., 2015; Gilman et al., 2017). We aimed to present core disgust materials through the videos since mutilation-related disgust (e.g., associated with injuries or surgeries) can induce potentially confounding emotions, such as fear or empathy toward others (Shenhav & Mendes, 2014). We examined eight video clips (~10 s each) with core-disgust-inducing content in a large ($N = 115$) online prestudy, of which we selected four to be used in the main experiment. For each of the clips, participants had been asked to assess the intensity of disgust on a 10-point Likert scale, name any other kind of emotion elicited, and indicate whether the intensity of the associated emotion would be bearable in experimental conditions. On this basis, we picked films that reliably induced medium-to-high disgust and did not tend to coelicit other emotions. The following clips were chosen: (a) Bear Grylls eating a huge squirming worm; (b) a woman puking on herself and her partner on a rollercoaster; (c) an excerpt from Dr Pimple Popper showing a gigantic skin cyst being squeezed out by a dermatologist; and (d) a man searching for a suppository in an extremely foul toilet (from the movie *Trainspotting*; for clips see <https://github.com/piolitwin/bcfs-feardisgust>). Each clip was cut into two sequential 5-s excerpts, forming a chronological storyline (Bosman et al., 2016), which yielded eight unique US. All clips were presented with sound.

Figure 1
Schematic Depiction of the Course of a Single Training/Experimental b-CFS Trial



Note. Participants were asked to report the location of the presented annulus (up/down) as well as the location of the cut in the annulus (left/right). Both tasks were scaffolded by exemplary black annuli with button-related instructions to minimize the risk of lapse responses. Task order was counterbalanced across blocks, but remained constant within blocks to react against trial-to-trial confusion. In the experimental session, the 2-down/1-up algorithm determining trial durations was driven solely by localization correctness. b-CFS = breaking continuous flash suppression. See the online article for the color version of this figure.

SCR was recorded with the use of a Biopac EDA100C amplifier and AcqKnowledge 5.0 software (Biopac Systems Inc., Santa Barbara, California, United States). The signal was collected at 1,000 Hz frequency (gain: 10 $\mu\text{s}/\text{V}$). Electrodes filled with isotonic gel were placed on the distal phalanges of the participant's left index and ring fingers.

Tasks

Breaking Continuous Flash Suppression

b-CFS (Jiang et al., 2007) is a method of rendering a target stimulus presented to one eye invisible through the presentation of a high-contrast, rapidly changing mask to the other eye (i.e., inducing interocular suppression). Over time, perceptual dominance shifts from the masks to the target, allowing participants to perceive the

target stimulus and to report its characteristics of interest (e.g., its location or shape). Accuracy measures or reaction times (RTs) serve as behavioral proxies for the ease with which the target escapes perceptual suppression, and may be compared between conditions to indicate how certain stimulus features are prioritized over others in reaching conscious access (Stein, 2019).

Taking recent methodological considerations into account (Lanfranco et al., 2023a, 2023b; Stein, 2019), we decided to use an accuracy-based b-CFS method which was slightly modified to fit the purposes of the current study (Figure 1). In each of the trials, participants were presented with a target stimulus (a clipped annulus) in one eye, and a rapidly flashing mask in the other eye. Thus, all of the trials involved interocular suppression. The target was presented either above or below the bilateral fixation cross displayed at the center of the black horizontal bar dividing the dichoptic scene

into upper and lower presentation areas. Participants were instructed to maintain their fixation on the cross and to avoid ocular movements and were not able to respond in the course of the trial. In all of the trials, participants consecutively performed two forced-choice tasks: they reported the position of a target with respect to the horizontal bar (up/down; localization task) and the side on which the annulus was cut (left/right; discrimination task). The position of the target was slightly radially jittered from the midpoint of the upper/lower presentation area at fixed eccentricity to counteract practice effects. Participants were instructed to report the annulus location (up/down arrows) and the side of the cut (left/right arrows) as accurately as possible by pressing buttons, and to provide their best guess if the target was not seen. In both tasks, black annuli were presented with additional instructions to facilitate intended responses. No feedback on the correctness of responses was provided throughout the experiment.

Each trial started with a fixation cross (500 ms), and target stimuli were presented between 300 and 600 ms after the onset of the Mondrian masks. In all trials, target stimuli were linearly ramped up to 100% contrast in 2 s. The presentation time differed between the trials—it was determined by the 2-down/1-up adaptive staircase method, decreasing the trial duration after two consecutive correct responses, and increasing it after an incorrect one. By varying trial durations based on participants' localization performance, we aimed to determine individual presentation time thresholds allowing reliable (i.e., 80%) target localization, thus avoiding floor- or ceiling-level performance. To test for the effects of conditioning, we then compared (localization and discrimination) performance levels between conditioned stimuli (CS+) and neutral stimuli (CS−). Importantly, we used shared (heterogenic) staircases for CS+/CS− stimuli to keep stimulus characteristics (i.e., presentation times) identical across conditions, while also keeping the performance level within the same range for all participants. Another advantage of this methodological approach is that less trials are needed for computing accuracies (within a staircased performance range) than that are needed for establishing stable perceptual thresholds per condition (for a similar approach see, Aldegheri et al., 2023). Limiting trial numbers is particularly relevant in conditioning experiments, due to the occurrence of extinction effects.

The staircases were allowed a wide range of 110 possible durations ranging from 1 to 6 s, spaced on a log scale with each step 1.0166 times longer than the previous one (rounded to presentation times possible on a 60 Hz monitor). Unequal up/down step sizes were used, with descending steps (11 durations) almost two times smaller than steps up (20 durations). Such specification yielded a 0.55 step-down/step-up ratio which is very close to the optimal one for 2-down 1-up staircases (García-Pérez, 1998). This allowed the algorithm to reliably converge toward the individual presentation time thresholds in localization tasks (expected accuracy: 80.35%; García-Pérez, 1998). In each of the experiments, two separate (interleaved) staircases were run for left and right eyes to account for the fact that the magnitude of eye dominance varies considerably across participants (Dieter et al., 2017).

There are important rationales behind our main methodological choices which may seem unorthodox, but have important advantages over alternative solutions. First, based on recent recommendations, we opted for nonspeeded accuracy-based measures, since RTs cannot rule out other postperceptual factors related to motor preparation or response criteria, even if participants report perceptual features orthogonal to the manipulation

(Lanfranco et al., 2023a; Stein, 2019). Thus, RTs do not necessarily reflect suppression times alone. Second, we decided to use trial durations as stimulus intensities, because using contrasts for this exact purpose could result in trial-to-trial changes in the conditioned property (i.e., perceived color), possibly precluding the transfer of conditioning effects between stimuli with different appearances. Third, we opted for within-staircase performance comparisons, since separate staircases for conditioned and neutral stimuli could result in varying presentation times and detectable differences in the thresholded property across conditions. Finally, we decided to abstain from using control trials without suppression (in which target and masks are presented to the same eye), which are supposed to capture all aspects of the b-CFS trials except for the interocular suppression. Visual phenomenology and high predictability of such trials differ from b-CFS experience and demonstrably entail poor sensitivity for measuring differences between conditions (Stein, 2019). Using accuracy-based outcome variables already ensures that measurements capture early perceptual rather than postperceptual processes. Numerous control trials would also needlessly contribute to conditioning extinction.

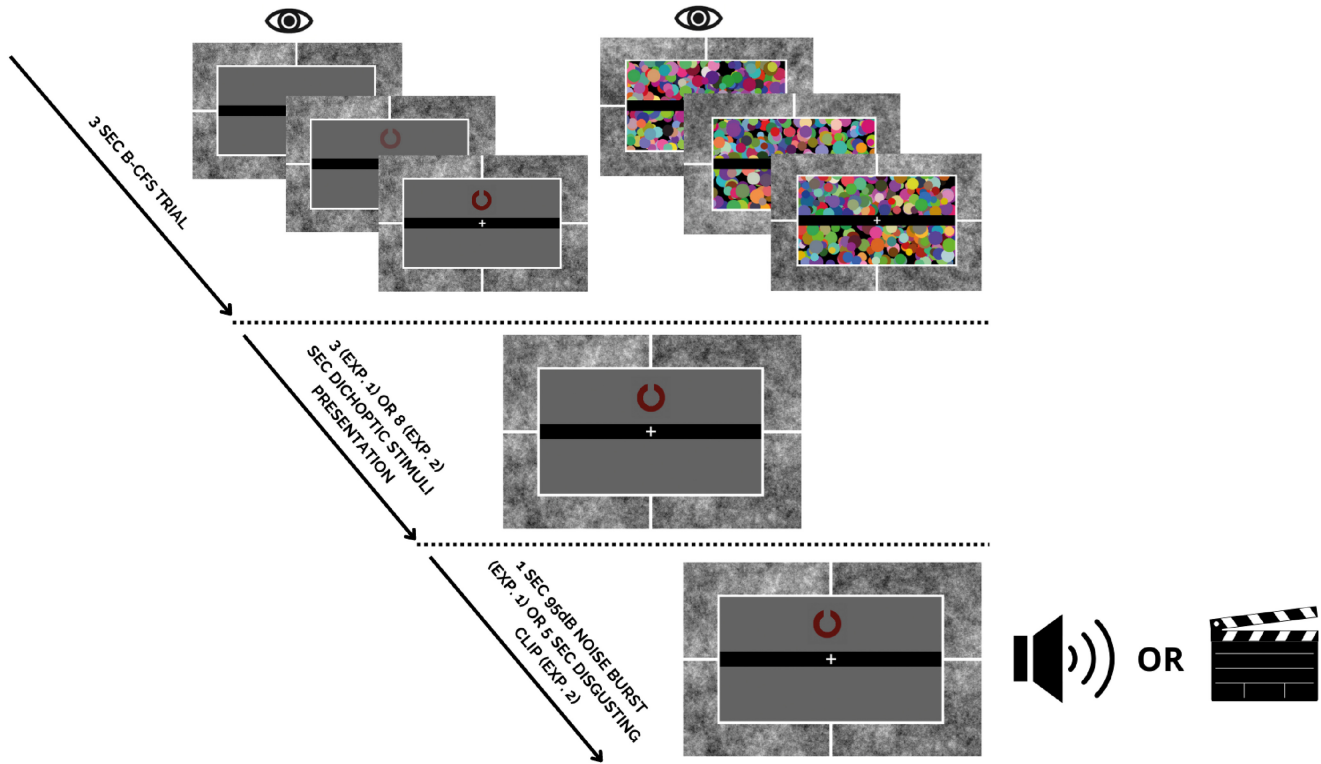
Fear and Disgust Conditioning

Conditioning was acquired in sensory conditions imitating the main experimental (b-CFS) task to ensure that the effects of learning transfer between experimental settings. Annulus color (red/blue) was used as a conditioned feature, with conditioned stimulus (CS+) color counterbalanced across the participants. Annuli were cut at 12 o'clock position (Figure 2) to maximize the similarity between stimuli used in conditioning and experimental trials while preventing accidental conditioning with the irrelevant feature (i.e., left/right cut placement). Participants were asked to passively observe subsequent b-CFS trials, in which a target was ramped up to 100% contrast over 2 s. After 3 s, the mask suppressing the target disappeared, revealing the unoccluded target either above or below the fixation point in the center. The target position was counterbalanced across the conditioning trials. In the fear conditioning experiment, an unoccluded target was visible for 4 s and the US presentation started after 3 s of CS+ onset, with both stimuli coterminating after another second (Sperl et al., 2016). In the disgust conditioning experiment, an unoccluded target was presented for 8 s and US presentations coincided with CS+ offset (David & Olatunji, 2011; Figure 2). The unconditioned stimuli followed the presentation of the target only during conditioned trials. Empty gray presentation areas were displayed during intertrial intervals, which were jittered and lasted either 7–9 s (Experiment 1) or 10–14 s (Experiment 2).

The general conditioning methodology was informed by the recent recommendations for successful and persistent fear conditioning (Lonsdorf et al., 2017). We used 24 trials in the acquisition phase, with 12 presentations of CS+ and 12 presentations of a control (unreinforced) stimulus (CS−); eight out of 12 CS+ presentations were paired with aversive US, giving a reinforcement rate of 66.7%. In the first 16 trials, CS+ was presented 8 times, but only four out of eight trials were associated with the US (50% reinforcement rate). The first and last four CS+ presentations were always reinforced. The exact order of CS+ and CS− presentations was randomized in a way that precluded three subsequent presentations of CS+/CS− stimuli as well as three subsequent (un)reinforced presentations of CS+ stimuli in the first 16 trials.

Figure 2

Schematic Depiction of a Reinforced CS+ Trial in the Conditioning Session or During Reacquisition in Experiment 1 (Fear Conditioning) and Experiment 2 (Disgust Conditioning)



Note. After a 3 s b-CFS presentation, participants dichoptically observed a CS+ annulus cut at 12 o'clock position, followed by US presentation. Exact stimuli presentation times were based on literature recommendations. In the case of CS− or unreinforced CS+ trials in the conditioning session, the trial terminated after annulus presentation. CS = conditioned stimuli; b-CFS = breaking continuous flash suppression; US = unconditioned stimuli. See the online article for the color version of this figure.

SCR was measured only during the training and the conditioning session. We analyzed nonspecific (spontaneous) electrodermal responses in the training period (which served as a baseline for SCR standardization) and event-related responses to US presentations during the conditioning phase. US-related SCRs were calculated as the amplitude of electrodermal reaction in a time window encompassing 6 s after US onset (noise burst, Experiment 1) or US presentation time + 6 s after US offset (disgusting clips, Experiment 2; scenes particularly disgusting for given participants could have also appeared at the end of the clips). Nonspecific SCRs of at least 0.02 μ s amplitude were automatically detected (and their exact magnitudes were determined) with the AcqKnowledge software. We had decided not to record trial-to-trial activity in the main experimental phase due to having observed in the pilot that once participants enter the experimental flow state, event-related SCR amplitudes are virtually absent in individual b-CFS trials.

Procedure

The experiment was carried out in a soundproof and dimmed laboratory room. Participants were asked to place their chin on a head-and-chin rest in front of the stereoscope. The monitor was positioned 60 cm in front of the chin rest, which amounted to an effective viewing distance of 68 cm (including the mirror stereoscope).

The procedure started with 48 practice b-CFS trials using blue and red annuli as targets. The training had a twofold purpose: it served (a) as a habituation phase for conditioning and (b) as a task familiarization procedure to avoid b-CFS practice effects affecting detection times during the main experimental trials (suppression tends to be stronger in early trials; Stein, 2019). Trial durations were preset to three different values: 2, 4, and 6 s, yielding eight practice trials of each particular trial duration for each annulus color. The varying presentation times were chosen to imitate intertrial changes in trial duration during the experiment proper while allowing correct localization and identification in at least some of the trials. To further facilitate task comprehension, the masks started to gradually fade after 2 s of presentation, revealing a completely unoccluded target after 4 s.

The conditioning acquisition phase followed thereafter. Upon completion, participants were asked to rate US aversiveness (on a 1–10 Likert scale) and to indicate the CS+ color. SCR electrodes were not removed after the conditioning phase to strengthen the accurate expectation that aversive events may accompany CS+ stimuli in all parts of the experiment.

Participants were then presented with 136 experimental trials divided into four blocks, resulting in 34 trials per block. Short breaks between the blocks were encouraged to prevent participants from straining their eyes. Each block included two types of trials. In regular experimental trials (32/34), participants had to report, in two

consecutive spatial 2AFC tasks, target localization and the side of the cut. Participants could respond only after the stimulus presentation had ended and were not exposed to the stimulus of interest during the response. They were asked to answer as accurately as possible and were explicitly instructed that there is no time limit for response. The order of task presentation was constant within blocks to minimize the risk of confusion but was varied within participants and counterbalanced across participants (e.g., for half of the participants the localization task came first in even blocks, and the discrimination task first in odd blocks, and vice versa for the other half of the participants). All experimental trials were followed by 1 s intertrial intervals. The number of trials per staircase (eye), annulus color, target position, and cut location were counterbalanced both within and across blocks. CS+ and CS− presentations were randomized in a manner precluding three subsequent presentations of CS+/CS− stimulus occurring within a given block. Taken together, we used 64 experimental trials per individual staircase, which is more than sufficient for the staircase to converge near the threshold, and is low enough for the conditioning effects to be sustained with occasional conditioning reinforcement.

In reacquisition trials (2/34), the CS+ target was presented in one of the positions (above/below the fixation point) and ramped up to 100% contrast over 2 s. After 3 s, the mask disappeared, revealing an unsuppressed target for 2 s. For fear conditioning, a white burst started after 1 s of unoccluded CS+ presentation, with both stimuli coterminating after another second. In the case of disgust conditioning, aversive clip onset coincided with CS+ termination. Intertrial intervals following reacquisition trials were jittered and lasted either 7–9 s (Experiment 1) or 10–14 s (Experiment 2), depending on the conditioning type. Both types of trials did not differ in terms of other stimuli presentation parameters (fixation point presentation time, mask type, etc.) except for the lack of position jitter in the reacquisition trials. Reacquisition trials were randomly scattered among regular trials and presented once per staircase in a given block. The location (up/down) and eye (left/right) of target presentation in reacquisition trials were counterbalanced within participants across the experiment. Before each block, participants were explicitly informed that they should expect intermittent US presentations incidental to CS+ trials. Upon completion of the final block, participants were debriefed and compensated.

Data Analysis

Outlier Exclusions

In order to determine potential outliers in the data, we calculated general performance scores (fraction of correct out of 128 total responses in the experiment) for each participant. As stated in the preregistration, participants for whom suppression was either too effective (chance performance) or too weak (ceiling performance) were excluded from further analyses, because random and ceiling performance levels artifactually reduce the sensitivity for finding a difference between experimental conditions (e.g., CS+ vs. CS−). Chance-level performers were identified by fitting a Bayesian binomial mixture model (Siedlecka et al., 2021). For the purpose of model specification, we safely assumed that population average performance could not exceed 95%, thus defining a cutoff point for exclusions related to the ceiling level performance.

Data from SCR “nonresponders” (Dawson et al., 2017) were excluded from SCR-related correlations but were used in analyses

concerning performance levels for CS+ and CS− stimuli. Nonresponders were defined as participants fulfilling at least one of the three following criteria: (a) less than five nonspecific SCR events, (b) mean event-related SCR < 0.02 μ s, or (3) mean standardized event-related SCR lower than 0.

Data Preprocessing

Following Vieira et al. (2017), individual event-related SCR amplitudes lower than 0.02 μ s were scored as 0 and retained in the analyses. Before statistical analysis, we normalized all SCR data with the use of the log (SCR + 1) correction (Dawson et al., 2017). Then, using both nonspecific and event-related SCRs (Braithwaite & Watson, 2015), we standardized individual SCRs with a z-score transformation (Ben-Shakhar, 1985) to account for individual differences in skin conductance responsiveness. We decided to standardize US-related SCRs to baseline reactivity (NS-SCRs) due to our pilot observations that electrodermal responses to CS+/CS− stimuli are either absent or indistinguishable from responses to other rapidly changing stimuli in the b-CFS procedure.

Data Analysis

Performance scores for CS+ and CS− stimuli were used as dependent variables in further analyses. To examine differences in performance levels (aggregated across both eyes), we used one-way (given that we made directional hypotheses) Bayesian paired *t*-tests with informed priors. The prior was specified based on recent guidelines for Bayesian *t*-tests (Gronau et al., 2020). To obtain the prior distribution, we used the effect size for localization accuracy performance ($d = 0.55$) found in the study of Vieira et al. (2017) on perceptual processing of fear-conditioned stimuli, given the close resemblance of their procedure and the relatively small effect size as compared to other studies. We assumed this effect to be the median of the effect size distribution, which yielded a normally distributed prior with $\mu = 0.55$ and $\sigma = 0.18$. The informed prior was specified accordingly for directional hypotheses CS+ > CS− (fear conditioning; Experiment 1) and CS+ < CS− (disgust conditioning; Experiment 2). The same tests and priors were used to examine performance in localization and discrimination tasks.

In order to examine whether localization and discrimination performance are differentially affected by the conditioning, we performed a within-subject ANOVA with conditioning (CS+ vs. CS−), task (localization vs. discrimination), and a Conditioning \times Task interaction as predictors, and performance level (% accuracy) as the dependent variable. We decided not to perform Bayesian analysis here due to the challenging (and, in our case, lacking reasonable justification) prior specification for factorial designs (Rouder et al., 2017).

To examine our second hypothesis, we correlated mean standardized SCRs to US in the conditioning session with the magnitude of the conditioning effect, defined as the difference in localization/discrimination performance (% accuracy) between CS+ and CS− stimuli. Difference values indicating no conditioning effect (i.e., resulting from CS− > CS+ accuracy in Experiment 1 or CS+ > CS− accuracy in Experiment 2) were recoded to 0 (meaning simply “no effect”) to avoid random variability which could potentially result in spurious correlations. Nonparametric correlations were used in the case of any distributions violating the assumption of normality.

Transparency and Openness

Data were collected in September and October 2022. As required by APA Style Journal Article Reporting Standards, we report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. Analyses were run using R 4.2.0 (R Core Team, 2022) and JASP 0.16.4.0 (Love et al., 2019). Full database, analysis pipeline, and research materials that could not be presented in the manuscript format (i.e., disgust-inducing clips) are available at <https://github.com/piolitwin/bcfs-fear disgust>. All hypotheses as well as the data analysis plan had been preregistered at the Open Science Framework (OSF) repository in a time-stamped document (<https://osf.io/dyw64/>) before the data collection started, and all analyses examining directional hypotheses reported in the current paper are identical to those stated in the preregistration document. The only small difference pertains to the prior specification: due to a typo, the mean of the prior distribution was defined as 0.5 in the preregistration, instead of 0.55 as derived from the study of Vieira et al. (2017). This difference is negligible as it does not influence the interpretation of the results and our findings do not depend on the exact prior specification. We also decided to not include exploratory analyses related to eye dominance effects due to faulty specifications of the preregistered linear mixed model.

Results

Experiment 1 (Fear)

Outliers

Based on the exclusion criteria described in the Method section, we excluded one participant from analyses related to the localization task (performing at ceiling level), and two participants from analyses regarding the discrimination task (one participant performing at ceiling level, and one performing at chance level). One of these participants was a multivariate outlier, who likely misunderstood the discrimination task (lower than random discrimination performance despite 88% localization accuracy), and was thus also excluded from analysis pertaining to the interaction between task and conditioning effects. Additionally, two participants were defined as SCR nonresponders and excluded from the SCR-related analyses due to experiencing less than five nonspecific SCR events. Taken together, the following numbers of participants were included in the eventual analyses: 59 participants for the localization task (57 in SCR-related analyses), 58 participants for the discrimination task (56 in SCR-related analyses), and 59 for the interaction between task and conditioning.

Results

Interocular suppression was successfully induced in both dominant (mean threshold: 2.28 s; $SD = 1.24$ s) and recessive (mean threshold: 3.36 s; $SD = 1.48$ s) eyes. Also, we managed to match the perceptual salience of red and blue annuli at the group level, as we did not observe systematic preferences for any of the colors, neither in the localization, $t(58) = 1.51$, $p = .137$, nor in the discrimination task, $t(57) = 1.69$, $p = .096$. Aversiveness of noise bursts was appropriate for the fear conditioning procedure: $M = 7.60$ (on a 10-point scale); $SD = 1.68$, indicating that our participants found the US unambiguously unpleasant yet bearable. Successful conditioning was confirmed by the presence of electrodermal response (mean standardized SCR > 0) in all of the participants: $M = 1.28$ μ s; $SD = 0.52$ μ s.

In congruence with our hypothesis, one-tailed Bayesian paired t -tests showed strong evidence that CS+ (i.e., fear-conditioned) stimuli were localized more accurately, $M = 82.76\%$, $SD = 9.43\%$, than CS- stimuli, $M = 77.62\%$, $SD = 11.70\%$, $t(58) = 2.62$, $p = .006$, $d = 0.34$, $BF_{10} = 12.275$, $\delta = .399$, 95% CI [0.188, 0.609] (Figure 3). Similarly, we found strong evidence that the cut location was discriminated more accurately in CS+ annuli, $M = 78.23\%$, $SD = 10.37\%$, than in CS- annuli, $M = 72.82\%$, $SD = 12.61\%$, $t(57) = 2.89$, $p = .003$, $d = 0.38$, $BF_{10} = 26.775$, $\delta = .424$, 95% CI [0.212, 0.637]. A 2×2 repeated-measures ANOVA with task (localization vs. discrimination) and conditioning (CS+ vs. CS-) as within-subject factors revealed main effects of task: $F(1, 58) = 37.34$, $p < .001$, $\eta_p^2 = 0.39$, indicating that localization accuracy was higher than discrimination accuracy, and Conditioning: $F(1, 58) = 8.46$, $p = .005$, $\eta_p^2 = 0.13$, showing that performance was generally better for CS+ than CS- stimuli. The Task \times Conditioning interaction turned out to be insignificant: $F(1, 58) = 0.001$, $p = .979$, $\eta_p^2 < 0.001$, indicating that conditioning did not differently affect performance in both tasks.

Nonparametric one-sided correlations were used to examine our second hypothesis pertaining to the relationship between the magnitude of the conditioning effects and mean standardized SCRs to US presentations in the conditioning phase. Participants who exhibited no conditioning effects (CS- performance \geq CS+ performance) were included in the analyses with a recoded score of 0; Kendall signed-rank correlations were used due to their robustness to nonnormal distributions and implemented correction for tied ranks. Analyses revealed positive correlations between conditioning-related accuracy increase and the mean magnitude of physiological response to US. Correlations were statistically significant both in the case of the localization task: $r_s(55) = .19$, $p = .023$ (Figure 4A), and the discrimination task: $r_s(54) = .24$, $p = .007$ (Figure 4B).

Experiment 2 (Disgust)

Outliers

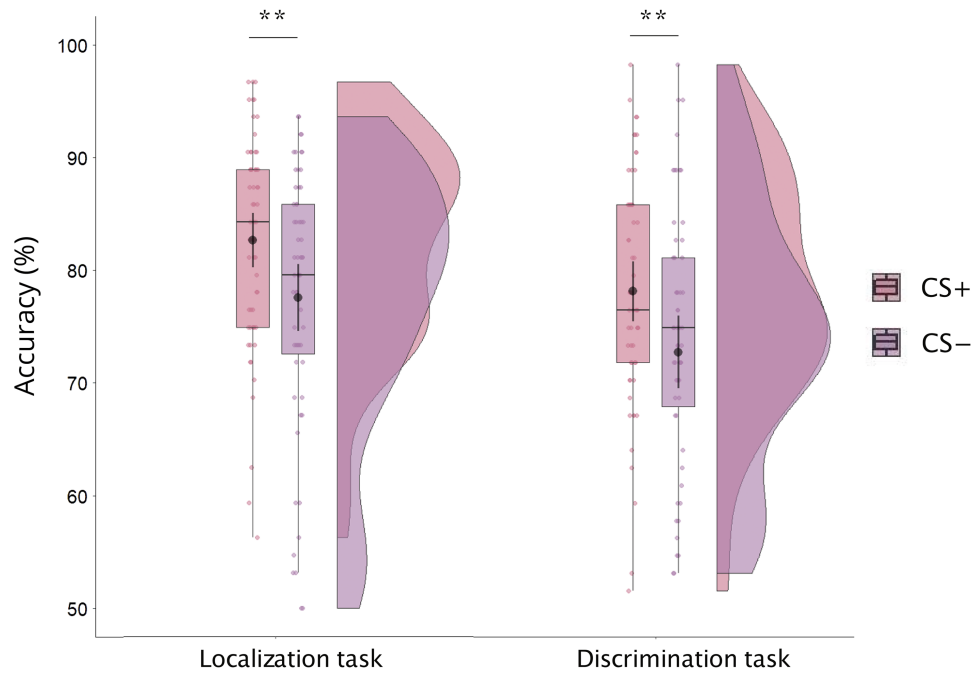
Based on the same outlier exclusion criteria we used in Experiment 1, we excluded four participants from analyses related to the localization performance (two participants performing on a ceiling level, and two participants performing on a chance level), and four participants from analyses related to the discrimination task (all of them performing on a chance level). Three participants were excluded from analyses pertaining to Task \times Conditioning interaction: two of them were multivariate outliers (random or worse performance in the discrimination task beside high localization performance), and one of the participants performed at a chance level in both tasks. Additionally, three participants were excluded from SCR-related analyses due to their US-related SCRs being indistinguishable from baseline skin conductance reactivity (mean standardized SCR to US < 0), suggesting that the presentation of the disgusting clips did not induce additional arousal in these participants. In sum, the final samples included 56 participants in the localization task (53 in SCR-related analyses), 56 participants in the discrimination task (53 in SCR-related analyses), and 57 participants in the analysis related to the interaction between task and conditioning.

Results—Preregistered Analyses

Again, we managed to successfully induce interocular suppression in both dominant (mean suppression time: 2.09 s; $SD = 1.34$ s) and

Figure 3

Localization and Discrimination Performance for Fear-Conditioned (CS+; Left Boxplot, Pink Color) and Neutral (CS−; Right Boxplot, Mauve Color) Stimuli in the Breaking Continuous Flash Suppression Tasks



Note. Black dots indicate mean performance across participants and associated 95% confidence intervals, while boxplots present medians \pm 1.5 interquartile range. Semitransparent dots depict performance scores for individual subjects, and kernel density plots visualize probability density distributions of accuracy separately for the CS+ and CS− conditions. CS = conditioned stimuli. See the online article for the color version of this figure.
** $p < .01$.

recessive (mean suppression time: 3.25 s; $SD = 1.70$ s) eyes. We can also assume that the perceptual salience of red and blue annuli was successfully matched in the whole sample, given that we did not observe differences in accuracy between trials in which red and blue annuli were presented as targets, neither in the localization, $t(55) = 0.11$; $p = .915$, nor in the discrimination task, $t(55) = 0.16$, $p = .870$. Aversiveness of disgusting clips, $M = 5.70$, $SD = 2.26$, was lower than for noise bursts, $M = 7.60$, $SD = 1.68$; see Experiment 1: $t(118) = -5.23$, $p < .001$, indicating moderate level of induced aversion. Physiological response to the US was clearly distinguishable from baseline on a group level, $M = 0.94 \mu\text{s}$, $SD = 0.55 \mu\text{s}$, although an exploratory analysis showed that it was significantly smaller than for fear conditioning, $M = 1.28 \mu\text{s}$, $SD = 0.52 \mu\text{s}$; see Experiment 1: $t(118) = -3.48$, $p < .001$.

Directional Bayesian paired t -tests showed that our hypotheses related to worse performance for disgust-conditioned stimuli were disconfirmed. We found strong evidence that disgust-conditioned stimuli were not localized less accurately, $M = 81.33\%$, $SD = 10.06\%$, than CS− stimuli, $M = 79.02\%$, $SD = 10.69\%$, $t(55) = 1.28$, $p = .898$, $BF_{10} = 0.011$. Similarly for discrimination, a one-tailed Bayesian paired t -test provided strong evidence that CS+ annuli were not inferiorly discriminated, $M = 79.13\%$; $SD = 11.34\%$, as compared to CS− annuli, $M = 75.25\%$; $SD = 11.78\%$, $t(55) = 2.16$, $p = .983$, $BF_{10} = 0.006$. Having observed that not only was performance for CS+ not worse, but CS+ accuracy was

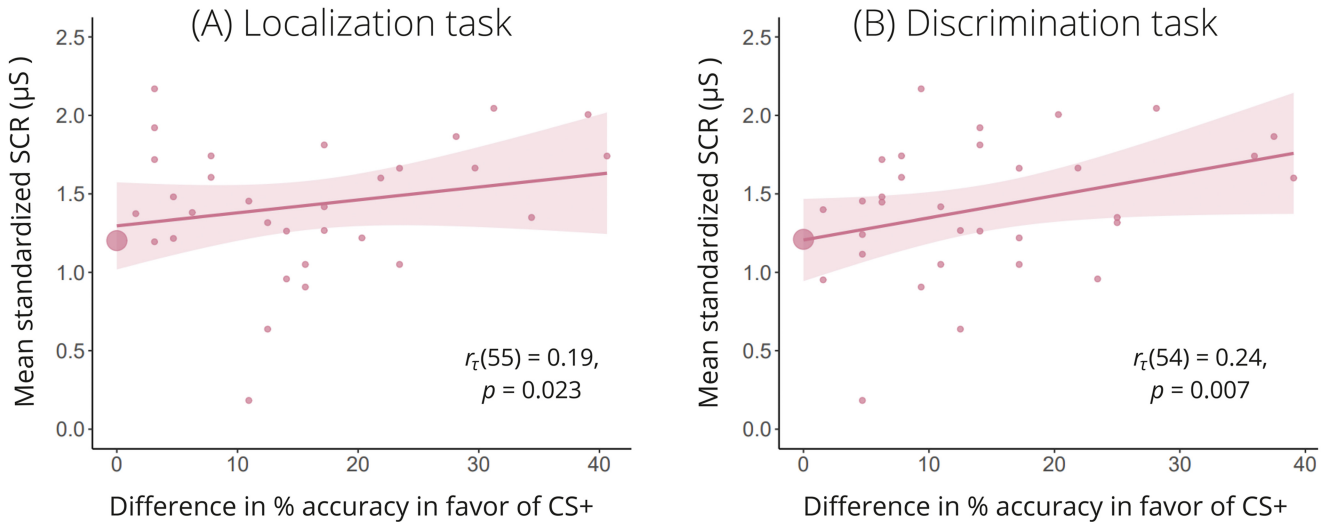
actually noticeably higher in both tasks, we decided to switch from our original analysis plan to exploratory analyses aimed at finding whether there is any kind of preference toward disgust-conditioned stimuli.

Results—Exploratory Analyses

We repeated the analyses described above using two-tailed (instead of directional) Bayesian paired t -tests with a normally distributed prior with the mean centered at 0 ($\mu = 0$) and the same standard deviation as the original prior ($\sigma = 0.18$). We did not find evidence that CS+ stimuli were localized more accurately, $M = 81.33\%$, $SD = 10.06\%$, than CS− stimuli, $M = 79.02\%$, $SD = 10.69\%$, $t(55) = 1.28$, $p = .205$, $d = 0.17$, $BF_{10} = 1.013$, $\delta = .110$, 95% CI $[-0.101, 0.322]$ (Figure 5). On the other hand, in the discrimination task, we observed significantly better performance for CS+ stimuli, $M = 79.13\%$, $SD = 11.34\%$, compared to CS− stimuli, $M = 75.25\%$, $SD = 11.78\%$, although Bayesian analysis showed that the evidence provided is weak at best, with alternative hypothesis being roughly two and a half times more probable than the null hypothesis, $t(55) = 2.16$, $p = .035$, $d = 0.29$, $BF_{10} = 2.54$, $\delta = .184$, 95% CI $[-0.029, 0.397]$. A 2×2 repeated-measures ANOVA with task (localization vs. discrimination) and conditioning (CS+ vs. CS−) as within-subject factors revealed a main effect of task: $F(1, 56) = 21.18$, $p < .001$, $\eta_p^2 = 0.274$, showing higher

Figure 4

Positive Correlations Between Mean Standardized SCR to US (y-Axis; μS) and the Magnitude of the Conditioning Effect (x-Axis, %) in Localization (A) and Discrimination (B) Tasks in Experiment 1



Note. Small dots present individual observations of people who performed better for the fear-conditioned (CS+) stimuli. Participants experiencing no conditioning effect (equal or better performance for CS− stimuli) were recoded to 0 and included in the analyses as separate observations. However, for the purpose of visual transparency of the plot, participants showing no conditioning effect were grouped into a large dot indicating SCR mean for all such observations (26 observations for the localization task and 24 observations for the discrimination task). SCR = skin conductance response; CS = conditioned stimuli; US = unconditioned stimuli. See the online article for the color version of this figure.

performance in the localization task. The main effect of Conditioning did not reach the statistical threshold: $F(1, 56) = 3.51, p = .066, \eta_p^2 = 0.059$, indicating that the numerical advantage of CS+ over CS− did not reach significance. Task \times Conditioning interaction also turned out to be insignificant: $F(1, 56) = 2.42, p = 0.125, \eta_p^2 = 0.041$, indicating that conditioning did not differentially affect performance in both tasks.

Due to our unexpected findings of a better CS+ performance, we decided to explore the relationship between the degree of the CS+ preference (the accuracy advantage for CS+) and mean standardized SCRs to US presentations in the conditioning phase in both tasks. Again, Kendall rank correlations (two-sided) were used due to the large number of tied ranks and all of the distributions violating normality assumptions. Analyses revealed a significant positive correlation between conditioning-related accuracy increase and the mean magnitude of physiological response to US in the localization task, $r_t(51) = .27, p = .008$ (Figure 6A). In the discrimination task, such a correlation was absent, $r_t(51) = .06, p = .571$ (Figure 6B).

Discussion

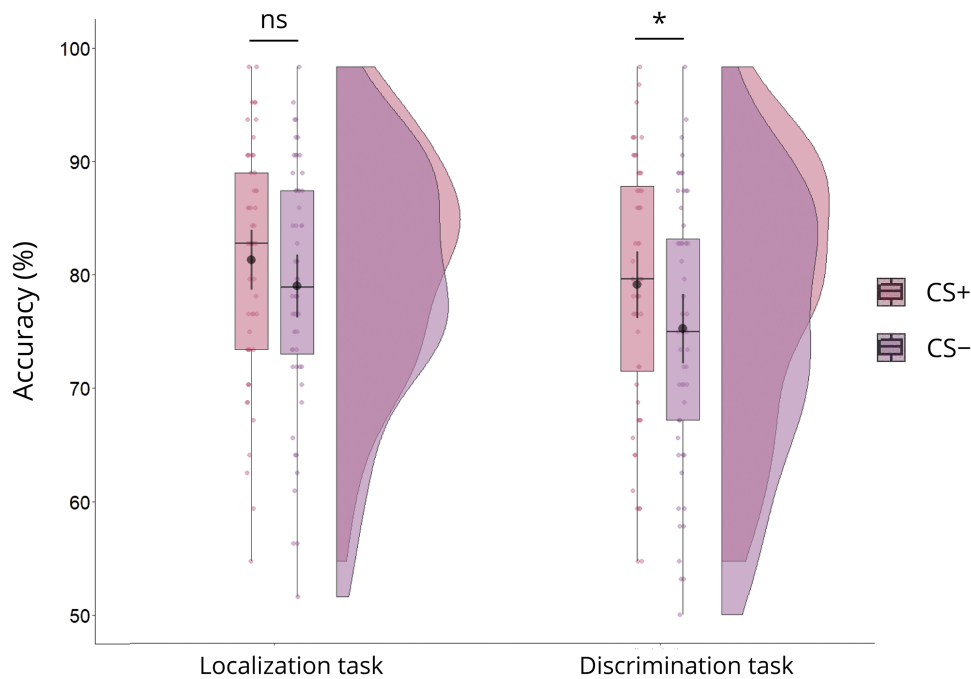
The study presents two experiments in which we examined whether stimuli conditioned with either fear or disgust gain differential (either facilitated or hindered) access to perceptual awareness. We used an accuracy-based b-CFS method to obtain a direct measure of perceptual modulations that are not contaminated by changes in response bias. A classical conditioning approach was used to isolate the effects of fear and disgust from lower-level features associated with naturally threatening or disgusting objects (cf. Gayet et al., 2019). Moreover, we studied whether perceptual effects of emotionally-laden stimuli are grounded in physiological responses and whether the direction of perceptual effects

(i.e., facilitation or suppression) depends on whether an emotion signals the need for immediate allostatic behavior. Based on the present literature, we hypothesized that, at individual threshold-level presentation times, perceptual performance should be enhanced for fear-conditioned stimuli (Experiment 1), and diminished for disgust-conditioned stimuli (Experiment 2), as compared to unconditioned stimuli. Accordingly, because both fear and disgust have been reported to entail enhanced physiological arousal, we expected increased arousal to be positively correlated with fear-related performance enhancement (Experiment 1) and negatively correlated with disgust-related impairment of performance (Experiment 2).

The first experiment confirmed our hypotheses that fear-conditioned stimuli are facilitated in visual awareness. The effects occurred regardless of the type of information to be reported, as both localization and discrimination performance scores were comparably superior for the threatening stimuli. Successful elicitation of fearful responses was warranted by the clear presence of skin conductance responses to US, which were much higher than baseline skin reactivity in virtually all of the participants. These mean standardized SCRs to US were positively correlated with the magnitude of the conditioning-related perceptual preference, indicating that fear-induced effects were indeed grounded in underlying arousal, confirming our second main hypothesis. These results back up previous b-CFS studies showing preferential processing of threatening stimuli (Gayet et al., 2016; Vieira et al., 2017; however, for conflicting b-CFS evidence see Hedger et al., 2015) as well as multiple reports based on experimental results obtained from other experimental paradigms (for reviews see De Cesarei & Codispoti, 2013; Lee et al., 2014). Importantly, the current accuracy-based paradigm measures perceptual performance (at a fixed presentation duration), and thus provides unequivocal evidence for the perceptual nature of the CS

Figure 5

Localization and Discrimination Performance for Disgust-Conditioned (CS+; Left Boxplot, Pink Color) and Neutral (CS−; Right Boxplot, Mauve Color) Stimuli in the Breaking Continuous Flash Suppression Tasks



Note. Black dots indicate mean performance with associated 95% confidence intervals, while boxplots present medians \pm 1.5 interquartile range. Semitransparent dots depict performance scores for individual subjects, and kernel density plots visualize probability density distributions of accuracy separately for the CS+ and CS− conditions. CS = conditioned stimuli. See the online article for the color version of this figure.

* $p < .05$.

+ advantage. Since the effects in question were present at the early stages of perceptual processing (i.e., they surfaced also in the localization task), the results are consistent with the hypothesis that arousal-mediated unconscious recognition accelerates further visual processing of stimuli associated with threat (cf. Gayet et al., 2016; Lee et al., 2014), although our design did not allow for this hypothesis to be tested directly.

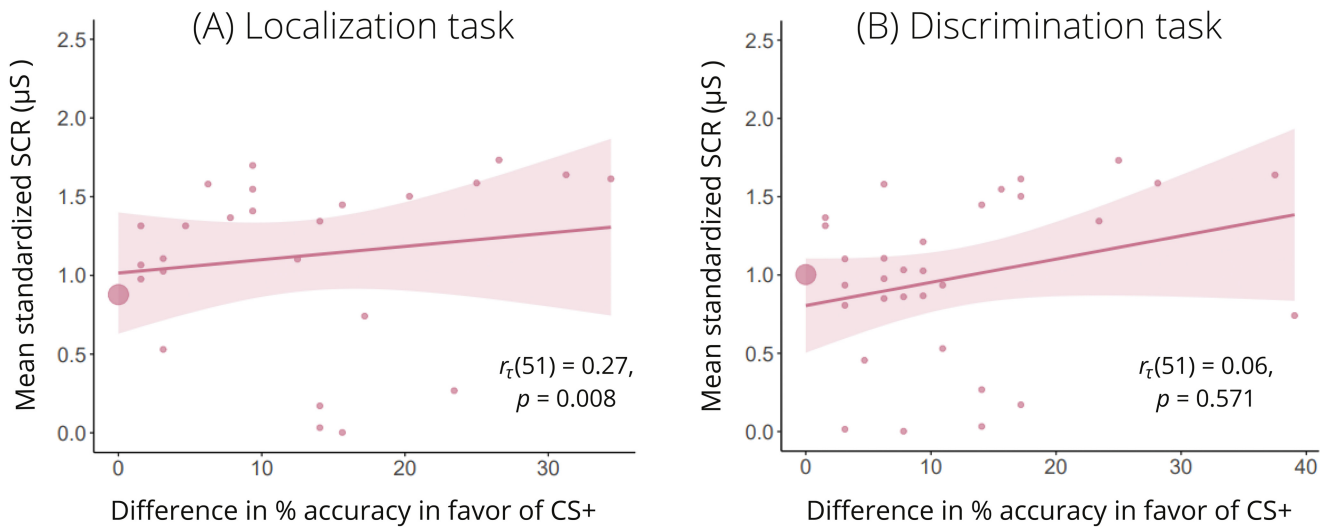
In contrast, the second experiment yielded results opposite to our initial hypotheses. We found strong evidence against perceptual suppression of disgust-conditioned stimuli in our preregistered directional tests. Having observed that accuracy rates were nominally higher for CS+ stimuli, and informed by the fact that evidence for the null in a directional test cannot be taken as evidence for the absence of an effect, we decided to run exploratory two-sided analyses to further examine perceptual effects of disgust. These exploratory analyses suggest that disgust-conditioned stimuli were perceptually prioritized over neutral stimuli, although these effects were weaker and less robust than those observed for fear-conditioned stimuli. Specifically, discrimination performance was significantly higher for CS+ stimuli than for CS− stimuli, but no such difference was observed for localization performance. While we tentatively interpret these results as indicating perceptual preference toward disgusting stimuli, we are hesitant to take them as evidence that disgust-induced effects on perception occur at later stages of perceptual processing; our discrimination task may simply be a more sensitive measure. Importantly, even though the effects

of disgust conditioning were less consistent than those observed for fear conditioning, the magnitude of the CS+ advantage was again proportional to the physiological response to the US during conditioning acquisition. This provides further evidence for a possible link between the extent to which a stimulus induces arousal, and its enhanced access to visual awareness.

Our results stand in contrast with the notion that fear and disgust instigate distinct profiles of perceptual effects, with disgust being associated with perceptual suppression (Krusemark & Li, 2011). Although our disgust-related results should be interpreted with caution due to their exploratory nature, they might be read as preliminary evidence for preferential visual processing of disgust-related stimuli. We find at least three (not necessarily exclusive) possible explanations for this tentative interpretation. The first option is that we accidentally conditioned the annuli with fear rather than disgust, at least for some of the participants. Upon leaving the lab room, individual participants spontaneously commented that “they were *afraid* that they would be presented with those disgusting clips again.” These occasional comments led us to believe that unmasked CS+ presentation in the experimental phase (announcing repeated exposure to disgusting video content) could in some cases elicit anxious anticipation rather than preemptive disgust. Indeed, materials including disgusting content have been shown to frequently coelicit other emotions, such as amusement (Berrios et al., 2015; Hemenover & Schimmack, 2007) or

Figure 6

Positive Correlations Between Mean Standardized SCR to US (y-Axis; μS) and the Magnitude of the Conditioning Effect (x-Axis, %) in Localization (A) and Discrimination (B) Tasks in Experiment 2



Note. Small dots present individual observations of people who performed better for the conditioned (CS+) stimuli. Participants experiencing no conditioning effect (equal or better performance for CS– stimuli) were recoded to 0 and included in the analyses as separate observations. For the purpose of visual transparency of the plot, participants showing no conditioning effect were grouped into a large dot indicating SCR mean for all of such observations (27 observations for the localization task and 21 observations for the discrimination task). SCR = skin conductance response; CS = conditioned stimuli; US = unconditioned stimuli. See the online article for the color version of this figure.

fear (Olatunji & Tomarken, 2023). Even though we aimed to mitigate this risk by selecting the most disgust-specific clips in a pre-study, we might have not fully succeeded in doing so. A close relationship with fear would provide an explanation for the disgust-related preference (as if it was actually a fear-related preference) as well as the heterogeneity of effects, possibly dependent on the type of emotion elicited, with a substantial number of participants performing worse for CS+ stimuli. Although we believe that incidental coelicitation of fear could have played a role as a confounding variable, it is unlikely to be fully responsible for the obtained effects, given that, after conditioning acquisition, disgust ratings for disgust-conditioned CS+ tend to be much higher than respective fear ratings (Olatunji & Tomarken, 2023).

The second possibility is that there is some kind of actual perceptual preference for the disgusting objects. For example, it may be related to attentional processing—stimuli following disgusting objects could be inferiorly detected not due to some disgust-related processing disturbances, but due to attentional “stickiness” making it harder to disengage with the disgusting object (Perone et al., 2021; van Hooff et al., 2013). Such ease and persistence of attentional capture could make CS+ stimuli breakthrough awareness faster, in the manner of top-down attention shortening suppression times in b-CFS (Zhang et al., 2012; but see Gayet et al., 2020). In fact, directing spatial attention to a visual object has been shown to increase its subjective contrast (Ling & Carrasco, 2006). Accordingly, if the disgusting stimuli preemptively attract attention, they could have increased the effective contrast (and thus competitive strength) of the CS+ stimuli. This mechanism allows otherwise subliminal percepts to breach the threshold for conscious perception (Carrasco et al., 2004), just like the increase in visual contrast of the target reduces suppression times in b-CFS (Tsuchiya & Koch, 2005).

The final option is that preferential processing of homeostatically relevant stimuli simply boils down to arousal. Exposure to highly arousing sensory stimulation has been shown to decrease visual contrast thresholds (Woods et al., 2013) and enhance the detection of high contrast stimuli (Sutherland & Mather, 2012) as well as coarse visual information (Lee et al., 2014) related to fundamental aspects of visual scenes (e.g., object shapes). Similarly, fear selectively facilitates the visual processing of low spatial frequency (“coarse”) information (Bocanegra & Zeelenberg, 2009). Since participants were asked to report the location and shape of presented annuli in our experiments, both perceptual tasks related to coarse aspects of visual input rather than fine details. Therefore, enhanced performance for CS+ stimuli could result from increased arousal, regardless of the exact emotion type. This interpretation sits well with our results: subjective aversion as well as physiological arousal induced by disgusting stimuli were lower compared to threatening stimuli, and disgust-related effects were proportionally weaker than fear-related effects. Yet, further studies—carefully controlling for aversion and arousal levels as well as including more comprehensive psychophysiological measurements—are needed to determine the most relevant factors driving perceptual preference for fear-conditioned and disgust-conditioned stimuli. In this context, it may also be essential to develop new disgust conditioning procedures that selectively evoke the emotion of disgust.

We believe that the current study provides convincing evidence for the modulation of early visual processing by homeostatically relevant stimuli. Key strengths of this study include that we (a) demonstrate enhanced perceptual access for distinct types of negative valence, (b) build on arousal measurements to support our valence-based interpretations, and (c) control for confounding factors in accordance with recent guidelines for b-CFS research (Lanfranco et al., 2023a, 2023b);

Stein, 2019). By presenting CS+/CS− stimuli at intensities converging towards individual threshold levels in a nonspeeded accuracy-based task design, we successfully controlled for postperceptual factors, such as differences in response criteria or postdetection response speeds, possibly present in paradigms based on response time measurements. Indeed, our supplementary analyses using SDT measures (see the online supplemental material S1) show that biases toward either of the two response options were absent in both experiments, regardless of the exact task type. Also, the use of a conditioning-based approach reduced the number of possible confounds as the initially neutral stimuli were matched in terms of low-level salience (such as luminance, contrast, size, or spatial frequency) and did not include any higher-order information that could be associated with naturally threatening or disgusting stimuli. This approach likely yields more robust effects and reduces the risk of future failed replications (e.g., findings on emotional perception using natural objects or faces frequently boil down to factors unrelated to experimental manipulation, such as low-level differences or presence of social cues; Lanfranco et al., 2023b). Indeed, a picture that emerges from conditioning-based studies on visual perception of threat (cf. Gayet et al., 2016; Vieira et al., 2017) seems to be much clearer as compared to studies on fearful facial expressions (Pournaghdali & Schwartz, 2020).

The present study also has some limitations to consider. One important limitation pertains to the scope of unconscious processing involved. Although we believe that modulation of conscious access is the most probable explanation for the differences in localization/discrimination performance observed here, other approaches, such as detection-discrimination dissociation (Stein & Peelen, 2021) or the usage of meta-*d'* (Fleming, 2017) could complement our approach to determine the contribution of conscious processes more conclusively. What can be safely concluded though is that participants must have had enhanced perceptual access (be it conscious or not) to the feature (e.g., location or indent side) of a CS+ stimulus as compared to a CS− stimulus, which shows that homeostatically relevant stimuli are prioritized in the visual system.

Another limitation concerns the possible underestimation of effect sizes, considering that standardized effect sizes were relatively small in comparison to the large mean differences in performance between CS+ and CS− conditions (i.e., difference in accuracy rates). In both experiments, a substantial proportion of the participants showed no preference for CS+ over CS− stimuli. We hypothesize that the specific colors of the CS+/CS− annuli could differently—but systematically—affect individual accuracy scores, resulting in high between-subject variability. Such color-specific effects could either be due to idiosyncratic color preferences, or to the unsuccessful matching of subjective luminance in unsupervised conditions of the flicker photometry procedure. Although we did not observe systematic differences in performance between annuli of different colors at the group level, participant-specific color preferences could still strongly influence individual results. For future studies, we recommend using perceptual features other than color, or determining exact RGB values during a pilot study, using the flicker photometry procedure on a sample of competent subjects.

Constraints on Generality

Our sample was relatively heterogeneous in terms of age or socioeconomic status due to the use of several different social media groups for recruitment purposes. However, it virtually exclusively comprised participants of Caucasian descent, reflecting the ethnically homogenous

character of Polish society. Cross-ethnic differences in SCR responsiveness during fear conditioning have previously been evidenced (Gold et al., 2022; Kredlow et al., 2017; Martínez et al., 2014); however, they strictly pertain to physiological reactivity—with the differences often being subtle (Gold et al., 2022) or subgroup-specific (Martínez et al., 2014)—rather than dynamics of fear acquisition or extinction per se. Also, age, education, or gender do not seem to predict failure to condition as evidenced by physiological responses (Kredlow et al., 2018). The fear conditioning paradigm is actually praised for its excellent translational value, evidencing similarities in fear learning not only cross-culturally, but even across species (Lonsdorf et al., 2017). Research on cross-cultural differences in disgust conditioning is much more scarce, but extant studies suggest that disgust may also be considered a universal emotion (Chapman & Anderson, 2012).

Since our study focused on low-level visual processing, and we used semantically (culturally) neutral basic shapes, we believe that the obtained results are widely generalizable and unlikely to be specific to the characteristics of the participants who took part in the current study. It is further evidenced by the fact that Experiment 1 essentially corroborates results previously obtained in (possibly more ethnically heterogeneous) samples from the Netherlands (Gayet et al., 2016) and Canada (Vieira et al., 2017).

Conclusion

The present study provides decisive evidence that stimuli associated with threat entertain preferential access to visual awareness. This adds to an existing body of evidence by using a paradigm that isolates influences of conditioning on perceptual processes from influences on postperceptual processes (e.g., response bias). In contrast with our initial hypothesis, we obtained strong evidence that disgust-conditioned stimuli presented around the visual threshold are not perceptually suppressed in the early visual system. In our exploratory analyses, they even yielded better discrimination performance, although the effects were less robust than for fear-conditioned stimuli. Taken together, our results suggest that homeostatically relevant stimuli are preferentially processed by the human visual system, thus gaining prioritized access to visual awareness. This facilitation of visual processing may be at least partially attributed to underlying physiological arousal during associative learning.

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